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Influence of the number of users on the energy efficiency of health centres

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ABSTRACT

The present work is aimed at evaluating the influence of various factors – mainly number of users – on both energy and environmental features of a Health Centre by quantifying their incidence on the sizing of the building, as well as on energy consumption and its management.

A total of 70 Health Centres located in eight Health Areas of Extremadura (a south western Region of Spain) were analyzed from both energy and environmental perspectives. In particular, the most influential parameters on buildings' daily management were studied. Also, a sensitivity analysis to establish empirical connections between energy indicators and the operating parameters was carried out. Finally, Geographic Information Systems (GIS) were used to explore possible correlations with other factors related to buildings' location.

1. Introduction

The concept of *energy* arises at present as a fundamental pillar for social–economic development. As a result of both economic growth and tendency to satisfy vast energy needs, specific actions in the ambit of energy management policies ought to be held in order to promote integration of environmental aspects and sustainable development.

According to the Spanish Institute for Energy Diversification and Saving (*IDAE*), the building sector has shown a great development as well as one of the highest impacts on carbon dioxide emissions in the atmosphere. This is mainly caused by vast rates of energy consumption, reported as 17% of the total energy consumption in the country (including 10% and 7% in the domestic and the tertiary sectors, respectively) [1]. Therefore, assuming 23% extra energy needs corresponding to material manufacturing, raw material and diverse transport needs, the final energy consumption associated to the building sector might be reported as 40% of total in Spain.

As a particular case within the abovementioned sector, *Health Centres* are specifically designed to hold Primary Health Assistance actions aimed at providing support for promoting, preventing, care and rehabilitation activities at a concrete urban district by specialized staff and suitable equipment. They are conceived by the welfare protocols of the World Health Organization as well as by the current regulatory framework to optimize user's first contact with the Health System [2].

Health Centres facilities are fully immersed in the social environment of the users. Their main distinguishing features are total accessibility and optimum procedures for health assistance from a perspective that integrates preventive, therapeutic and rehabilitation aspects.

Therefore, measures to improve the energy efficiency of Health Centres should account for climatic and local conditions, indoor climate environment [3] and cost-effectiveness. Besides, they should not contravene other specific requirements concerning this type of building, like accessibility, feasibility of supplies [4] and reliability of facilities.

The Public Health System in Extremadura is structured into territorial demarcations known as *health areas*, each including specific facilities devoted to ensure adequate assistance to the assigned population. Such areas are divided into *health zones* – also referred to as *basic health zones* – in order to optimize performance and efficiency of Primary Assistance [5].

The health zone is regarded as the territorial and population framework of Primary Assistance, where direct health care is available and which guarantees continuous, integral and permanent assistance by the staff of the Primary Assistance Team. It is a unique health demarcation that involves the various population centres assigned to each team.

Each health zone has a *head town*, where a Health Centre is located as a functional unit to support the basic actions of the Primary Assistance Team, and a series of local surgeries to support health assistance to users from other locations of the health zone different from that of the head town.

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2. Methodology

A total of 70 Health Centres located in eight Health Areas of Extremadura were studied from both energy and environmental perspectives. In particular, the most influential operating parameters on the daily management of the buildings were analyzed.

Final electricity consumption records corresponding to the period 2006–2007 (as well as those regarding other types of fuels such as natural gas or diesel oil) were profusely analyzed in order to perform a comparison among the various energy indicators of different buildings. This allowed the calculation of both the average annual consumption and the arithmetic mean consumption for each year relating electricity and fuel for heating.

The determination of the final energy consumption needed a previous transformation of the corresponding thermal energy into electricity consumption, which was carried out through a correlation in terms of the Coefficient of Performance (COP) of the heat pump, assumed as 2.6. This way, the final energy consumption of each building was obtained in electric kWh and referred to annual periods in all cases [6]. The Health Centres considered in the present study share similarities in air conditioning systems: either heat pump for winter/summer, or diesel oil boiler and cooling units for winter and summer terms, respectively (supported by air condensation in both cases).

Provided that a large number of medical care buildings in Extremadura are observed to be over- or undersized, the annual energy consumption of the targeted Health Centres was normalized according to their real dimension so that coherence is guaranteed in data comparison and subsequent conclusions [7].

Data collection was carried out by directly visiting each of the targeted buildings. Information obtained *in situ* was verified and contrasted with other sources. This way, data referring to morphological aspects of the buildings were compared to the original construction projects, and information regarding assistance records (diagnosis techniques and equipments) was obtained at the Primary Assistance Office of the Health Service of Extremadura.

Statistical analysis techniques based on simple and multiple correlations were used to quantify the connection between variables and to estimate accuracy of the equations involved.

3. Materials and methods

The effective number of users of facilities in a Health Centre was determined by initially calculating the ratio between number of users and size of the building. This allowed the computation of the building energy consumption per effective number of users.

3.1. Determination of number of users in a Health Centre

Two clearly distinguished types of users might be set in Health Centres. On the one hand, those from the population nucleus at which the Centre is located and who typically make use of all facilities; on the other hand, those from the reference health zone. Note that some of the facilities of Health Centres are not used by the latter population, like daytime primary care consultations, for which a doctor and a nurse move to specific dependences (mainly referred to as Local Surgeries) enabled in some of the surrounding towns [8].

Support units are defined as those independent units with specific human and technical resources to provide social-health assistance to a reference population nucleus in a Health Centre, in the ambits of Radiology, Physiotherapy, Mental Health, Family Guidance and Planning Centre, and Drug Dependency Care Centre among others.

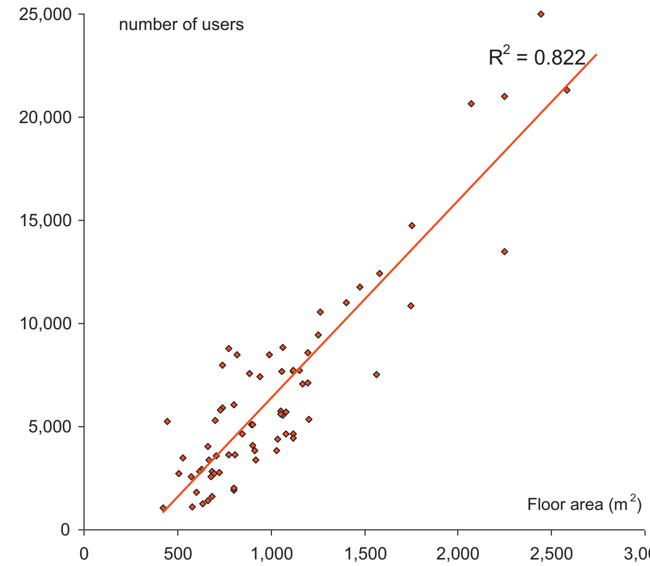

Fig. 1. Relation between number of users and floor area for the Health Centres considered in the present work.

A detailed analysis on the assistance demand for each Health Centre was carried out in order to achieve an accurate estimate of the number of users. This information was compared with the records available at archives and documentary sources of the health information system of the Regional Health Service in Extremadura.

The so-obtained value for number of users was found to be a suitable analysis parameter, provided that it virtually remains constant throughout the building lifetime, mainly due to the negligible population growth rate in rural areas of Extremadura [9]. This way, it was regarded as an appropriate reference parameter to scale a Health Centre.

Furthermore, according to the analysis of the functional parameters and of the abovementioned records, the number of users in Health Centres was found to depend on three variables: the population of the head town (P_B), the number of users in the health zone (P_{ZBS}) and the number of support units for the Health Centre (AP). Such variables were seen to be interconnected as shown in the following empirical expression, Us being the calculated number of users:

$$\text{Us} = (P_B + (0.07\ \text{AP} + 0.5)(P_{ZBS} - P_B)) \quad (1)$$

For some of the targeted Health Centres, the calculated value was seen to be similar for the three sets of users. However, significant differences were achieved for some other ones. The same value was found for the three types of users if large population nuclei were considered, due to the fact that these towns are urban health zones themselves, in which all inhabitants correspond to the head town [10].

3.2. Relation between number of users and building size

The number of users and the dimension of the Health Centre were observed to follow a linear dependence [11]. Data regarding these two variables are plotted in Fig. 1 and were fitted as ($R^2 = 0.822$):

$$y = 9.58\,\text{Us} - 3260 \quad (2)$$

Besides, the dependence of the ratio *floor area per user* on the number of users of a Health Centre was modelled. According to

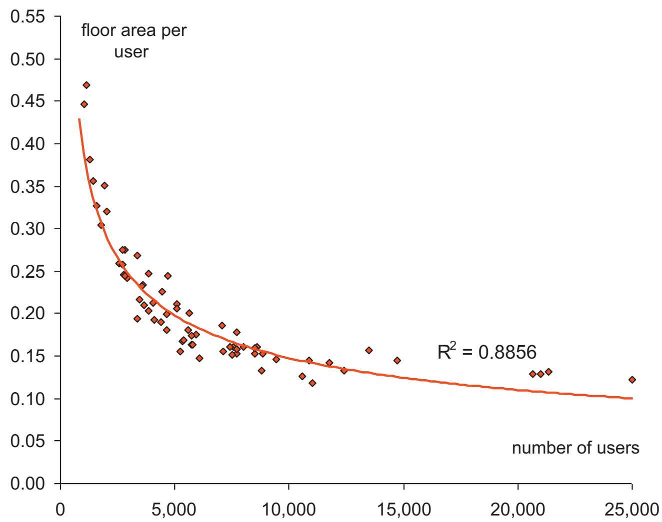

Fig. 2. Relation between floor area per user and number of users for the Health Centres considered in the present work.

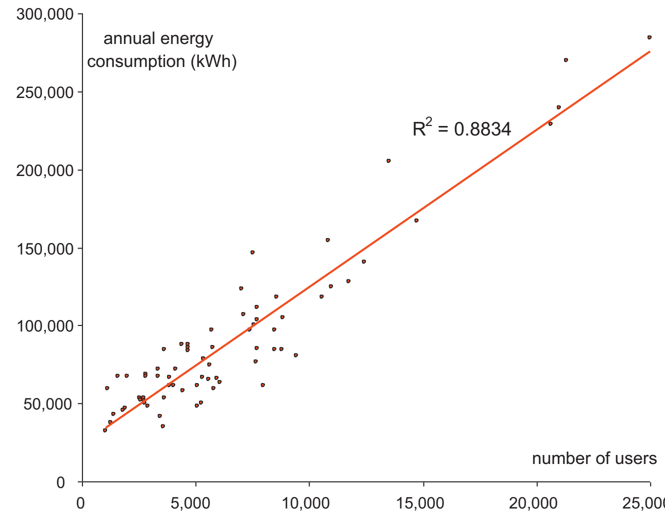

Fig. 3. Relation between annual energy consumption and number of users for the Health Centres considered in the present work.

the dispersion plot in Fig. 2, data were fitted to the exponential equation:

$$y = 7.48\,\mathrm{Us}^{-0.426} \quad (3)$$

with $R^2 = 0.8856$. As can be seen, the lower the number of users, the larger the floor area required by each user. This might be explained by the fact that there are certain health care units having a minimum floor area which does not depend on the number of users. The highest ratios were found to correspond to those Health Centres with lower number of users.

3.3. Relation between energy consumption and number of users

Quantitative and qualitative analyses of the environmental and energy parameters of Health Centres have regarded the annual energy consumption per unit floor area as the main energy indicator to test the energy efficiency of such buildings. However, it should be brought to mind that a specific parameter to account for the number of virtual users should be considered in sizing calculations of new constructions.

The ratio between the annual energy consumption by the building under standard (climatic, occupancy and operating) conditions and the number of users is a suitable energy indicator to test the building's efficiency. As can be observed in Fig. 3, energy efficiency is strongly correlated for the set of Health Centres considered in the ambit of the Autonomous Community of Extremadura.

As shown in Fig. 4, the annual energy consumption per unit floor area, measured in kWh/m^2, was observed to follow an increasing trend for each of the targeted Health Centres if plotted against number of users. However, this tendency becomes linear from approximately 7000 users on. This is due to the fact that the greater the number of users, the higher the number of Basic Health Care Units, thus resulting in an optimum distribution of users per physician.

On the one hand, 7000 might be stated as the threshold number of users for a Health Centre to be regarded as efficient from a purely energetic point of view. No coherent conclusions regarding energy efficiency could be drawn below such limiting value, provided that linearity is no longer approached in that case.

On the other hand, the behavior of these parameters for Health Centres exceeding 25,000 users has not been explored, although practical experience suggests they are too large to be properly managed in terms of energy efficiency.

3.4. Global heating potential as a function of number of users

As it is well known, atmospheric warming caused by carbon dioxide emissions (among other gases), referred to as the greenhouse effect, appears as a consequence of global warming. These emissions trap the reradiated heat from the planet surface and thus may lead to a temperature increase thereof.

The conversion factors [12] provided by the Fourth Intergovernmental Panel on Climatic Change were used in the present work in order to estimate the greenhouse effect potential for each of the targeted Health Centres. Note that such parameters were referred to a time horizon of one hundred years.

This way, the global heating potential (GHP) was determined as a function of the number of users, as shown in Fig. 5. Data were fitted to the following second order polynomial expression, with correlation index $R^2 = 0.8749$:

$$y = 0.0001x^2 + 8.34x + 35,200 \quad (4)$$

4. Results

Energy consumption in efficient Health Centres were observed as up to 20% less than that of non-efficient ones, even though the latter met Spain's Technical Building Code [13]. This is mainly due

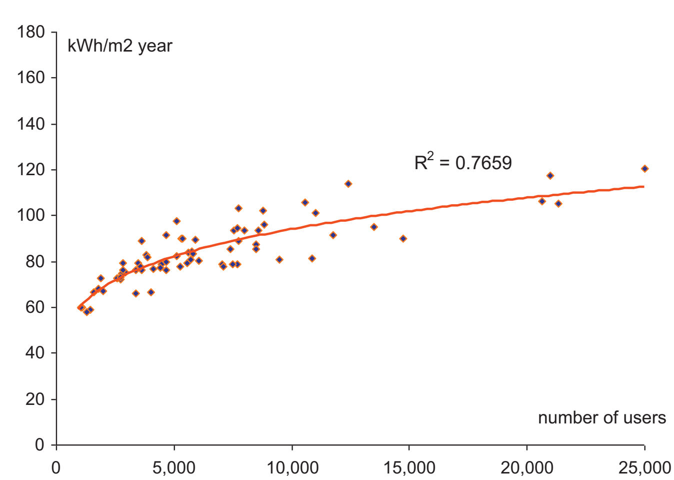

Fig. 4. Relation between annual energy consumption per unit floor area and number of users for the Health Centres considered in the present work.

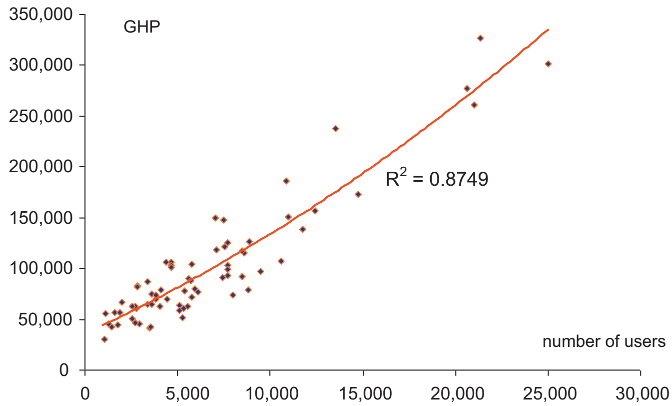

Fig. 5. Global heating potential (GHP) as a function of the number of users for the Health Centres considered in the present work.

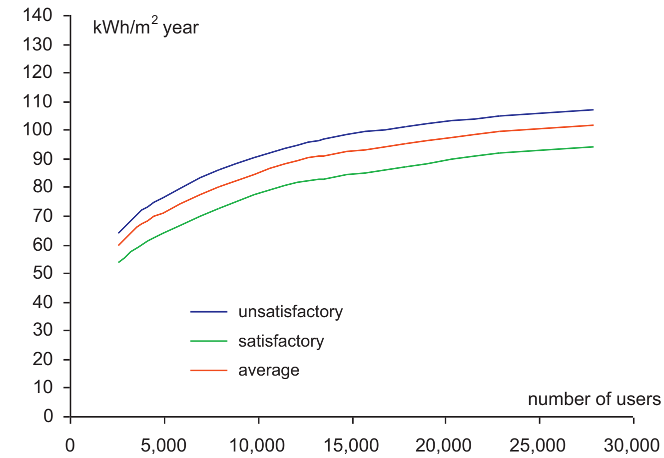

Fig. 7. Influence of the management factor on the annual mean energy consumption of Health Centres.

to the particular operating conditions. Control over use and management factors is thus essential to guarantee energy efficiency of the building. For such purpose a non-dimensional experimental parameter referred to as *management factor* was defined. It was determined for each of the Health Centres under study and accounts for the degree of commitment to energy management by staff and managers of the building. The parameter was set to range between 0.80 (to represent zero sensitivity to energy saving measures) and 1.00 (full implication on energy efficiency strategies).

The management factor was then determined by identifying the operating hours of heating/cooling equipments, the staff responsible for their handling as well as the degree of commitment to strategies on energy save and efficiency.

Also, the efficiency of facilities was proved to be somehow linked to the number of users of a Health Centre, provided that the floor area was seen to be directly proportional to number of users as described in Section 3.2. Fig. 6 shows that efficiency of facilities increases with floor area, as larger buildings allow the installation of high efficiency equipments, heat recovery devices, etc. without significant increase in initial investment.

Fig. 7 represents the mean annual energy consumption per unit floor area as a function of number of users for each of the targeted Health Centres. Note that three different management factors were accounted for. As expected, unsatisfactory management factors were found to be associated to higher energy consumption rates [14].

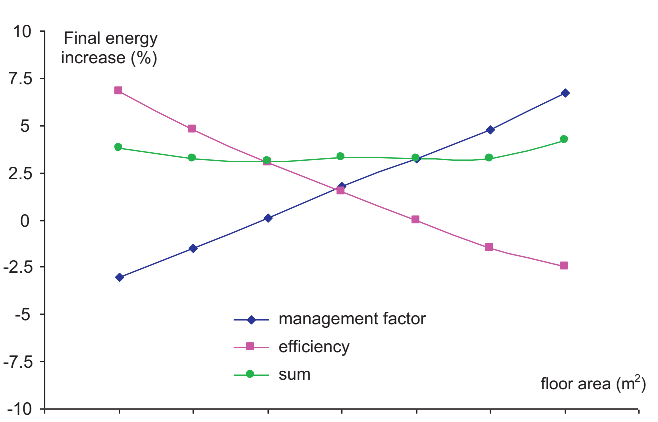

Fig. 6. Final energy increase as a function of the floor area of Health Centres.

The standard deviation of the estimate and the correlation coefficient between the energy indicators and the operating parameters were calculated in all cases.

However, maintaining the management factor within an acceptable range is far from straightforward, provided the growing number of professionals whose attention must be drawn on environmental and energy efficiency strategies [15]. Given the fact that there is no *director* of a Health Centre as such, but instead a *coordinator* with exclusively assistance ascriptions (and with no responsibility on management regarding operating costs of the building), the leadership role on the abovementioned matter is substantially diluted.

The energy efficiency of Health Centres was observed to be improvable by an appropriate management of buildings' operating parameters, which might be achieved via specific actions like the following: controlling the operating hours of heating/cooling equipments, ensuring water tightness of the building [16], controlling the use of artificial lighting, avoiding unnecessary use of electric stoves and similar devices (mainly used when heat is unevenly distributed by standard heating units), avoiding extra energy waste caused by *stand-by* modus in electric equipments, etc.

Thermal comfort should be achieved through an efficient use of energy. Since facilities are expected to meet comfort requirements throughout the whole year, auxiliary energy consumption should be minimized and acclimatization equipments should therefore be operated to meet the needs that could not be overcome by natural procedures [17]. In this sense, the architectural design of the building plays a key role, and should therefore be carried out following the basic principles of bioclimatic techniques, which include the selection of specific materials according to their life cycle [18].

The outer envelope of the building, composed of wall enclosures limiting the living space from the external environment (air, land, other buildings, etc.) and of inner partitions separating the living space from non-living areas in contact with the outside [19], might be regarded as a key element that strongly influences environmental and energy efficiency in a Health Centre [20].

Besides, exhaustive maintenance protocols are crucial to ensure the design conditions, especially regarding management of energy costs [21]. The relevance of the maintenance operations management arises from equipment deterioration and from the potential consequences on users' and building's safety. Therefore, in terms of energy efficiency, special emphasis must be paid to avoid *energy damage*, i.e. to avoid installation of equipments operating at higher energy consumption rates than expected at standard operating and design conditions.

5. Conclusions

The results achieved in the present work led to predict a directly proportional relationship between the number of users in a Health Centre, its floor area and the annual energy consumption of the building. These variables were also observed to be related with other operating parameters of the facilities. As a result, all environmental and energy indicators of the building should be based on the real number of users. Moreover, the latter variable was also proved to influence the specific indicators regarding environmental and energy aspects of the building.

Results were collected from 70 targeted Health Centres, and statistical correlation techniques were applied to obtain the most accurate mathematical expression to model the behavior of the variables involved. Moreover, Geographic Information Systems (GIS) were used in search of possible correlations with other factors related to building's location.

Low efficiency, the lack of reliable information, and important management difficulties, were the key criteria to regard Health Centres designed for a number of users below 7000 or exceeding 25,000 as environmentally and energetically inefficient. Therefore, it must be pointed out that the number of users should meet the abovementioned range in order to both ensure energy efficiency and minimize environmental impact.

The annual energy consumption was proved to decrease in facilities with a high associated management factor. It should also be pointed out that the smaller the facilities (i.e. the lower the staff members and the number of users), the more effectively energy management might be carried out.

However, in order to satisfy a higher assistance demand (and hence a higher number of actual users), it is possible to design more efficient facilities both from standpoints of energy efficiency and use of renewable sources. This way, the progressive reduction of polluting emissions would be favored, and the potentials of global warming, of eutrophication, of ozone photochemical synthesis and of acidification would be optimized.

It should be finally noted that the consideration of the indicated parameters, as well as the recommendations that follow from their application to the operating protocols regarding the facilities of Health Centres, might serve the Regional and State Health Departments in the ambit of the European Union as reference for further design of more environmentally and energetically efficient buildings.

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