Analysis on Energy Efficiency in Healthcare Buildings

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ABSTRACT
The aim of this paper is to analyze and quantify the average healthcare centres' energy behavior and estimate the possibilities of savings through the use of concrete measures to reduce their energy demand in Extremadura, Spain. It provides the average energy consumption of 55 healthcare centres sized between 500 and 3,500 m^2. The analysis evaluated data of electricity and fossil fuel energy consumption as well as water use and other energy-consuming devices. The energy solutions proposed to improve the efficiency are quantified and listed. The average annual energy consumption of a healthcare centre is 86.01 kWh/m^2, with a standard deviation of 16.8 kWh/m^2. The results show that an annual savings of €4.77/m^2 is possible. The potential to reduce the energy consumption of a healthcare centre of size 1,000 m^2 is 10,801 kWh by making an average investment of €11,601, thus saving €2,961/year with an average payback of 3.92 years.

Keywords: energy efficiency, healthcare centre, healthcare engineering, small healthcare facilities.

1. INTRODUCTION
It is estimated that in Spain the public health spending is about 63.8 billion euros, which represents 71.8% of the total health spending in the country. The total health expenditure in Spain is 8.5% of the GDP, public health expenditure represents 6.1% of the GDP and it is a cost per capita of €1.421 per year [1].

Public health is the largest enterprise both in number of workers and spending budget for many regions in Spain. The public sector employs more than one million people and manages a budget of almost €60 billion, an amount similar to total public spending in countries such as Ireland or Portugal [2].

Responsibility for health facility managers should extend beyond the control of the buildings and assume a more active role in aspects such as the management of energy and environmental emissions. It is necessary to establish measures of energy saving and

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efficiency in all buildings sectors, including the healthcare sector. Within the healthcare sector, consumption on lighting alone amounts to approximately 1,000 GWh per year, which represents 0.6% of the Spain electricity consumption and is responsible for the production of nearly 600,000 metric tons of CO_2 each year [3].

In Extremadura, a region in the Southwest of Spain, healthcare buildings of Regional Health Service consume 22 billion kWh of electricity annually, 450,000 liters of diesel and 40,000 m^3 of natural gas. These buildings emit 27,000 metric tons of CO_2 and other greenhouse gases [4], providing care to a population of 1.07 million. However, the potential for energy savings from a healthcare centre [5] has not yet been studied in significant samples of buildings in Spain, where 2,956 healthcare centres were operational in 2010 [6].

Murray et al. (2008) showed that the smaller health service buildings in Scotland represented 29% of the total floor area of all buildings linked to the National Health Service of Scotland [7]. Santamaria et al. (1994) carried out a detailed analysis of audits for 30 health care buildings in Greece (Hellas) to quantify the potential global energy savings as 20% [8], hence suggesting possible savings of substantial energy in these buildings.

Vanhoudt et al. (2011) demonstrated that in a hospital in Belgium, it is possible to save up to 71% of the primary energy system by using thermal energy storage in combination with a heat pump compared to a gas-based boilers and water chiller [9]. Yun et al. (2012) demonstrated 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 can potentially reach a 50% increase [10].

Martini et al. (2007) reported on the energy behavior of different types 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 [11]. This involved evaluating the interactions among these variables and the energy consumption for each specialty service provided in the most common buildings, and detecting areas of over consumption and/or inadequate infrastructure.

Energy efficiency and energy use are major components of sustainability [12]. Specific measures to improve the energy efficiency of a particular building should consider climatic and local conditions, indoor climate environment [13] and amortization in terms of both economic and environmental aspects [14].

The present paper is aimed at analyzing and quantifying the average healthcare centres' energy behavior, as well as at estimating the potential savings through the use of concrete measures to reduce the energy demand in Extremadura, Spain.

2. METHODS

The energy consumption of 55 healthcare buildings was analyzed by using the data collected through audits carried out during 2005-2011 by the Extremadura Agency for Energy and financed through a collaborative agreement with the Ministry of Health and Dependence of Extremadura. The sample represents 52.38% of the healthcare centres and 42% of the population in the region.

To ensure the homogeneity of the sample, 55 similar buildings were selected with respect to the heating system used (every one of the buildings uses a heat pump or a diesel boiler). The buildings selected had a floor area between 500 and 3,500 m^2, and provided care to a population between 3,500 and 25,000. All buildings were constructed between 1985 and 2007 [15].

The energy audits include the use of instruments to measure energy use for the whole buildings and for energy systems within the building. In addition, computer simulation programs were considered to recommend energy retrofits for the facility.

To quantify the energy consumption in each building, scalar network analyzer and energy counters were installed. Field inspections to analyze the initial conditions and check the development of the measures implemented were performed. To determine annual consumption of water, gas and electricity, the billings from the supply companies were analyzed. The reactive power, the service water heating (SWH), the air conditioning systems, the lighting system, the external enclosures and renewable energy generation were also analyzed.

Equation 1 shows the evaluation of the annual savings achieved with the implementation of each of the tested measures.

$$V = \left[\sum_{n=1}^{m} (Ei_n - Ef_n) \times Ce \right] + g \tag{1}$$

where V is the achieved savings expressed in euros, Ei_n is the annual energy consumption in kWh, Ef_n is the estimated annual energy consumption after the application of the measure under test in kWh described in paragraph 3, Ce is the energy cost expressed in €/kWh, and g is the application of taxes.

Values of the investment and the cost of energy were updated according to equations 2 and 3 to compare the potential savings provided for in each audit during the period from 2005 to 2011.

$$Ve = Ce \times (1 + 0.04)^n \tag{2}$$

$$Va = Ci \times (1 + 0.02)^n \tag{3}$$

where Va represent the adjusted value for cost of investment *(Ci)*, Ve is the adjusted value for cost of energy *(Ce)* and n is the number of years. The values 0.02 and 0.04 derive from macroeconomic estimates of 2010 in Spain.

In the course of the investigation, certain parameters were identified in the relations between planned savings and other functional and operating costs of each healthcare centre, such as the year of construction, the construction area, the number of users and the service portfolio, using mathematical techniques. The empirical validity of the equations obtained from the study was tested applying the Student t-test for independent samples, using a confidence level of 95% in all cases.

3. RESULTS

The percentages of the average distribution of the consumption of energy by end-use, can be seen in Figure 1, which shows that air conditioning and the heating system represent 50% of annual demand for energy from a healthcare centre [16], 30% for lighting, 8% for hot water and 12% for the equipment.

Analysis of the average energy consumption demonstrates the existence of a correlation between the average final annual energy consumption and the built surface area in each healthcare centre. Dispersion of the sample diagram is depicted in Figure 2, for a sample size of 55.

The correlation is given by equation 4 below (R^2=0.9009):

$$C = 107.31Sc - 20{,}029 \tag{4}$$

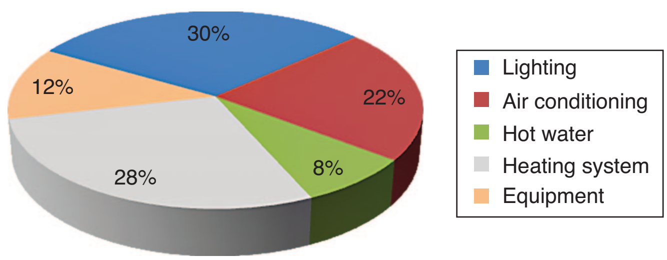

Figure 1. Distribution of annual energy demand for all fuels, by sector of consumption, in healthcare centres.

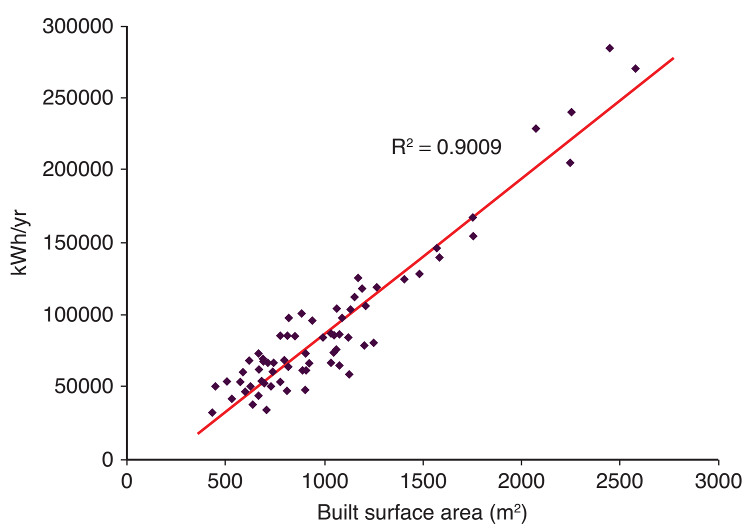

Figure 2. Relationship between the annual energy consumed and the built surface area in a healthcare centre.

where C is the annual consumption of final energy from the healthcare centre, expressed in kWh per year, and Sc is the built surface area in m^2.

3.1. The Reactive Power Compensation

Devices such as motors or transformers involve magnetic fields and consume a so-called reactive power, causing drops in voltage, losses due to the Joule effect within wires, higher energy consumption and reduction in the availability of power and penalties in the electricity bill for their consumption [17]. The reactive elements can create voltage fluctuations and harmonic noise when switched on or off. They will supply or sink reactive power regardless of whether there is a corresponding load operating nearby, increasing the system's no-load losses. In the worst case, reactive elements can interact with the system and with each other to create resonant conditions, resulting in system instability and severe overvoltage fluctuations. To address this issue, installation of power capacitors is proposed. An automatic power factor correction unit consists of a number of capacitors that are switched by means of contactors. These contactors are controlled by a regulator that measures power factor in an electrical network. Depending on the load and power factor of the network, the power factor controller will switch the necessary blocks of capacitors in steps to make sure the power factor stays above a selected value.

The reactive power consumption in each building was obtained and the annual savings for each building was calculated as 0.86 €/m^2 with a standard deviation of 0.70 €/m^2. Moreover, the updated annual savings was correlated with the investment.

3.2. Improvement in Service Water Heating

Healthcare centres consume a large amount of domestic service hot water [18]. The average hot water consumption per healthcare centre was calculated as 450 liters/m^2. In the case of production of hot water by means of water heaters, or storage tanks, timers with programmed disconnection can be installed in order to interrupt operation when no activity takes place. As regards the consumption of drinking water, the installation of low consumption taps and tanks with double push button is proposed.

Potential annual savings to an average of €792.22 per building under study was observed, which yields an annual savings 0.61 €/m^2, with a standard deviation of 0.51€/m^2. This saving is determined by monitoring the water heating consumption for a year in healthcare centres.

3.3. Improvement in the Lighting System

Lighting for a typical healthcare centre represents on average 30% of the total electrical energy use. The installation of electronic ballast in fluorescent lamps, replacing fluorescent and incandescent lamps by others of higher performance (e.g., LEDs), organizing lighting according to activity type and limiting the intensity and timing of the control of lighting (by occupancy sensors) are some of the proposed solutions [19]. The adequacy of the parameters of lighting lamps to each unit and the increase of the maintenance of the lighting system were also analyzed.

In the course of the investigation, the updated annual savings was shown to be correlated to the investment. Such correlation is represented in Figure 3, and data were fitted to the following expression:

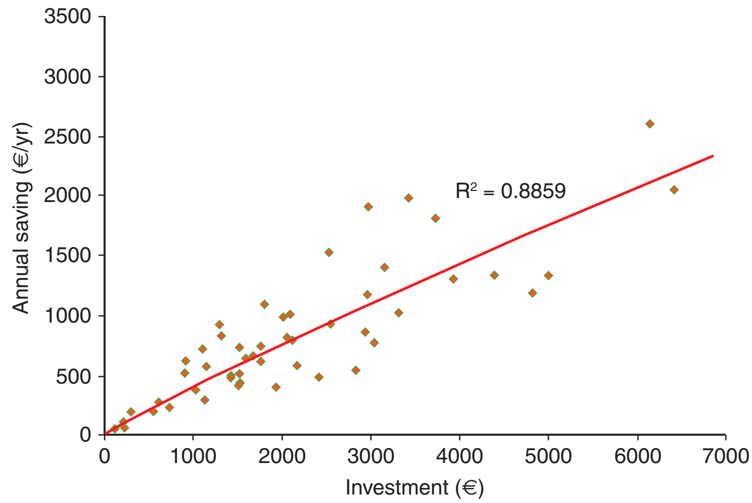

Figure 3. Correlation between investment and annual savings regarding the improvement of lighting systems in healthcare centres.

$$E = 0.754 i^{0.91} \tag{4}$$

where E is the annual savings from the healthcare centre and i the required investment expressed in euros. This equation enables calculation of the average investment in lighting systems to ensure a given annual savings.

The average savings reached €809.90 per year for each of the buildings under study, which yields an annual savings of 0.73 €/m^2 with a standard deviation of 0.42 €/m^2. The involved calculations were performed by computer simulation software based on the performance of the luminaries and field inspections.

In addition to the reduction in total facility electrical energy use, retrofits of the electrical systems decrease space cooling loads and therefore further reduce the electrical energy use in the buildings [20]. These cooling energy reductions as well as possible increases in thermal energy use (for space heating) should also be accounted for when evaluating the cost-effectiveness in lighting equipment.

3.4. Heating, Cooling and Ventilation Systems

Heating, cooling and ventilation systems for a typical healthcare centre represents on average 50% of the total electrical energy use. The introduction of efficient air conditioning technologies that minimize energy consumption is proposed. 16% of the installed air conditioning devices had been operating for less than 5 years, 31% for a period in the range 5-10 years and the remaining 43% for more than 10 years. The replacement of low-performing machines aged more than 8 years by new, high-performance models was suggested.

Other feasible measures to be carried out in this area are the following: maintenance of air-conditioning systems, zoning according to air conditioning units and installation of air-handling system adjustable thermostats [21].

Average annual savings was calculated to approach €800.00 for each of the buildings under study, which might also be expressed as 0.75 €/m^2, with 0.45 €/m^2 standard deviation. Calculations were performed based on a reference of the optimized efficiencies of some other air conditioning devices which had previously been analyzed.

3.5. Measures on External Enclosures

The improvement of the thermal insulation of the building enables to lower the heating/cooling loads [22]. The proposed measures include the following actions: increasing the insulation level of roofs [23], sealing doors and windows to prevent infiltrations, installing blinds to reduce direct beam solar radiation, installing overhangs, replacing single glazing with double glazing, and applying protective glazing films.

The main thermal losses in hallways, waiting rooms and corridors were observed to occur when access doors remained open, provided that the most usual type of access to healthcare centres consists of windshield partition doors, a system that loses effectiveness as doors might even remain open during the busiest periods in the building [24].

The average annual savings per sample building was computed by energy computer simulation as €716.50, which represents an annual savings of 0.68 €/m^2 with a standard deviation of 0.48 €/m^2.

3.6. Renewable Energy Generation

The replacement of conventional energy generation with renewable energy is recommended mainly because some renewables can become more profitable over time than conventional energy sources [25] and also because renewables are intrinsically linked to the concept of environmental sustainability [26].

The installation of biomass and solar thermal facilities was found to contribute with average annual savings of €537.04 per building under study (0.55 €/m^2 annual savings with standard deviation 0.42 €/m^2). It should be noted that the high initial costs associated to the installation of renewable equipments was accounted for in the above mentioned calculations. The potential renewable energy sources for the stated purposes are listed below:

a) Biomass: Replacement of heating boilers using fossil fuels, diesel or natural gas, with biomass boilers. The current biomass energy conversion technology ensures the efficient operation of the facilities [27]. Carbon dioxide emissions in the combustion of biomass are almost neutral, provided it is part of the base that the plant vegetable retains a higher volume of CO_2 during its growth as compared with that released during combustion [28].

b) Solar thermal energy: Use of solar thermal energy for hot water generation allows reduction of energy consumption and decrease of greenhouse gas emissions. In smaller buildings, hot water demand is relatively low and therefore, the current systems usually do not use central distribution networks [29], provided such demand is satisfied by the electric hot water heater near the consumption points. Installation of solar collectors on roofs ensures a drastic reduction of energy consumption and is regarded as an efficient energy supply alternative. If larger buildings with higher associated energy consumption rates are accounted for, remarkable efficiency of solar thermal energy equipment has been reported [30].

c) Solar photovoltaic: It is fed into the public grid power generated by a photovoltaic field, allowing the production of electricity from solar energy. It is a performance that can serve to considerably lower energy cost and contribute to the overall decrease in emissions [31].

d) Geothermal energy: Use of low temperature geothermal energy is based on the fact that the ground below a depth of 7-10 m is maintained at a stable temperature, about 17°C, regardless of time of year or weather conditions. This energy source allows to increase the performance of the air conditioning equipment and has been set as a renewable energy in Europe since 2009 [32].

3.7. Optimization of Energy Billing

To ensure a reduction of energy billing, the optimization of the contractual conditions with the electricity supply companies is suggested. The power of recruitment should be adapted to the actual consumption by selecting the best rate, by accounting for time discrimination and by taking advantage of opportunities of negotiation arising from the high energy demand associated to the buildings and the dynamism of market prices, in other words, by identifying opportunities derived from the scale economy [33] within the particular restrictions of current legislation.

If the above mentioned considerations are accounted for, the corresponding average annual savings is calculated as €662.96 per sample building. This rate was obtained from the average savings achieved in the audits performed and is equivalent to 0.59 €/m^2 annual savings with a standard deviation of 0.49 €/m^2.

3.8. Results of Application of Measures

The results for the application of the particular measures described in the preceding subsections are shown in Table 1.

Furthermore, Figure 4 depicts the payback time derived from each of the measures under consideration, while Table 2 lists the results regarding the quantification of their environmental impact.

Healthcare centres with greater potential saving rates – hence suggested for immediate implementation of the proposed energy saving measures – were identified as those built between 1990 and 2000, as shown in Figure 5 based on the mean of the average results reported in the audits.

4. DISCUSSION

Energy efficiency investments should be oriented to change the current trend of growth of energy consumption and to consolidate a culture of energy saving [34]. The results

Table 1. Average savings due to application of energy saving measures

Item	Annual savings (€/yr)	Annual savings (€/m^2)	Investment (€)
Energy billing	662.96	0.59	0
Reactive Power Compensation	1,332.23	0.86	1,670.12
Service Water Heating	792.22	0.61	299.23
Heating, Cooling and Ventilation	809.90	0.75	2,093.78
Lighting	800.00	0.73	6,340.00
External enclosures	716.50	0.68	4,544.00
Renewable energy	537.04	0.55	4,853.93
Total	5,650.85	4.77	19,801.06

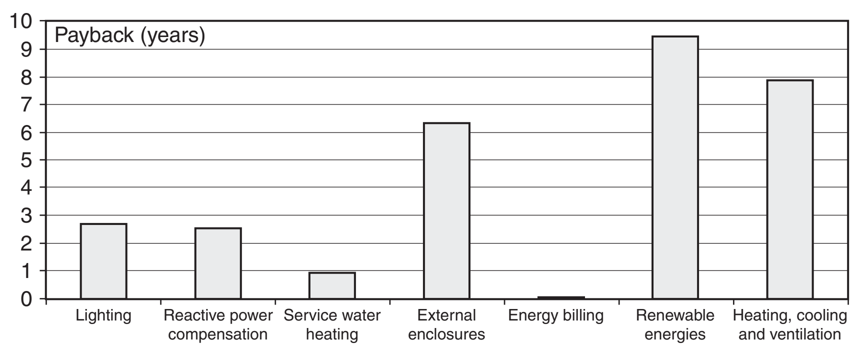

Figure 4. Average payback time for each of the proposed energy saving measures.

Table 2. Annual environmental impact.

Item	Value
Healthcare buildings	55
Energy savings (kWh/yr)	594.072
CO_2 savings (kg/yr)	385.553
Particles savings (kg/yr)	26.276
SO_2 savings (kg/yr)	4.087
NO_2 savings (kg/yr)	220
CO savings (kg/yr)	58

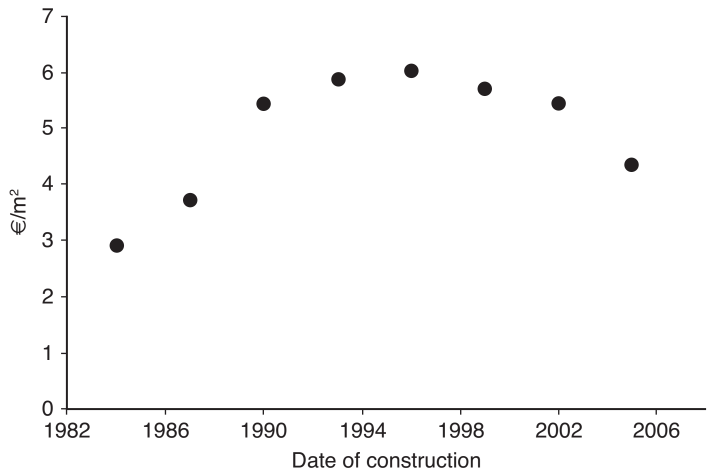

Figure 5. Average annual savings per built surface area vs. date of construction.

reported in this paper for the implementation of a set of energy saving measures on 55 healthcare buildings lead to a significant potential annual savings of 4.77 €/m^2.

Provided energy consumption is strongly linked to the management of the building users [35], it is strongly advisable to promote awareness-raising campaigns for energy saving actions, defining reasonable goals to enhance motivation, which preferably should involve changing users' habits, as it requires no investment, such as turning lights or computers off, and moderate use of air conditioning and heating systems. An energy audit is an appropriate tool to analyse energy costs and model the distribution of consumption. It allows identification of key parameters affecting energy consumption and assessment of various possibilities of energy saving based on profitability, thus enabling decrease costs of operation, maintenance and replacement. The energy and the environmental efficiencies should definitely be major quality indicators in the management of healthcare centres. Coherent selection of energy service companies for planning, implementation and financing of energy efficiency measures would improve the management of this type of public buildings and would also promote investment on efficient technology.

Potential cost savings was assumed by negotiating the price of energy. However, it should be noted that this is likely only in countries where price strategies are not set by the current normative and thus scale economy is allowed. On the other hand, given the particular nature of the issue under study, it should also be kept in mind that extreme strategies might result in fatal medical errors [36]: thermal discomfort or inadequate lighting levels might affect medical diagnosis [37] and appropriate measures for infection control might be directly affected by insufficient ventilation. Given the particular features of this type of public building, none of the energy saving measures can compromise health and performance of the users [38]. Potential consequences of extreme handling of energy saving measures should therefore be balanced out considering that the building performance should ensure aseptic conditions [39].

The results are extrapolated to similar buildings with limitations due to the wide variety of healthcare building designs mainly based on architectural conception, climate conditions, interior facilities and building locations.

5. CONCLUSIONS

The results reported in the present study lead to conclude that potential energy savings can be achieved in healthcare buildings smaller than 3,500 m^2. A sampling set of 55 healthcare buildings was selected to undergo simulation of energy efficiency actions, which resulted in a final annual savings of 4.77 €/m^2. An average investment of €11,601 was estimated to potentially decrease energy consumption by 10,801 kWh and to achieve annual savings of €2,961 (thus resulting in an average payback time of 3.92 years and avoiding the emission of 7,010 kg CO_2). Annual energy consumption was observed to decrease in efficiently managed buildings and to be more effectively implemented in small buildings rather than in those designed for a large number of users.

Measures to improve the energy efficiency of healthcare centres should account for weather conditions and local particularities, as well as for the inside environment and cost-effectiveness aspects. On another note, they should not break other essential requirements linked to this type of buildings, such as accessibility, supply security, and reliability of facilities. Assuming budgetary and the financial feasibility of the discussed measures, they should be prioritized according to the period of return on investment.

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CONFLICT OF INTEREST

The author indicates no potential conflicts of interest.

NOMENCLATURE

C	Annual consumption of final energy, kWh/year
Ce	Energy cost, €/kWh
Ci	Investment cost, €
E	Annual savings from lighting system, €
Ef	Estimated annual energy consumption, kWh/year
Ei	Annual energy consumption, kWh/year
g	Taxes, €
i	Value of investment in lighting system, €
n	Number of years, year

Sc Built surface area, m^2
V Saving value, €
Va Adjusted value for investment cost, €
Ve Adjusted value for energy cost, €

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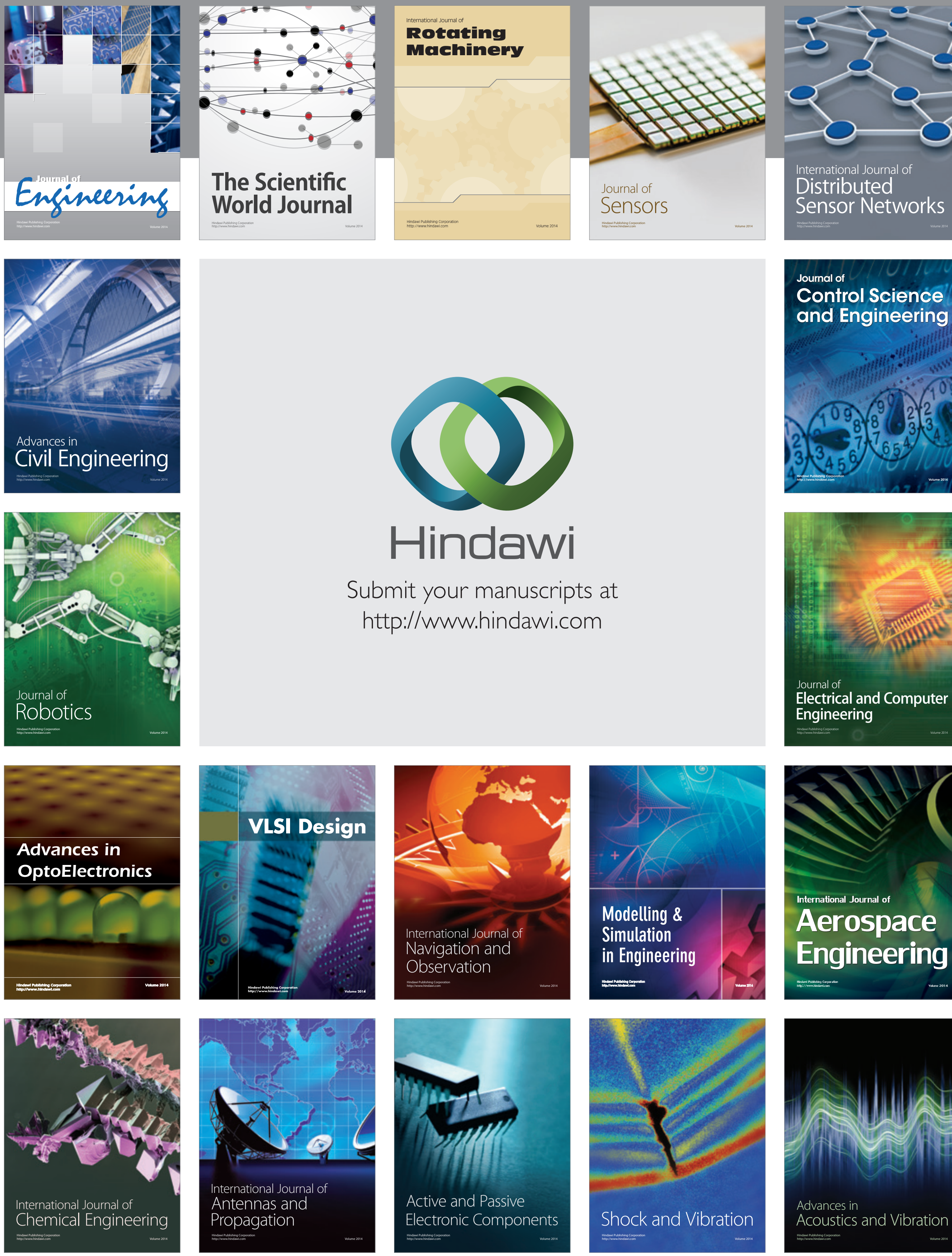
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