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A prediction model based on neural networks for the energy consumption of a bioclimatic building

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ABSTRACT

Energy in buildings is a topic that is being widely studied due to its high impact on global energy demand. This problem involves the performance of an adequate management of the energy demand, combining both convectional and renewable sources. To this end, the use of control strategies is an important tool. These control strategies can take advantage of knowledge of variables that act as disturbances in the closed loop scheme. Thus, it is of great importance the development of predictions of such variables. The main objective of this paper is to develop and assess a short-term predictive neural network model of the electricity demand for the CIESOL bioclimatic building, located in the southeast of Spain. The performed experiments show a quick prediction with acceptable final results for real data with a short-term prediction horizon equal to 60 min and with a mean error of 11.48%. One-step ahead predictions and dynamic modeling simulations have also been evaluated.

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1. Introduction

Nowadays, the global energetic model is unsustainable in economic, social and environmental terms, where a *sustainable model* can be defined as that which "satisfies the actual needs without compromising the ability of future generations to satisfy their own needs" [1]. Consequently, due to the high impact of the production and consumption of electricity, it becomes increasingly necessary a proper electricity demand management to achieve energy efficiency. New saving mechanisms and control approaches, as demand side management [2], are able to optimize the electricity consumption maintaining, at the same time, the quality of the service and the satisfaction of the users' needs. These mechanisms require an estimation of the load curve. Furthermore, the optimal exploitation of the renewable energy sources is another fundamental aspect with the aim to shift the load peaks whenever it is possible. In this line, over the past twenty years a special emphasis has been made in the construction of buildings with bioclimatic architecture, which can benefit from both solar energy and natural air flow for their use in natural heat and passive cooling thus reducing the intensive electricity consumption. In this paper, the CDdI-ARFRISOL-CIESOL (www.ciesol.es) building has been chosen for the study and development of a model based on neural networks for the short-term prediction of electric power demand.

To achieve these objectives and to manage the electric energy demand in an efficient way, it is necessary to calculate an accurate and reliable prediction of the load curve. Such prediction will have to be made taking into account the most influential factors over the demand. There are numerous techniques that have been applied to the task of electricity demand prediction, such as engineering, statistical and artificial intelligence methods. A complete review of buildings energy prediction techniques may be viewed at [3,4]. Occasionally, it is common to find a combination of techniques [5]. Finally, some comparatives between different prediction techniques can be found in [6–10].

Engineering methods use physical principles to calculate the thermal dynamic and the energy behaviour on a building or in subcomponents level. They can be classified into detailed methods and simplified methods. Comprehensive methods use complex physical functions and thermal dynamics very elaborated to calculate, with accurate, the energy consumption of all the building's components taking as input the information of the building and the environment like weather variables, construction details, building's operation and equipment [11,12]. The International Organization for Standardization (ISO) has developed a standard for the calculation of the energy consumption for heating and cooling from a building and his components [13]. There is an updated list, maintained by the U.S. Department of Energy, with energy simulation tools [14]. Although these methods are accurate, they require a detailed

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Fig. 1. The CDdI-ARFRISOL-CIESOL building.

comprehensive parameters set from the building and the environment and these details are not always available. On the other hand, there are some simplified tools for the energy simulation [15,16].

Statistical methods try to correlate the energy consumption with the most influential variables. These empirical models are developed from the historical data which are used to train the model. The majority of the models developed are based on simplified variables, usually one or two weather variables [17–20].

Artificial intelligence methods are a research line that has been experiencing an increasing focus over the past years because of their good fit to this kind of problems. Artificial intelligence includes several techniques as artificial neural networks, fuzzy logic, support vector machine, genetic programming or a combination of them which is also known as hybrid system. Neural networks are widely used for the task of building energy consumption prediction because they are good at solving non-linear problems and fit well to this complex problem [21–23]. Fuzzy logic is a form of probabilistic logic that deals with reasoning that is approximate rather than fixed or exact, fuzzy logic's success in these applications has been attributed to its ability to effectively model real world data [24,25]. Support vector machines are increasing their presence in research and industry over the last years, they are effective dealing with non-linear problems even with small historical data sets [26–28].

Finally, there are some cases where system information is only known partially, which it is called a gray system. In this way, a gray model can be used to analyze the energetic behaviour of the building when only incomplete or uncertain data are available [29–31].

To quantify energy demand inside buildings is, in general, a complex process. More specifically, in the case of the CIESOL building there are several factors that influence on the energy consumption as weather variables, building's construction, building's occupants and their behaviour, lighting and/or HVAC (Heating, Ventilating and Air Conditioning) equipment utilization and their performance, etc. Therefore, in this paper a characterization of load in different conditions and categorization of such conditions has been developed. At the end, a prediction model based on artificial neural networks (ANN), which has been chosen by its distinctive features for this problem, has been obtained. The development process has been done following a concrete methodology for the proper architecture and structure selection for a NARX model and the selection of the embedding delay and the embedding dimension to reconstruct the state space. Finally, the obtained prediction model has been evaluated using a battery of tests spanning working and non-working days, different temperature conditions for winter and summer, different radiation conditions with cloudy and sunny days and also nightly consumption.

This paper is organized as follows. In Section 2, CDdI-ARFRISOL-CIESOL building is briefly described. Section 3 shows an analysis of the energy demand profile of the building used as case study. In Section 4, the methodology used to develop the model based on neural networks is widely described. Finally in Section 5, the results of different experiments are showed and discussed.

2. Scope of the research: the CDdI-ARFRISOL-CIESOL building

The CIESOL building (Fig. 1) is a solar energy research center located in Almería, in the south-east of Spain (+36° 49′49.68″, −2° 24′25.92″, with an elevation of 27 m) where there is a

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