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Quantitative analysis on energy efficiency of health centers according to their size

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ABSTRACT

The current study presents the results obtained from evaluating 70 health centers in Extremadura (Spain), after researching the morphological and functional parameters that have a greater influence on sizing such buildings as well as the empirical relationships with their energy consumption and emissions. Results have been compared to energy audits conducted over the 2005–2010 period.

A mathematical formulation that allows efficient quantification of the optimal floor area of health centers is proposed. It also forecasts their annual energy consumption, which can be used as a reference for future projects planning and as an indicator to assess energy management of such buildings.

Optimal sizing of health centers is determined based on the health services provided, by optimizing energy consumption and minimizing greenhouse emissions to the atmosphere.

1. Introduction

The building sector is regarded as showing one of the highest impacts on carbon dioxide emissions to the atmosphere, mainly due to vast rates of energy consumption, reported as 17% of total energy consumption in Spain-as sum of 10% domestic sector and 7% tertiary sector- [1]. Therefore, assuming 23% extra energy needs corresponding to material manufacturing and transport activities, the final energy consumption regarding the building sector might be estimated as 40% of total in the country.

A health center is a building specifically designed to hold primary health care regarding promoting, preventing, care and rehabilitation supports at a concrete urban area, and which has appropriate staff and equipment in order to satisfy those needs [2]. This health facility is fully immersed in the social environment of the users, and thus very close to them. Its main distinguishing features are total accessibility and procedures for health assistance from a perspective that integrates preventive, therapeutic and rehabilitation aspects [3].

The four critical areas that project teams and building owners need to address are regarded as reliability, flexibility, integrated design and commissioning, and economics. However, a relevant fifth category is often accounted for by designers: sustainability. Energy efficiency and energy use are major components of sustainability [4]. Specific measures to improve the energy efficiency of a particular building should consider climatic and local conditions, indoor climate environment [5] and amortization in terms of both economic and environmental aspects [6].

The annual energy consumption in health centers of Extremadura, a region in South-western Spain, is reported to exceed 22 million kWh electric energy, 450,000 l diesel and 40,000 m^3 natural gas, servicing a population of 1,070,000. These centers release 27,000 t CO_2 and other greenhouse gases [7] into the atmosphere, which sets a greater demand to integrate environmental considerations into the design and construction of these buildings.

Health centers are high traffic buildings since each user visits the facility an average of 15 times per year for general medical, nursing or pediatric visits [8]. This yields 225,000 average medical visits per year for a 15,000 inhabitant baseline health center. Such type of building is therefore an ideal place for consumers to perceive the advantages of an eco-friendly building.

The potential savings from energy management of health centers have not yet been systematically and thoroughly studied.

Murray, Pahl and Burek (2008) showed that the smaller health service buildings in Scotland reached 29% of the total floor area of buildings linked to the National Health Service of Scotland, and proposed 0.2 GJ/m^3 as a reference value [9]. Santamouris et al. (1994) carried out a detailed analysis of audits regarding 30 health care buildings in Hellas (Greece) to quantify the potential global energy saving as 20% [10]. Giridharan, Lomas, Short and Fair (2013) performed a set of computer simulations to show that light-touch

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low carbon interventions could produce comfortable conditions in bedrooms into the 2050s in UK Midlands [11].

Hignett and Lu (2009) reported on the use of the building design guide by architects and designers in UK to point out the fact that an excessive set of restrictions might derive into a relevant loss of freedom of design possibilities. They concluded that new research evidences regarding standardized space requirements were needed in order to ensure appropriate clinical interventions [12]. Yun, Kim and Kim (2012) proved that a change in the occupancy patterns of a building with respect to the initial design settings might result in higher rates of energy consumption for lighting purposes, which was seen to potentially reach a 50% increase [13].

Martini, Discoli and Rosenfeld (2007) reported on the energy behaviour of each type of health service facility of the Argentinian Public Health Network, and assessed correlations between energy consumption rates and a series of variables, i.e. space, use, infrastructure and equipment [14].

However, there are few previous studies, even though their actual savings projections are great, given that 2956 health centers operated in Spain in 2010 [15].

The standard method used to estimate the size of a health center is based on a functional plan [16], which constitutes the initial scenary for designers to develop the building project. Such plan defines spaces, areas, units, service portfolio and projected staff, and is usually designed by the corresponding healthcare management team. The functional plans acknowledge that the space available to provide adequate health care in the health center can be calculated based on the floor area used by the corresponding facilities, applying a conversion factor which integrates circulation, hallways, entries as well as the space occupied by the partition walls, structure, underfloor voids, etc. [17,18].

The present work is aimed at analyzing the ample and scattered information available on these buildings, regarding their date of construction, location, space distribution, and number of users, occupancy area, and the health services provided in order to find mathematical models to efficiently quantify health centers' optimal floor plan design. This model will enhance the building's energy and environmental features [19]. In this context, the current study seeks to define an indicator of expected energy consumption in a health center, which will be used to estimate its energy consumption. This study is based on previous works by the same authors [20–23].

2. Methodology

In order to develop the present study, qualitative and quantitative morphological and energy features have been analyzed from 70 health centers (66.66%) in Extremadura (Spain). Results were compared to energy audits conducted [24] in 55 of them (52.38%) by the Energy Agency of Extremadura over the 2005–2010 period.

To ensure sample homogeneity, similar buildings have been selected according to their climate control system. All cases were based on usage of heat pump in summer-winter or diesel boilers in winter and cooling systems in summer, condensed by air. Studied facilities size ranges between 500 and 3500 m^2, in areas showing between 3500 and 25,000 healthcare users, and were built between 1985 and 2007. All the health centers under study had similar equipment and offered the same healthcare services.

In order to analyze the obtained data, statistical analysis techniques were used based on single and multiple correlations. The degree of correlation between variables was determined as well as the accuracy of each equation to meet relations among them. In all cases, the standard error of the estimate and the correlation coefficient were calculated, establishing through geographic information systems (GIS) the influence of related factors to the building location [25].

In order to perform a comparison among the various energy indicators of different health centers, final electricity consumption records for 2006 and 2007 [26]–as well as those regarding other types of fuels such natural gas or diesel oil- were thoroughly analysed. The final energy consumption was obtained after conversion of the corresponding thermal energy into equivalent electricity consumption. To do so, a relation was set as a function of the coefficient of performance (COP) of a conventional air-condensation heat pump [27] to yield the following expression:

$$C = \frac{C_t}{2.6} + C_e \quad (1)$$

where C, C_t and C_e represent the annual consumptions for final, thermal and electric energies, respectively (all expressed in kWh).

The actual number of users in a health center, U_S, was determined as [20]:

$$U_s = (P_B + (0.07A_P + 0.5)(P_{BHz} - P_B)) \quad (2)$$

where P_B is the population of the head town, A_P the number of support units for the health center and P_{BHZ} the number of users in the Basic Health Zone. A series of support units, defined as independent units with appropriate human and technical resources which provide social-health assistance to health centers, were considered in the present work to cover the following scopes: radiology, physiotherapy, mental health, family guidance and planning center, and drug dependency care center.

All the health centers under study were classified into three groups. Group 1 corresponds to all centers whose interior design features match austere spaces mainly in size, conventional geometric shapes, minimal interior hallways, lack of split levels, simple or non-existent entrance lobbies and, in general, a low level of circulation. Group 1 is usually associated with buildings with low construction budgets. Group 2 corresponds to health centers that have in common open spaces with partially differentiated internal circulatory spaces, spacious waiting rooms, medium size lobbies and medium to high quality construction. Finally, Group 3 includes more expensive buildings, with noticeable architectural design, large common areas with non-traditional structural shapes, double height waiting rooms, different circulation in various circuits, large lobbies and oversized waiting rooms.

It has been proven that 47% of health centers in Extremadura belong to the first group, 39% to the second, while the third one is a minority, including only 10 buildings representing 14% of the sample. Extrapolation of results to the rest of the buildings was carried out under the assumption of all having similar operational and functional characteristics.

The empirical validity of the equations obtained from the study was tested applying the Student t-test for independent samples, using in all cases a confidence level of 95%.

3. Materials and methods

By means of statistical analysis, the average of the independent variable final annual energy consumption per unit floor area of the sample is 86.01 kW h/m^2, with a standard deviation of 16.87 and a variance of 284.68. Fig. 1 illustrates the sample frequency histogram.

The results obtained from this study are shown below.

3.1. Dependence of energy consumption on floor area

By quantitative analysis of the energy parameters, the annual final energy consumption has been proved to be a valid indicator to assess energy efficiency in health centers, as there is a strong correlation (R^2 = 0.924) between the buildings under study. X and Y axes in Fig. 2 represent total floor area expressed in m^2 and