A quantitative analysis of final energy consumption in hospitals in Spain

Alfonso González González[1], Justo García-Sanz-Calcedo[2*], David Rodríguez Salgado[3]

[1]Department of Mechanical, Energy and Materials Engineering, University of Extremadura, Mérida, Spain

[2]Department of Graphical Expression, University of Extremadura, Badajoz, Spain

[3]Department of Mechanical, Energy and Materials Engineering, University of Extremadura, Badajoz, Spain

ABSTRACT

The accurate identification of the final energy consumption in hospitals is a key task to determine potential savings and therefore to set appropriate design criteria. However, correlations between consumption and functional indicators for Spanish hospitals have not been yet accounted for in detail. A total of 80 Eco-Management and Audit Schemes (EMAS) from 20 hospitals were analysed in the period 2005-2014 in order to seek correlations between energy consumption and climate conditions, gross domestic product (GDP), built surface area, number of available beds and number of staff.

The results set the average annual energy consumption in a Spanish hospital for standard operating conditions as 0.27 MWh/m^2, 9.99 MWh/worker and 34.61 MWh/bed (standard deviations 0.07 MWh/m^2, 3.96 MWh/worker and 12.49 MWh/bed, respectively). The geographic location was seen to show a direct influence on those values, as opposed to the specific type of management (TM), the number of available beds, the GDP or the particular climate conditions.

Keywords: healthcare centre; hospital; energy consumption; healthcare engineering.

1. INTRODUCTION

There is a global commitment on the reduction of CO_2 emissions to stabilize total levels below 450 ppm, or similarly to prevent a global temperature increase of 2ºC as compared to the year 1990 [1]. The average annual energy consumption in Spanish hospitals reaches 20% of the total consumption in the tertiary sector in Spain [2]. The energy demand of hospitals is among the highest of non-residential buildings [3].

Several strategies devoted to reduce CO_2 emissions have been developed by governments worldwide since the signing of Kyoto Protocol [4]. In this sense, specific programmes widely have promoted the use of renewable energies at final stages of consumption as well as the reduction of

CO_2 emissions both in energy production processes and in actions involving the improvement of energy efficiency [5]. It is the latter issue, i.e. energy efficiency, that is not being successfully accounted for in general terms, provided the energy saving goals for 2020 are not being satisfied in their intermediate stages so far [6]. Such particular fact, together with the increasing awareness on the climate change and thus on specific actions to promote sustainability, sets a notable relevance to the energy management of buildings.

According to the Spanish Institute for Energy Diversification and Saving (*IDAE*), the building sector is regarded to show a high impact on CO_2 emissions, mainly due to the high energy consumption associated to the great variety of actions it involves [7]. Among the different types of buildings corresponding to the tertiary sector in Spain, those of the Healthcare System achieve the highest energy intensity (5.2 toe/bed) followed by public administration management ones (1.647 toe/worker), while the lowest intensities are achieved by buildings devoted to education activities (0.079 toe/student) [8]. Also, United States Department of Energy (2009) estimates that hospitals are the buildings –out of those of the tertiary sector– with the highest rates of energy resources consumption [9] and Short et al. (2012) stated that 30% of the emissions generated by the public sector in the United Kingdom are linked to the healthcare system [10].

On another note, Santamouris et al. (2008) carried out a detailed analysis of audits for 30 healthcare buildings in Greece (Hellas) to quantify the potential global energy savings as 20% [11], hence suggesting potential energy saving procedures in these buildings. Additionally, Vanhoudt et al. (2011) reported a potential primary energy saving up to 71% in a Belgian hospital by using thermal energy storage in combination with a heat pump instead of gas-based boilers and water chiller [12].

In the same line of research, Kapoor and Kumar (2011) identified HVAC systems to show the highest energy consumption rates in hospitals, followed by lightning systems (30-65% and 30-40%, respectively) [13]. Moreover, the Australian Department for Health conducted a study, which concluded that HVAC systems were responsible for the highest energy consumption rates and the highest volumes of CO_2 emissions to the atmosphere in a suburban hospital (namely 65% and 47%) [14].

In the particular case of the Spanish Health System, the potential energy savings derived from the energy management in hospitals has not been systematically accounted for yet, although some other studies on small healthcare buildings and healthcare centres have elsewhere been reported [15]. San José et al. (2009) computed the average annual energy consumption for 300-bed small-sized hospitals or a health centres as 8.885 kWh/bed, and for those exceeding 300 beds as 10.043 kWh/bed [16]. The 2010 Energy Saving and Efficiency Guide for hospitals, issued by the Energy Foundation from Madrid Regional Government, reports the annual energy consumption in a small hospital as 40,000 kWh with an annual expense of €8,400 [17].

Renedo et al. (2006) studied different cogeneration alternatives for a Spanish hospital building. The authors proved that the size of the facility and the control strategy show a strong influence on the system economy, and found that the most important parameter is the electricity produced [18]. In addition, Garcia-Sanz-Calcedo (2014) reported on the analysis of energy efficiency in healthcare buildings to conclude that the potential to reduce the energy consumption of a healthcare building sized 1,000 m^2 is 10,801 kWh by making an average investment of €11,601, thus saving €2,961/year with 3.92 years average payback time [19].

The number of hospitals in Spain approaches 790, most of which are public centres, which amounts up to around 160,000 available beds [20]. Energy consumption in the Spanish hospital sector reached 0.6 Mtoe, which stands for 7% of the total energy consumption in the whole tertiary sector and represents an expenditure which amounts to about 600 M€ [21]. Roman et al., (2017) stress the need that central, regional and local administrations get involved in order to ensure better estimates of the energy savings achieved and therefore to plan future efficiency measures at the lowest possible cost to taxpayers [22].

The small amount of research which has been done up so far has only been carried out on a small number of sample buildings and therefore has little statistical relevance. The purpose of the present work is to analyse and assess the average consumption of final energy in hospitals in Spain by stating specific energy operating ratios as a function of several functional indicators, i.e. built surface area, number of beds and number of workers.

2. METHODOLOGY

An analytical study was performed for the period 2005 to 2014 in 20 Spanish hospitals that had been built between 1980 and 2005, half of which were private.

Data were collected according to the regulations stated by the Eco-Management and Audit Scheme (EMAS) [23], a voluntary environmental management European Union instrument which recognises those organizations which have not only set up an Environmental Management System [24] but have also reached an agreement of continual improvement, which is verified through independent audits [25]. EMAS is a management tool developed to assess, inform and improve their environmental achievements. A total of 80 EMAS statements have been accounted for in the present work, which correspond to the set of hospitals listed in Table 1.

Table 1. List of hospitals under study

Hospital	**Management**	**Built surface area (m^2)**	**No. workers**	**No. beds**	**Province**
Hospital Asepeyo de Coslada	Private	22,000	389	200	Madrid
HM Universitario de Madrid	Private	7,717	257	110	Madrid

HM Universitario Montepríncipe	Private	19,521	503	197	Madrid
HM Universitario Torrelodenes	Private	10,808	291	136	Madrid
HM Universitario San Chinarro	Private	33,989	520	190	Madrid
Hospital Clínico San Carlos	Public	175,000	5,811	996	Madrid
Hospital Juan Ramón Jiménez	Public	126,241	2,711	725	Huelva
Hospital Costa del Sol	Public	24,408	1,271	366	Málaga
HAR de Benalmádena	Public	7,077	178	48	Málaga
Hospital Virgen de las Nieves	Public	81,681	4,977	1,075	Granada
Hospital Victoria Eugenia	Private	7,330	372	39	Seville
Hospital General Univ. de Valencia	Public	72,524	2,281	550	Valencia
Fundación Hospital Calahorra	Public	18,858	386	91	La Rioja
Hospital Galdakao-Usansolo	Public	72,000	1,599	383	Vizcaya
Hospital de Zumarraga	Public	14,125	470	130	Guipúzcoa
Asepeyo (CEPRA) Sant Cugat Vallés	Private	15,007	343	120	Barcelona
Hospital de Figueras	Private	31,319	740	168	Gerona
Hospital de Manacor	Public	28,333	1,076	226	Balearic
Hospital de Palamós	Private	21,151	643	136	Gerona
Hospital Perpetuo Socorro	Private	10,409	236	195	Las Palmas

The figures for the number of beds and the number of workers were obtained from annual data published by the Ministry of Health [26] and from the EMAS statements, respectively, and in both cases they were achieved by computing the average over the range of years under study. It should also be noted that the built surface area stands for the surface strictly devoted to healthcare together with that of common room spaces.

The final energy consumption was obtained after conversion of the corresponding thermal energy into equivalent electric power consumption. To do so, a relation was set as a function of the Coefficient of Performance (COP) of a conventional air-condensation heat pump to yield the following expression:

$$C = \frac{C_t}{\mu.} + c_e \tag{1}$$

where C, C_t and *Ce* represent the annual consumptions for final, thermal and electric energies, respectively (expressed in MWh), and μ is a dimensionless coefficient allied with local province climate conditions corresponding to the hospital location. In particular, it has been reported as 2.58, 2.70 and 2.65 for North Atlantic, Continental and Mediterranean climate regions [27].

Two different analyses were conducted in the present work. On the one hand, the average energy consumption as a function of three different indicators -namely the built surface area, the number of workers and the number of available beds- was carried out. On the other hand, a second analysis was conducted in order to get detailed information from the statistical data used in this research, for which Analysis of Variance (ANOVA) tests were carried out using different factors. In this sense, it should be noted that ANOVA tests require all samples to follow a normal distribution and to show the same variance, which had previously been verified by Levene test [28]. This type of analysis is appropriate when different data sets are compared among each other and data are sorted by criteria which are related to certain aspects that –a priori– might show an influence on energy consumption in hospitals and are represented by qualitative variables in the study.

Energy consumption was analysed according to the two most usual Types of Management (TM) for Spanish hospitals, i.e. private or public. Moreover, data handling was carried out by considering two well-defined periods (2005-2008 and 2009-2014) featured by two different stages in terms of the budgetary perspective derived from the deep crisis undergone by Spanish economy.

As referred to Geographic Location (GL), energy consumption was surveyed for hospitals in Madrid, Andalusia, Valencia, Rioja, Basque Country, Catalonia and Canary Islands in order to seek the additional influence (apart from latitude) of the particular Autonomous Community, provided that management protocols should meet the regional administrative regulations.

The Gross Domestic Product (GDP) is the monetary value of all finished goods and services produced within a country's borders during a specific period, and is regarded as a representative indicator to measure the growth or decrease of goods and services production. The influence of GDP *per capita* for each hospital location was also analysed, and results were sorted by the four following categories: < €20,000, €20,000-€25,000, €25,000-€30,000 and >€30,000, namely GDP1 to GDP4 respectively.

On another note, design and operation of healthcare buildings are usually influenced by their size, and therefore four different categories were set as referred to the Number of Beds (NB): <200 beds, 200-500 beds, 500-1,000 beds and >1,000 beds, namely NB1 to NB4 respectively.

A Heating Degrees-Day Year (HDDY) is defined as the sum of the difference between a reference temperature of 15ºC and the average temperature of the day whenever such temperature is lower than 15ºC, accounted for over a whole year:

$$HDDY = \sum_{i=1}^{n} \left(T_{Rh} - \frac{T_{max} + T_{min}}{2}\right) \cdot X_H \tag{2}$$

where T_{Rh} represents the heating reference temperature (15ºC), T_{max} and T_{min} are the maximum and the minimum daily temperatures respectively, and X_H is a logical coefficient that stands for unity/zero depending on the fact that the average daily temperature is lower/greater than 15ºC. Similarly, a cooling degrees-day year (CDDY) is defined as the sum of the difference between the maximum exterior average temperature and a reference cooling temperature of 23ºC, accounted for over a whole year:

$$CDDY = \sum_{i=1}^{n} \frac{T_{max} - TBc}{2} \cdot Ni \cdot Xc \tag{3}$$

where T_{Bc} represents the cooling reference temperature (23ºC), T_{max} is the maximum temperature (either daily- or monthly-), Ni is the number of days of the considered month and X_C is a logical coefficient that stands for unity/zero depending on the fact that the average maximum temperature is greater/lower than 23ºC.

Finally, in order to consider the climate severity, the total degrees-days year (TDDY) were determined as the sum of the heating degrees-days (HDDY) and the cooling degrees-days (CDDY), all expressed in Celsius degrees:

$$TDDY = HDDY + CDDY \tag{4}$$

In order to best accomplish the present study, three analytic intervals were set for HDDY and CDDY directly related to the local climate conditions for each hospital location: 500-1,000 ºC, 1,000-1,500 ºC and >1,500 ºC, namely HDDY1/CDDY1 to HDDY3/CDDY3.

3. RESULTS

In this section, the correlation between the average annual energy consumption and the three indicators under study (namely built surface area, number of workers and number of available beds) is firstly analysed. Next, results for the climatic analysis are presented and the results for the conducted ANOVA tests according to the classification factors are finally discussed.

3.1 Correlation between the average annual energy consumption and the built surface area, the number of workers and the number of available beds in a hospital.

All possible correlations were accounted for, and a linear dependence was concluded to best describe the data sample. This is in good agreement with some studies on hospital management elsewhere reported [29], which modelled the correlation with the built surface area, the number of workers and the number of available beds. The sample data sets used to perform the correlation analysis were selected by considering the average energy consumption of the 20 hospitals under study within the period 2005-2014. Note outliers were excluded from the final analysis, in particular data regarding Galdakao-Usansolo hospital provided they lacked statistical relevance.

3.1.1. Relation between average annual energy consumption and built surface area.

The dependence of the average annual energy consumption (*EC*, expressed in MWh) on the built surface area (*A*, in m^2) is sketched in Fig. 1, which shows a high correlation between the two variables ($R^2 = 0.9247$) and yields the analytical expression of equation (5).

$$EC=0.21A+1,265.03 \tag{5}$$

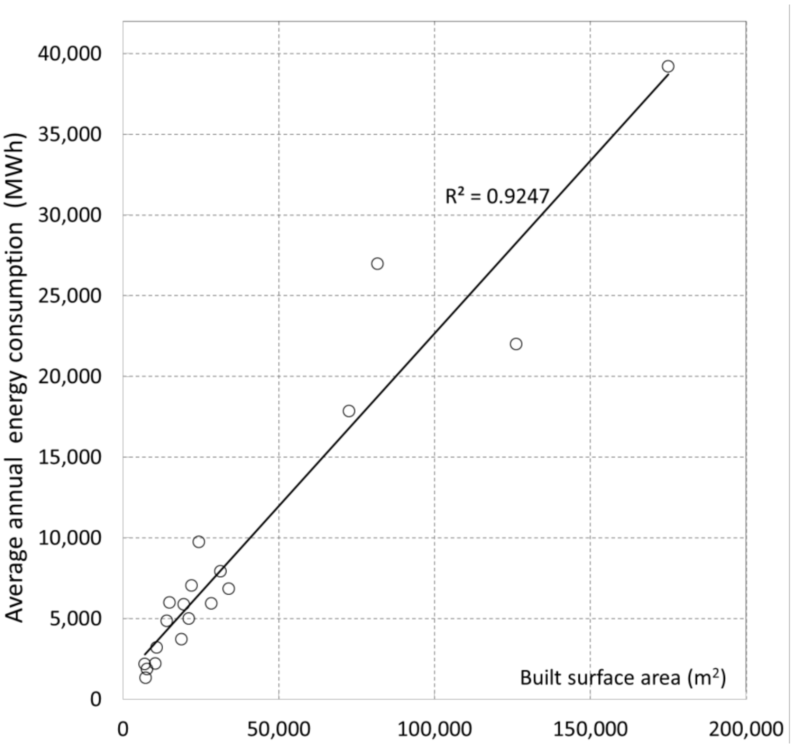

Fig. 1. Average annual energy consumption against built surface area for the set of 20 sample hospitals under study.

3.1.2. Relation between average annual energy consumption and number of workers.

Fig. 2 proves the average annual energy consumption and the number of workers in a hospital (*NW*, computed along the whole year) are correlated variables ($R^2 = 0.9525$), with an analytical dependence as in equation (6).

$$EC=6.03\ NW+2{,}004.01 \tag{6}$$

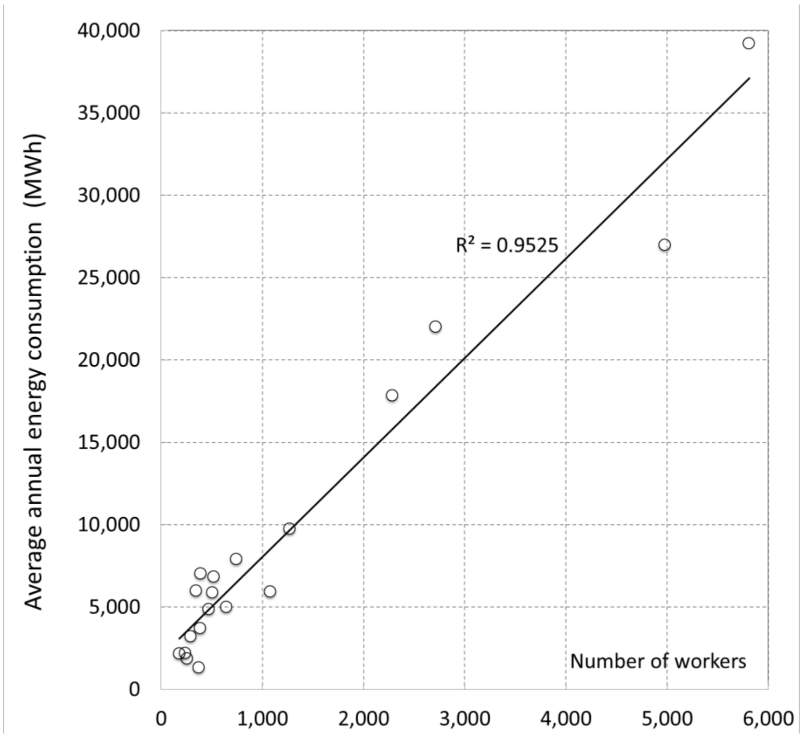

Fig. 2. Relation between the average annual energy consumption and the number of workers for the set of 20 sample hospitals under study

3.1.3. Relation between average annual energy consumption and number of available beds.

Similarly, Fig. 3 and equation (7) stand for the relation between the average annual energy consumption and the number of available beds, with a correlation index (R^2 = 0.9180) slightly lower than those of the two abovementioned linear fits.

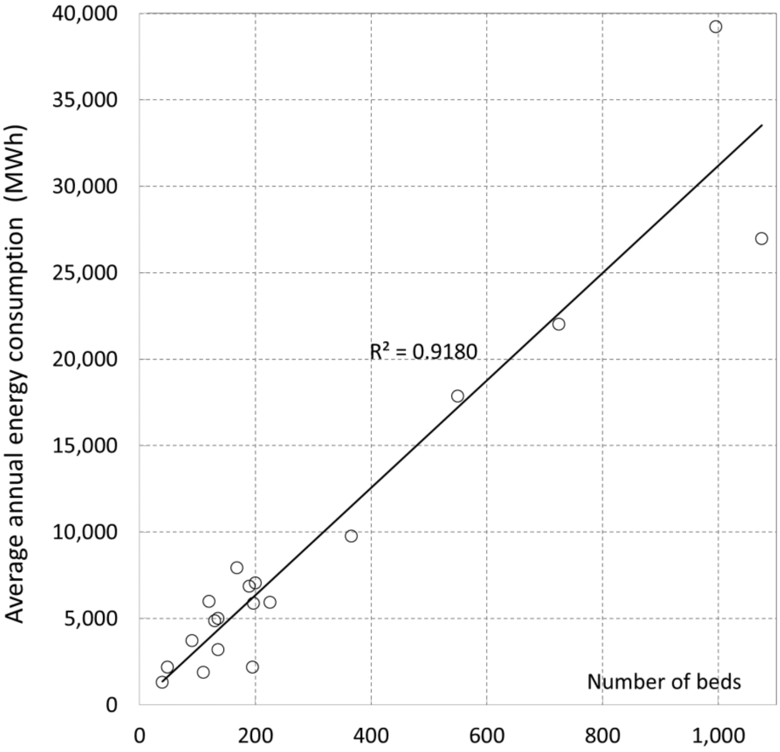

Fig. 3. Relation between the average annual energy consumption and the number of available beds for the set of 20 sample hospitals under study.

$$EC = 31.07NB + 139.84 \tag{7}$$

3.2. Impact of local climate conditions on the energy consumption in hospitals.

Energy consumption relating each of the three indicators under study was assessed in terms of the local climatic conditions for each of the 20 sample hospitals (parametrised through the corresponding total degrees-days), and no statistical correlation was observed for any of the three variables, as observed in Fig. 4.

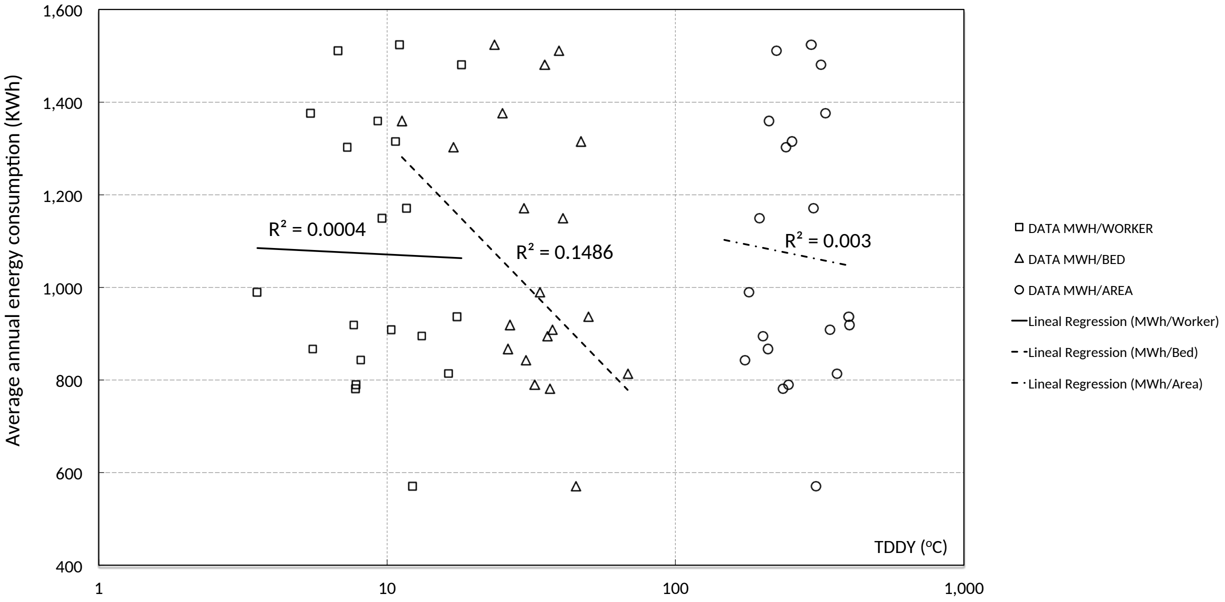

Fig. 4. Relation between average annual energy consumption per square metre, worker or bed, and the local climate conditions parametrized as total degrees-day year for the set of 20 sample hospitals.

3.3. ANOVA results

The present subsection reports on the results obtained from the statistical analysis of the variance (ANOVA). The factors studied as well as the average annual energy consumption in the sample set of Spanish hospitals are next analysed as related to the three indicators under study, namely the built surface area, the number of workers and the number of available beds. Table 2 lists the *p*-values yielded by the variance analysis. In order to determine whether any of the differences between the means are statistically significant, the *p*-values should be compared to the significance level to assess the null hypothesis. A significance level $\alpha = 0.05$ was assumed for the present study, so that if the *p*-value is less than or equal to the significance level then the null hypothesis could be rejected and it could be concluded that not all population means are equal. Otherwise, if the *p*-value is greater than the significance level, there is not enough evidence to reject the null hypothesis that the population means are all equal.

Table 2. Variance Analysis (note AAEC stands for average annual energy consumption)

Test factors	$\frac{MWh\ AAEC}{m^2\ built\ surface\ area}$	$\frac{MWh\ AAEC}{No.\ workers}$	$\frac{MWh\ AAEC}{No.\ beds}$
Type of management (TM)	Public – Private (0.65)	Public – Private (0.27)	Public – Private (0.37)
Number of beds (NB)	NB (0.24)	NB (0.39)	NB (0.77)
Gross domestic product (GDP)	GDP (0.83)	GDP (0.13)	GDP (0.29)
Total degrees-day year (TDD)	TDD (0.91)	TDD (0.92)	TDD (0.32)

Geographic location (GL)	GL (0.55)	GL (0.41)	GL (0.04)*
Range of years	2005 to 2008 and 2009 to 2014 (0.21)	2005 to 2008 and 2009 to 2014 (0.02)*	2005 to 2008 and 2009 to 2014 (0.05)*

** Population means are taken to be significantly different at the significance level 0.05.*

As observed in Table 2, if the factor "type of management" is accounted for, ANOVA variance analysis does not show significant differences for the three statistical indicators ($p_{Surface}$ 0.65; $p_{Workers}$ 0.27; p_{Beds} 0.37), which means that there is no direct link between the type of management and the energy consumption as related to the built surface area, the number of workers or the number of available beds. The same applies for the dependence on the number of beds, the gross domestic product and the degrees-days year: no significant differences are observed in the energy consumption rates in the sample hospitals as related to those factors. To a large extent, this might be due to awareness-raising policies on energy efficiency. However, some of the factors under study were identified to show a direct correlation with the achieved energy consumption rates, namely the geographic location and the particular time period ranging from 2005 to 2014, as described in the two following subsections.

3.3.1. Energy consumption as related to geographic location (GL)

If the classification according to the geographic location is accounted for, ANOVA analysis yields significant differences for one of the three statistical indicators, namely built surface area, for which differences were quantified by ($F(3,16) = 3.12$; $p < 0.05$). Subsequently, a multiple comparison analysis (*post hoc* test) was carried out via Fisher test (see Table 3) so that the existing differences were thoroughly examined. As a result, no direct correlation between the hospital's category and the associated energy consumption rate was observed as a function of its built surface area or the number of workers, but only as a function of the number of available beds. In particular, mean diff. stands for the difference between the means of the two compared samples in each row. The standard error of the mean (SEM) is a measure of how far a particular sample mean is likely to be from the true population mean and is always smaller than the standard deviation (SD). All other terms (??-value, prob., and Sig.) allow evaluation of the degree of similarity between the means of the samples compared. Finally, the lower and upper confidence limits (LCL and UCL) define the 95% confidence interval for the true mean difference between the means.

Table 3. Fischer test for means comparison with significance level 0.05.

	Mean diff.	SEM	*t*-value	Prob.	Sig.	LCL	UCL
Basque Country-Madrid	22.62	7.88	2.87	0.01	1	5.59	39.65
Basque Country-Andalusia	20.56	8.08	2.55	0.02	1	3.11	38.01
Basque Country-Valencia	23.43	9.65	2.43	0.003	1	2.58	44.28
Basque Country-Rioja	12.11	11.82	1.02	0.32	0	-13.43	37.66
Canary Islands-Basque Country	-41.53	11.82	-3.51	0	1	-67.08	-15.99
Canary Islands-Catalonia	-33.38	11.15	-2.99	0.01	1	-57.46	-9.30

A cross-variable analysis of the qualitative variables presented in the previous section was carried out in order to best determine their relation with the energy consumption of a hospital. In particular, the specific aim was to determine if the variable analysis in pairs had any effect on energy consumption, and a two-ways variance analysis was performed for such purpose. As a main result, it should also be noted that no significant influence on energy consumption was found for the coupled interactions among the qualitative variables under study. The p-values obtained are shown in Table 4, and can be observed that all values are p>0.05.

Table 4. Interaction Multivariate analysis results.

Test Interaction factors	$\frac{MWh\ AAEC}{m^2\ built\ surface\ area}$	$\frac{MWh\ AAEC}{No.\ workers}$	$\frac{MWh\ AAEC}{No.\ beds}$
Geographic location – Type of management	0.22	0.45	0.86
Geographic location – Total degrees-day year	1	1	1
Type of management - Gross domestic product	0.20	0.25	0.46
Type of management - Number of beds	0.77	0.74	0.97
Gross domestic product - Number of beds	0.81	0.69	0.34
Number of beds - Total degrees-day year	0.92	0.79	0.49
Total degrees-day year - Type of management	0.66	0.90	0.65

** Population means are taken to be significantly different at the significance level 0.05.*

3.3.2. Analysis of the energy consumption in the period 2005 to 2014

Regarding the abovementioned issue on the dependence of energy consumption on the number of available beds, the number of workers and the built surface area in a hospital (subsection 3.1), the incidence of the strong economic crisis suffered by Spain is seen as one of the potential reasons for the notable decrease in energy consumption between 2005 and 2009. In order to thoroughly assess this point, the ANOVA test was applied for the factors “final energy consumption between 2005 and 2009” and “final energy consumption between 2009 and 2014” to state significant differences in two out of the three yields. In particular, a statistical significance (Table 2) in the yields regarding the number of workers and the number of available beds was reported ($p_{Workers}$ 0.02 and p_{Beds} 0.05 respectively*)*, whereas such was not the case for the hospital’s built surface area ($p_{Surface}$ 0.21). It might therefore be concluded that there is no direct correlation between the energy consumption in a hospital and its built surface area, while energy consumption and the number of workers (and also the number of available beds) are statistically correlated.

The average annual energy consumption per available bed was computed as 34,609.98 kWh/year/bed. Energy consumption rates according to the three statistical indicators under study are shown in Table 5 below lists the classification according to percentiles and type of statistic indicator.

Table 5. Classification according to percentiles and type of statistic indicator

Indicator	***Average annual energy consumption (kWh)***						
	Percentiles						
	10%	*25%*	*50%*	*75%*	*90%*	*Average*	*SD*
$\frac{Average\ energy\ consumption\ (kWh)}{Built\ surface\ area\ (\mathrm{m}^2)}$	193.98	210.36	249.44	320.01	366.56	271.00	70.97
$\frac{Average\ energy\ consumption\ (kWh)}{Number\ of\ workers}$	5,496.23	7,555.76	9,420.30	11,752.54	16,462.75	9,962.99	3,960.10
$\frac{Average\ energy\ consumption\ (kWh)}{Number\ of\ beds}$	22,684.64	26,510.92	34,347.58	39,654.32	47,419.01	34,535.33	12,492.16

4. DISCUSSION

Any action to improve the efficiency of a hospital ought to account for both the climatic and the specific working conditions in this kind of building, and must not disregard other requirements like for instance the accessibility, safety and reliability of its facilities [30]. It should be noted that thermal discomfort or inadequate lighting levels may affect medical diagnosis [31], and also that inadequate handling of acclimation equipment may be detrimental to infection control. Therefore, given the particular features of this kind of public buildings, none of the energy saving procedures should compromise health safety or care effectiveness to users [32].

An important element for energy saving has been seen to be strongly linked to the daily management of the hospital [33], which is suitable to be directly controlled by the staff workers. It is therefore suggested that employees and users increase their awareness on the relevance of energy saving through additional training and sensitivity campaigns, so that comfort in hospitals is finally achieved via a rational use of energy.

In this sense, former studies have reported that the achievement of an efficient energy management of healthcare facilities (either clinics or hospitals) needs a previous detailed knowledge of the factors which allow the identification of the key elements that would ensure energy optimisation [34]. Such information would definitely result, on the one hand, in an improvement in the management of resources, and on the other hand in both energy consumption and facility-sizing savings.

An estimate of energy consumption should be computed by applying an adequate control protocol [35] (like for instance a comparison with the ratios reported along the present work) before setting the appropriate energy saving actions. The optimisation of the building design as referred to its thermal envelope has elsewhere been reported as a key factor to achieve relevant energy savings [36]. The implementation of an efficient LED-technology [37] lighting system monitored by a control unit accounting for temperature, humidity and lighting level for each individual room or section [38] is also highly advisable.

A second action devoted to improve energy saving in hospitals lies in the increase of efficiency of heating and cooling systems by solar collectors, mainly regarding hot domestic water and cogeneration [39]. This might be complemented with an equilibrium of the hospital's hydraulic distribution systems as well as with the implementation of variable-flow distribution systems including frequency-speed drivers in pumping equipment [40].

Finally, the hiring of specialized companies could definitely improve the building's energy management, thus ensuring relevant energy savings and a decrease in greenhouse emissions [41].

The promotion of awareness campaigns focused on energy saving protocols, as well as the identification of reasonable goals to improve motivation, are strongly advisable. Such actions should definitely involve a change in the user habits, like for instance turning lights and computers off when not in use and ensuring a moderate use of air conditioning or heating equipment. An energy audit is a suitable tool to assess energy costs and to monitor the associated energy flows in a building, which allows the identification of the key parameters that affect energy consumption and the further design of potential profitability-based energy saving measures to moderate operation, maintenance and replacement costs.

The information related to the environmental efficiency of Spanish hospitals registered in EMAS is sufficient but there are certain deficiencies in the indicators that make it difficult to make a comparative evaluation. This is due to the fact that the chosen indicators are not always used with the same criteria, and consequently they do not quantify the analysed parameter appropriately. In turn, this is likely to be because of a wrongly chosen indicator. Both energy consumption and environmental efficiency should definitely be quality indicators in the management of buildings in the healthcare sector.

The results of the present research study might serve as a starting point for the selection of appropriate indicators to accurately quantify energy consumption costs. Moreover, the implementation of this study to different types of institutions or to healthcare buildings in some other countries might definitely be a matter of great interest.

5. CONCLUSION

The results presented in the preceding sections showed correlations between the average energy consumption in hospitals and the number of workers, the number of available beds and the built surface area, in relation to the correlation analysis presented in section 3. However, in a more detailed study, considering the factors defined in section 2 (TM, GDP, HDDY, CDDY, HCNB, GL and Range Year), the following conclusions can be obtained. The geographic location of the hospital was seen to be directly linked to the energy consumption, whereas such is not the case for the type of management, the number of beds or the gross domestic product. Furthermore, the energy consumption corresponding to the period 2009-2014 was observed to be lower to that of the period 2005-2008. Moreover, a multivariate analysis among the abovementioned factors proved, it should also be noted that no significant influence on energy consumption was found for the coupled interactions among the qualitative variables under study.

Another relevant outcome was that no relation between energy consumption and climate conditions in hospitals was observed, according to the records of total degrees-days for the set of buildings under study. This evinced that neither the energy demand nor the performance of the facilities were appropriately optimised for the sample set of hospitals.

Out of the three statistical indicators under study, that of the number of available beds was regarded as the most suitable one in order to determine the energy consumption rates. Such indicator is one of the most widely used in EMAS, and it has been herein stated to be consistent and appropriately quantified.

Finally, the average energy consumption in a Spanish hospital for standard operating conditions was computed as 0.27 MWh/m^2, 9.99 MWh/worker and 34.61 MWh/bed (standard deviations 0.07 MWh/m^2, 3.98 MWh/worker and 12.48 MWh/bed, respectively).

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A quantitative analysis of final energy consumption in hospitals in Spain

Alfonso González González[1], Justo García-Sanz-Calcedo[2*], David Rodríguez Salgado[3]

[1]Department of Mechanical, Energy and Materials Engineering, University of Extremadura,
Mérida, Spain

[2]Department of Graphical Expression, University of Extremadura, Badajoz, Spain

[3]Department of Mechanical, Energy and Materials Engineering, University of Extremadura,
Badajoz, Spain

ABSTRACT

The accurate identification of the final energy consumption in hospitals is a key task to determine potential savings and therefore to set appropriate design criteria. However, correlations between consumption and functional indicators for Spanish hospitals have not been yet accounted for in detail. A total of 80 Eco-Management and Audit Schemes (EMAS) from 20 hospitals were analysed in the period 2005-2014 in order to seek correlations between energy consumption and climate conditions, gross domestic product (GDP), built surface area, number of available beds and number of staff.

The results set the average annual energy consumption in a Spanish hospital for standard operating conditions as 0.27 MWh/m^2, 9.99 MWh/worker and 34.61 MWh/bed (standard deviations 0.07 MWh/m^2, 3.96 MWh/worker and 12.49 MWh/bed, respectively). The geographic location was seen to show a direct influence on those values, as opposed to the specific type of management (TM), the number of available beds, the GDP or the particular climate conditions.

Keywords: healthcare centre; hospital; energy consumption; healthcare engineering.

1. INTRODUCTION

There is a global commitment on the reduction of CO_2 emissions to stabilize total levels below 450 ppm, or similarly to prevent a global temperature increase of 2ºC as compared to the year 1990 [1]. The average annual energy consumption in Spanish hospitals reaches 20% of the total consumption in the tertiary sector in Spain [2]. The energy demand of hospitals is among the highest of non-residential buildings [3].

Several strategies devoted to reduce CO_2 emissions have been developed by governments worldwide since the signing of Kyoto Protocol [4]. In this sense, specific programmes widely have promoted the use of renewable energies at final stages of consumption as well as the reduction of

CO_2 emissions both in energy production processes and in actions involving the improvement of energy efficiency [5]. It is the latter issue, i.e. energy efficiency, that is not being successfully accounted for in general terms, provided the energy saving goals for 2020 are not being satisfied in their intermediate stages so far [6]. Such particular fact, together with the increasing awareness on the climate change and thus on specific actions to promote sustainability, sets a notable relevance to the energy management of buildings.

According to the Spanish Institute for Energy Diversification and Saving (*IDAE*), the building sector is regarded to show a high impact on CO_2 emissions, mainly due to the high energy consumption associated to the great variety of actions it involves [7]. Among the different types of buildings corresponding to the tertiary sector in Spain, those of the Healthcare System achieve the highest energy intensity (5.2 toe/bed) followed by public administration management ones (1.647 toe/worker), while the lowest intensities are achieved by buildings devoted to education activities (0.079 toe/student) [8]. Also, United States Department of Energy (2009) estimates that hospitals are the buildings –out of those of the tertiary sector– with the highest rates of energy resources consumption [9] and Short et al. (2012) stated that 30% of the emissions generated by the public sector in the United Kingdom are linked to the healthcare system [10].

On another note, Santamouris et al. (2008) carried out a detailed analysis of audits for 30 healthcare buildings in Greece (Hellas) to quantify the potential global energy savings as 20% [11], hence suggesting potential energy saving procedures in these buildings. Additionally, Vanhoudt et al. (2011) reported a potential primary energy saving up to 71% in a Belgian hospital by using thermal energy storage in combination with a heat pump instead of gas-based boilers and water chiller [12].

In the same line of research, Kapoor and Kumar (2011) identified HVAC systems to show the highest energy consumption rates in hospitals, followed by lightning systems (30-65% and 30-40%, respectively) [13]. Moreover, the Australian Department for Health conducted a study, which concluded that HVAC systems were responsible for the highest energy consumption rates and the highest volumes of CO_2 emissions to the atmosphere in a suburban hospital (namely 65% and 47%) [14].

In the particular case of the Spanish Health System, the potential energy savings derived from the energy management in hospitals has not been systematically accounted for yet, although some other studies on small healthcare buildings and healthcare centres have elsewhere been reported [15]. San José et al. (2009) computed the average annual energy consumption for 300-bed small-sized hospitals or a health centres as 8.885 kWh/bed, and for those exceeding 300 beds as 10.043 kWh/bed [16]. The 2010 Energy Saving and Efficiency Guide for hospitals, issued by the Energy Foundation from Madrid Regional Government, reports the annual energy consumption in a small hospital as 40,000 kWh with an annual expense of €8,400 [17].

Renedo et al. (2006) studied different cogeneration alternatives for a Spanish hospital building. The authors proved that the size of the facility and the control strategy show a strong influence on the system economy, and found that the most important parameter is the electricity produced [18]. In addition, Garcia-Sanz-Calcedo (2014) reported on the analysis of energy efficiency in healthcare buildings to conclude that the potential to reduce the energy consumption of a healthcare building sized 1,000 m^2 is 10,801 kWh by making an average investment of €11,601, thus saving €2,961/year with 3.92 years average payback time [19].

The number of hospitals in Spain approaches 790, most of which are public centres, which amounts up to around 160,000 available beds [20]. Energy consumption in the Spanish hospital sector reached 0.6 Mtoe, which stands for 7% of the total energy consumption in the whole tertiary sector and represents an expenditure which amounts to about 600 M€ [21]. Roman et al., (2017) stress the need that central, regional and local administrations get involved in order to ensure better estimates of the energy savings achieved and therefore to plan future efficiency measures at the lowest possible cost to taxpayers [22].

The small amount of research which has been done up so far has only been carried out on a small number of sample buildings and therefore has little statistical relevance. The purpose of the present work is to analyse and assess the average consumption of final energy in hospitals in Spain by stating specific energy operating ratios as a function of several functional indicators, i.e. built surface area, number of beds and number of workers.

2. METHODOLOGY

An analytical study was performed for the period 2005 to 2014 in 20 Spanish hospitals that had been built between 1980 and 2005, half of which were private.

Data were collected according to the regulations stated by the Eco-Management and Audit Scheme (EMAS) [23], a voluntary environmental management European Union instrument which recognises those organizations which have not only set up an Environmental Management System [24] but have also reached an agreement of continual improvement, which is verified through independent audits [25]. EMAS is a management tool developed to assess, inform and improve their environmental achievements. A total of 80 EMAS statements have been accounted for in the present work, which correspond to the set of hospitals listed in Table 1.

Table 1. List of hospitals under study

Hospital	**Management**	**Built surface area (m^2)**	**No. workers**	**No. beds**	**Province**
Hospital Asepeyo de Coslada	Private	22,000	389	200	Madrid
HM Universitario de Madrid	Private	7,717	257	110	Madrid

HM Universitario Montepríncipe	Private	19,521	503	197	Madrid
HM Universitario Torrelodenes	Private	10,808	291	136	Madrid
HM Universitario San Chinarro	Private	33,989	520	190	Madrid
Hospital Clínico San Carlos	Public	175,000	5,811	996	Madrid
Hospital Juan Ramón Jiménez	Public	126,241	2,711	725	Huelva
Hospital Costa del Sol	Public	24,408	1,271	366	Málaga
HAR de Benalmádena	Public	7,077	178	48	Málaga
Hospital Virgen de las Nieves	Public	81,681	4,977	1,075	Granada
Hospital Victoria Eugenia	Private	7,330	372	39	Seville
Hospital General Univ. de Valencia	Public	72,524	2,281	550	Valencia
Fundación Hospital Calahorra	Public	18,858	386	91	La Rioja
Hospital Galdakao-Usansolo	Public	72,000	1,599	383	Vizcaya
Hospital de Zumarraga	Public	14,125	470	130	Guipúzcoa
Asepeyo (CEPRA) Sant Cugat Vallés	Private	15,007	343	120	Barcelona
Hospital de Figueras	Private	31,319	740	168	Gerona
Hospital de Manacor	Public	28,333	1,076	226	Balearic
Hospital de Palamós	Private	21,151	643	136	Gerona
Hospital Perpetuo Socorro	Private	10,409	236	195	Las Palmas

The figures for the number of beds and the number of workers were obtained from annual data published by the Ministry of Health [26] and from the EMAS statements, respectively, and in both cases they were achieved by computing the average over the range of years under study. It should also be noted that the built surface area stands for the surface strictly devoted to healthcare together with that of common room spaces.

The final energy consumption was obtained after conversion of the corresponding thermal energy into equivalent electric power consumption. To do so, a relation was set as a function of the Coefficient of Performance (COP) of a conventional air-condensation heat pump to yield the following expression:

$$C = \frac{C_t}{\mu.} + c_e \tag{1}$$

where C, C_t and Ce represent the annual consumptions for final, thermal and electric energies, respectively (expressed in MWh), and μ is a dimensionless coefficient allied with local province climate conditions corresponding to the hospital location. In particular, it has been reported as 2.58, 2.70 and 2.65 for North Atlantic, Continental and Mediterranean climate regions [27].

Two different analyses were conducted in the present work. On the one hand, the average energy consumption as a function of three different indicators -namely the built surface area, the number of workers and the number of available beds- was carried out. On the other hand, a second analysis was conducted in order to get detailed information from the statistical data used in this research, for which Analysis of Variance (ANOVA) tests were carried out using different factors. In this sense, it should be noted that ANOVA tests require all samples to follow a normal distribution and to show the same variance, which had previously been verified by Levene test [28]. This type of analysis is appropriate when different data sets are compared among each other and data are sorted by criteria which are related to certain aspects that –a priori– might show an influence on energy consumption in hospitals and are represented by qualitative variables in the study.

Energy consumption was analysed according to the two most usual Types of Management (TM) for Spanish hospitals, i.e. private or public. Moreover, data handling was carried out by considering two well-defined periods (2005-2008 and 2009-2014) featured by two different stages in terms of the budgetary perspective derived from the deep crisis undergone by Spanish economy.

As referred to Geographic Location (GL), energy consumption was surveyed for hospitals in Madrid, Andalusia, Valencia, Rioja, Basque Country, Catalonia and Canary Islands in order to seek the additional influence (apart from latitude) of the particular Autonomous Community, provided that management protocols should meet the regional administrative regulations.

The Gross Domestic Product (GDP) is the monetary value of all finished goods and services produced within a country's borders during a specific period, and is regarded as a representative indicator to measure the growth or decrease of goods and services production. The influence of GDP *per capita* for each hospital location was also analysed, and results were sorted by the four following categories: < €20,000, €20,000-€25,000, €25,000-€30,000 and >€30,000, namely GDP1 to GDP4 respectively.

On another note, design and operation of healthcare buildings are usually influenced by their size, and therefore four different categories were set as referred to the Number of Beds (NB): <200 beds, 200-500 beds, 500-1,000 beds and >1,000 beds, namely NB1 to NB4 respectively.

A Heating Degrees-Day Year (HDDY) is defined as the sum of the difference between a reference temperature of 15ºC and the average temperature of the day whenever such temperature is lower than 15ºC, accounted for over a whole year:

$$HDDY = \sum_{i=1}^{n} (T_{Rh} - \frac{T_{max} + T_{min}}{2}) \cdot X_H \tag{2}$$

where T_{Rh} represents the heating reference temperature (15ºC), T_{max} and T_{min} are the maximum and the minimum daily temperatures respectively, and X_H is a logical coefficient that stands for unity/zero depending on the fact that the average daily temperature is lower/greater than 15ºC. Similarly, a cooling degrees-day year (CDDY) is defined as the sum of the difference between the maximum exterior average temperature and a reference cooling temperature of 23ºC, accounted for over a whole year:

$$CDDY = \sum_{i=1}^{n} \frac{T_{max} - TBc}{2} \cdot Ni \cdot Xc \tag{3}$$

where T_{Bc} represents the cooling reference temperature (23ºC), T_{max} is the maximum temperature (either daily- or monthly-), Ni is the number of days of the considered month and X_C is a logical coefficient that stands for unity/zero depending on the fact that the average maximum temperature is greater/lower than 23ºC.

Finally, in order to consider the climate severity, the total degrees-days year (TDDY) were determined as the sum of the heating degrees-days (HDDY) and the cooling degrees-days (CDDY), all expressed in Celsius degrees:

$$TDDY = HDDY + CDDY \tag{4}$$

In order to best accomplish the present study, three analytic intervals were set for HDDY and CDDY directly related to the local climate conditions for each hospital location: 500-1,000ºC, 1,000-1,500ºC and >1,500ºC, namely HDDY1/CDDY1 to HDDY3/CDDY3.

3. RESULTS

In this section, the correlation between the average annual energy consumption and the three indicators under study (namely built surface area, number of workers and number of available beds) is firstly analysed. Next, results for the climatic analysis are presented and the results for the conducted ANOVA tests according to the classification factors are finally discussed.

3.1 Correlation between the average annual energy consumption and the built surface area, the number of workers and the number of available beds in a hospital.

All possible correlations were accounted for, and a linear dependence was concluded to best describe the data sample. This is in good agreement with some studies on hospital management elsewhere reported [29], which modelled the correlation with the built surface area, the number of workers and the number of available beds. The sample data sets used to perform the correlation analysis were selected by considering the average energy consumption of the 20 hospitals under study within the period 2005-2014. Note outliers were excluded from the final analysis, in particular data regarding Galdakao-Usansolo hospital provided they lacked statistical relevance.

3.1.1. Relation between average annual energy consumption and built surface area.

The dependence of the average annual energy consumption (EC, expressed in MWh) on the built surface area (A, in m^2) is sketched in Fig. 1, which shows a high correlation between the two variables ($R^2 = 0.9247$) and yields the analytical expression of equation (5).

$$EC=0.21A+1{,}265.03 \tag{5}$$

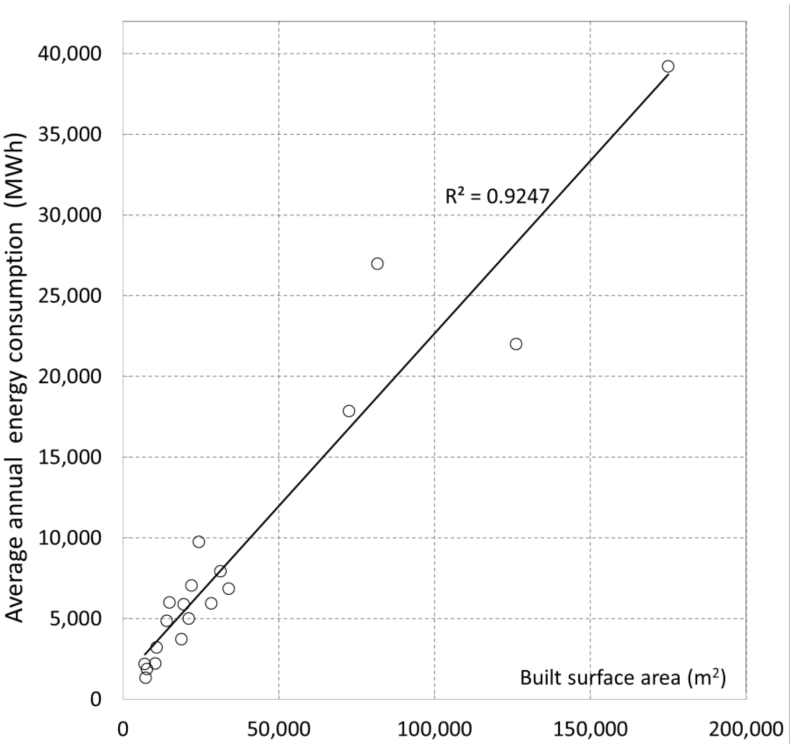

Fig. 1. Average annual energy consumption against built surface area for the set of 20 sample hospitals under study.

3.1.2. Relation between average annual energy consumption and number of workers.

Fig. 2 proves the average annual energy consumption and the number of workers in a hospital (*NW*, computed along the whole year) are correlated variables ($R^2 = 0.9525$), with an analytical dependence as in equation (6).

$$EC=6.03\ NW+2{,}004.01 \qquad (6)$$

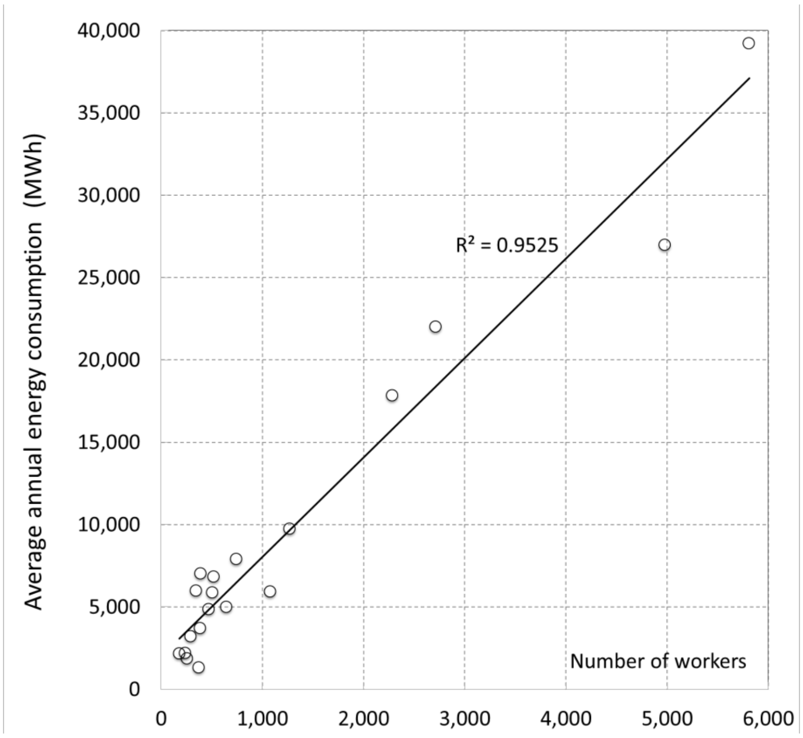

Fig. 2. Relation between the average annual energy consumption and the number of workers for the set of 20 sample hospitals under study

3.1.3. Relation between average annual energy consumption and number of available beds.

Similarly, Fig. 3 and equation (7) stand for the relation between the average annual energy consumption and the number of available beds, with a correlation index (R^2 = 0.9180) slightly lower than those of the two abovementioned linear fits.

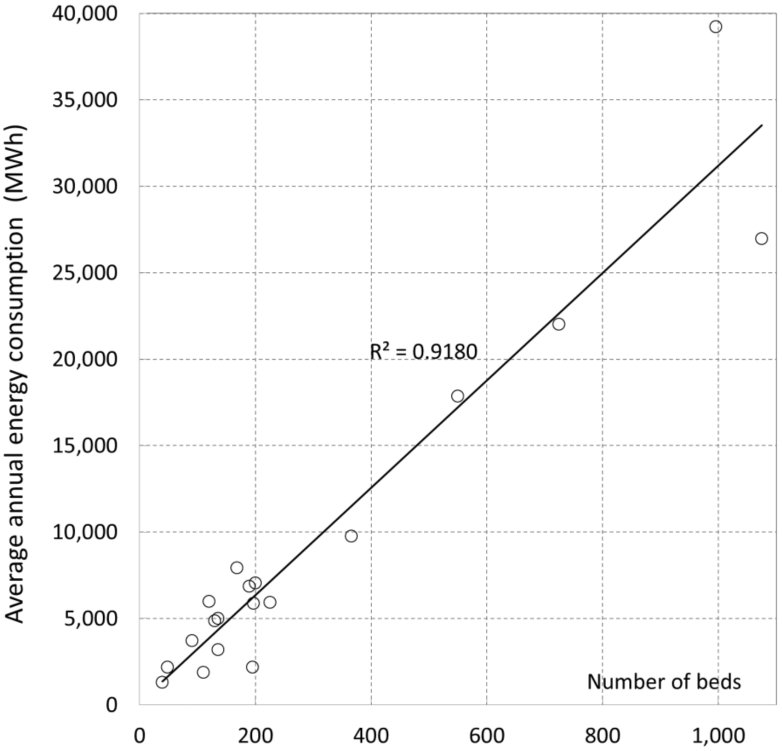

Fig. 3. Relation between the average annual energy consumption and the number of available beds for the set of 20 sample hospitals under study.

$$EC = 31.07NB + 139.84 \tag{7}$$

3.2. Impact of local climate conditions on the energy consumption in hospitals.

Energy consumption relating each of the three indicators under study was assessed in terms of the local climatic conditions for each of the 20 sample hospitals (parametrised through the corresponding total degrees-days), and no statistical correlation was observed for any of the three variables, as observed in Fig. 4.

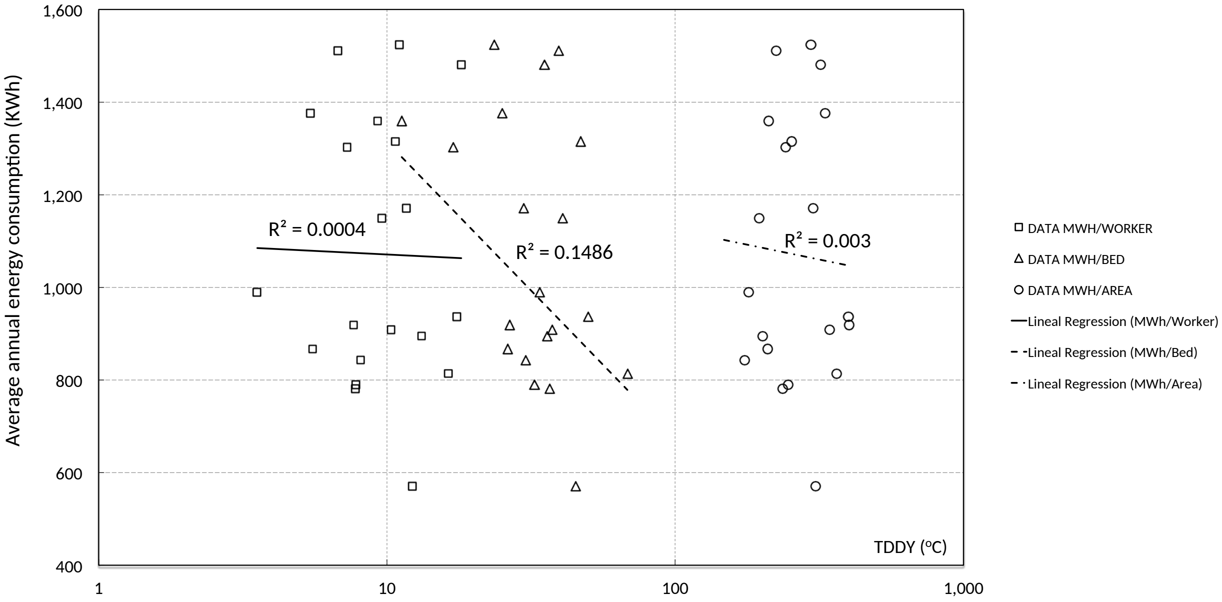

Fig. 4. Relation between average annual energy consumption per square metre, worker or bed, and the local climate conditions parametrized as total degrees-day year for the set of 20 sample hospitals.

3.3. ANOVA results

The present subsection reports on the results obtained from the statistical analysis of the variance (ANOVA). The factors studied as well as the average annual energy consumption in the sample set of Spanish hospitals are next analysed as related to the three indicators under study, namely the built surface area, the number of workers and the number of available beds. Table 2 lists the *p*-values yielded by the variance analysis. In order to determine whether any of the differences between the means are statistically significant, the *p*-values should be compared to the significance level to assess the null hypothesis. A significance level $\alpha = 0.05$ was assumed for the present study, so that if the *p*-value is less than or equal to the significance level then the null hypothesis could be rejected and it could be concluded that not all population means are equal. Otherwise, if the *p*-value is greater than the significance level, there is not enough evidence to reject the null hypothesis that the population means are all equal.

Table 2. Variance Analysis (note AAEC stands for average annual energy consumption)

Test factors	$\frac{MWh\,AAEC}{m^2\,built\,surface\,area}$	$\frac{MWh\,AAEC}{No.\,workers}$	$\frac{MWh\,AAEC}{No.\,beds}$
Type of management (TM)	Public – Private (0.65)	Public – Private (0.27)	Public – Private (0.37)
Number of beds (NB)	NB (0.24)	NB (0.39)	NB (0.77)
Gross domestic product (GDP)	GDP (0.83)	GDP (0.13)	GDP (0.29)
Total degrees-day year (TDD)	TDD (0.91)	TDD (0.92)	TDD (0.32)

Geographic location (GL)	GL (0.55)	GL (0.41)	GL (0.04)*
Range of years	2005 to 2008 and 2009 to 2014 (0.21)	2005 to 2008 and 2009 to 2014 (0.02)*	2005 to 2008 and 2009 to 2014 (0.05)*

** Population means are taken to be significantly different at the significance level 0.05.*

As observed in Table 2, if the factor “type of management” is accounted for, ANOVA variance analysis does not show significant differences for the three statistical indicators ($p_{Surface}$ 0.65; $p_{Workers}$ 0.27; p_{Beds} 0.37), which means that there is no direct link between the type of management and the energy consumption as related to the built surface area, the number of workers or the number of available beds. The same applies for the dependence on the number of beds, the gross domestic product and the degrees-days year: no significant differences are observed in the energy consumption rates in the sample hospitals as related to those factors. To a large extent, this might be due to awareness-raising policies on energy efficiency. However, some of the factors under study were identified to show a direct correlation with the achieved energy consumption rates, namely the geographic location and the particular time period ranging from 2005 to 2014, as described in the two following subsections.

3.3.1. Energy consumption as related to geographic location (GL)

If the classification according to the geographic location is accounted for, ANOVA analysis yields significant differences for one of the three statistical indicators, namely built surface area, for which differences were quantified by ($F(3,16) = 3.12$; $p < 0.05$). Subsequently, a multiple comparison analysis (*post hoc* test) was carried out via Fisher test (see Table 3) so that the existing differences were thoroughly examined. As a result, no direct correlation between the hospital’s category and the associated energy consumption rate was observed as a function of its built surface area or the number of workers, but only as a function of the number of available beds. In particular, mean diff. stands for the difference between the means of the two compared samples in each row. The standard error of the mean (SEM) is a measure of how far a particular sample mean is likely to be from the true population mean and is always smaller than the standard deviation (SD). All other terms (??-value, prob., and Sig.) allow evaluation of the degree of similarity between the means of the samples compared. Finally, the lower and upper confidence limits (LCL and UCL) define the 95% confidence interval for the true mean difference between the means.

Table 3. Fischer test for means comparison with significance level 0.05.

	Mean diff.	SEM	*t*-value	Prob.	Sig.	LCL	UCL
Basque Country-Madrid	22.62	7.88	2.87	0.01	1	5.59	39.65
Basque Country-Andalusia	20.56	8.08	2.55	0.02	1	3.11	38.01
Basque Country-Valencia	23.43	9.65	2.43	0.003	1	2.58	44.28
Basque Country-Rioja	12.11	11.82	1.02	0.32	0	-13.43	37.66
Canary Islands-Basque Country	-41.53	11.82	-3.51	0	1	-67.08	-15.99
Canary Islands-Catalonia	-33.38	11.15	-2.99	0.01	1	-57.46	-9.30

A cross-variable analysis of the qualitative variables presented in the previous section was carried out in order to best determine their relation with the energy consumption of a hospital. In particular, the specific aim was to determine if the variable analysis in pairs had any effect on energy consumption, and a two-ways variance analysis was performed for such purpose. As a main result, it should also be noted that no significant influence on energy consumption was found for the coupled interactions among the qualitative variables under study. The p-values obtained are shown in Table 4, and can be observed that all values are p>0.05.

Table 4. Interaction Multivariate analysis results.

Test Interaction factors	$\frac{MWh\,AAEC}{m^2\,built\,surface\,area}$	$\frac{MWh\,AAEC}{No.\,workers}$	$\frac{MWh\,AAEC}{No.\,beds}$
Geographic location – Type of management	0.22	0.45	0.86
Geographic location – Total degrees-day year	1	1	1
Type of management - Gross domestic product	0.20	0.25	0.46
Type of management - Number of beds	0.77	0.74	0.97
Gross domestic product - Number of beds	0.81	0.69	0.34
Number of beds - Total degrees-day year	0.92	0.79	0.49
Total degrees-day year - Type of management	0.66	0.90	0.65

** Population means are taken to be significantly different at the significance level 0.05.*

3.3.2. Analysis of the energy consumption in the period 2005 to 2014

Regarding the abovementioned issue on the dependence of energy consumption on the number of available beds, the number of workers and the built surface area in a hospital (subsection 3.1), the incidence of the strong economic crisis suffered by Spain is seen as one of the potential reasons for the notable decrease in energy consumption between 2005 and 2009. In order to thoroughly assess this point, the ANOVA test was applied for the factors “final energy consumption between 2005 and 2009” and “final energy consumption between 2009 and 2014” to state significant differences in two out of the three yields. In particular, a statistical significance (Table 2) in the yields regarding the number of workers and the number of available beds was reported ($p_{Workers}$ 0.02 and p_{Beds} 0.05 respectively), whereas such was not the case for the hospital’s built surface area ($p_{Surface}$ 0.21). It might therefore be concluded that there is no direct correlation between the energy consumption in a hospital and its built surface area, while energy consumption and the number of workers (and also the number of available beds) are statistically correlated.

The average annual energy consumption per available bed was computed as 34,609.98 kWh/year/bed. Energy consumption rates according to the three statistical indicators under study are shown in Table 5 below lists the classification according to percentiles and type of statistic indicator.

Table 5. Classification according to percentiles and type of statistic indicator

Indicator	***Average annual energy consumption (kWh)***						
	Percentiles						
	10%	*25%*	*50%*	*75%*	*90%*	*Average*	*SD*
$\frac{Average\ energy\ consumption\ (kWh)}{Built\ surface\ area\ (\mathrm{m}^2)}$	193.98	210.36	249.44	320.01	366.56	271.00	70.97
$\frac{Average\ energy\ consumption\ (kWh)}{Number\ of\ workers}$	5,496.23	7,555.76	9,420.30	11,752.54	16,462.75	9,962.99	3,960.10
$\frac{Average\ energy\ consumption\ (kWh)}{Number\ of\ beds}$	22,684.64	26,510.92	34,347.58	39,654.32	47,419.01	34,535.33	12,492.16

4. DISCUSSION

Any action to improve the efficiency of a hospital ought to account for both the climatic and the specific working conditions in this kind of building, and must not disregard other requirements like for instance the accessibility, safety and reliability of its facilities [30]. It should be noted that thermal discomfort or inadequate lighting levels may affect medical diagnosis [31], and also that inadequate handling of acclimation equipment may be detrimental to infection control. Therefore, given the particular features of this kind of public buildings, none of the energy saving procedures should compromise health safety or care effectiveness to users [32].

An important element for energy saving has been seen to be strongly linked to the daily management of the hospital [33], which is suitable to be directly controlled by the staff workers. It is therefore suggested that employees and users increase their awareness on the relevance of energy saving through additional training and sensitivity campaigns, so that comfort in hospitals is finally achieved via a rational use of energy.

In this sense, former studies have reported that the achievement of an efficient energy management of healthcare facilities (either clinics or hospitals) needs a previous detailed knowledge of the factors which allow the identification of the key elements that would ensure energy optimisation [34]. Such information would definitely result, on the one hand, in an improvement in the management of resources, and on the other hand in both energy consumption and facility-sizing savings.

An estimate of energy consumption should be computed by applying an adequate control protocol [35] (like for instance a comparison with the ratios reported along the present work) before setting the appropriate energy saving actions. The optimisation of the building design as referred to its thermal envelope has elsewhere been reported as a key factor to achieve relevant energy savings [36]. The implementation of an efficient LED-technology [37] lighting system monitored by a control unit accounting for temperature, humidity and lighting level for each individual room or section [38] is also highly advisable.

A second action devoted to improve energy saving in hospitals lies in the increase of efficiency of heating and cooling systems by solar collectors, mainly regarding hot domestic water and cogeneration [39]. This might be complemented with an equilibrium of the hospital's hydraulic distribution systems as well as with the implementation of variable-flow distribution systems including frequency-speed drivers in pumping equipment [40].

Finally, the hiring of specialized companies could definitely improve the building's energy management, thus ensuring relevant energy savings and a decrease in greenhouse emissions [41].

The promotion of awareness campaigns focused on energy saving protocols, as well as the identification of reasonable goals to improve motivation, are strongly advisable. Such actions should definitely involve a change in the user habits, like for instance turning lights and computers off when not in use and ensuring a moderate use of air conditioning or heating equipment. An energy audit is a suitable tool to assess energy costs and to monitor the associated energy flows in a building, which allows the identification of the key parameters that affect energy consumption and the further design of potential profitability-based energy saving measures to moderate operation, maintenance and replacement costs.

The information related to the environmental efficiency of Spanish hospitals registered in EMAS is sufficient but there are certain deficiencies in the indicators that make it difficult to make a comparative evaluation. This is due to the fact that the chosen indicators are not always used with the same criteria, and consequently they do not quantify the analysed parameter appropriately. In turn, this is likely to be because of a wrongly chosen indicator. Both energy consumption and environmental efficiency should definitely be quality indicators in the management of buildings in the healthcare sector.

The results of the present research study might serve as a starting point for the selection of appropriate indicators to accurately quantify energy consumption costs. Moreover, the implementation of this study to different types of institutions or to healthcare buildings in some other countries might definitely be a matter of great interest.

5. CONCLUSION

The results presented in the preceding sections showed correlations between the average energy consumption in hospitals and the number of workers, the number of available beds and the built surface area, in relation to the correlation analysis presented in section 3. However, in a more detailed study, considering the factors defined in section 2 (TM, GDP, HDDY, CDDY, HCNB, GL and Range Year), the following conclusions can be obtained. The geographic location of the hospital was seen to be directly linked to the energy consumption, whereas such is not the case for the type of management, the number of beds or the gross domestic product. Furthermore, the energy consumption corresponding to the period 2009-2014 was observed to be lower to that of the period 2005-2008. Moreover, a multivariate analysis among the abovementioned factors proved, it should also be noted that no significant influence on energy consumption was found for the coupled interactions among the qualitative variables under study.

Another relevant outcome was that no relation between energy consumption and climate conditions in hospitals was observed, according to the records of total degrees-days for the set of buildings under study. This evinced that neither the energy demand nor the performance of the facilities were appropriately optimised for the sample set of hospitals.

Out of the three statistical indicators under study, that of the number of available beds was regarded as the most suitable one in order to determine the energy consumption rates. Such indicator is one of the most widely used in EMAS, and it has been herein stated to be consistent and appropriately quantified.

Finally, the average energy consumption in a Spanish hospital for standard operating conditions was computed as 0.27 MWh/m^2, 9.99 MWh/worker and 34.61 MWh/bed (standard deviations 0.07 MWh/m^2, 3.98 MWh/worker and 12.48 MWh/bed, respectively).

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