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On the use of artificial neural networks to model household energy consumptions

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Abstract

Modern houses are more and more frequently characterized by the presence of “smart” metering devices, capable of measuring air temperature, relative humidity, air quality, and in the more sophisticated cases, even electric equipment consumptions. In addition, other relevant parameters such as illuminance may often be determined and they can be used as proxy variables to account for other important aspects (such as solar irradiance) influencing the energy balance of a building. Such information, in combination with weather data which can be retrieved by other sources (or by additional sensors), may conveniently contribute to the creation of a “black box” model in which, given a few input variables it is possible to output a variable which would result from otherwise complex calculations (e.g. an energy balance) requiring many data. The availability of such a “black box” could be helpful under many points of view, such as benchmarking energy consumptions and stimulating virtuous behavior from the occupants. To test whether such approach can be feasible, an EnergyPlus model of a real house was made, trying to accurately reproduce building features, systems set-points, and occupant behaviors. The overall simulated energy consumptions were compared with the real ones resulting from energy bills, thus ensuring a good agreement with reality. The dataset resulting from EnergyPlus was then used to train an artificial neural network (ANN) capable of yielding hourly energy consumptions based on limited input data. Finally, the relative importance of the different input variables was analyzed to understand which might influence prediction accuracy most.

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Keywords: Artificial Neural Network (ANN); Energy consumptions prediction; Smart houses; Energy saving

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1. Introduction

Reduction of energy consumptions is one of the main objectives that need to be addressed in order to limit global warming. Among the different energy uses, the building sector is responsible of a 40% share of the total [1], mostly because of poor envelope characteristics and inefficient HVAC systems. National and international regulations [2] are trying to stimulate a widespread improvement of the abovementioned characteristics, also by means of substantial economic incentives with particular reference to retrofitting existing buildings. However, even when the building and its systems comply with regulations, the actual energy consumption may be hard to predict and, in many cases, the use of conventional approaches may lead to surprising, and contradictory, results [3]. The role of the occupants' behavior appeared in the last years as the key issue to understand in order to get reliable predictions [4], thus suggesting that any effective energy-saving policy needs to involve and engage the final user. In large buildings such problems are solved by means of a building energy management system (BEMS), but in residential buildings it seems unlikely a widespread use of such solutions. On the other hand, the spreading of low cost devices capable of monitoring indoor environmental parameters as well as energy consumptions, combined with the use of more numerous and more powerful portable devices, might significantly contribute to help the occupants to adopt energy efficient lifestyles.

From this point of view, one critical point is understanding how the complex energy flux of a building can be analyzed in order to give the occupants information about the way they use energy. The most obvious answer could be that of using calculation methods complying with the national regulations, but that would imply a collection of data that could be impossible to gather for a non-expert user. Similarly, any dynamic simulation tool (like the well-known EnergyPlus) would similarly require very detailed information about the building, its systems, and the user behavior in order to be accurate. Therefore, a "black-box" approach using a limited number of input variables to predict the energy consumption seems more feasible. The key to the success of such approach is a suitable modeling of the black box behavior. Conventional statistical methods, such as multiple regression analysis, could be used in this case, but growing evidences suggest that artificial neural networks (ANN) and machine learning (ML) techniques may do the job in a more reliable and efficient way [5-12]. The success of ANNs depends on five distinctive features: learning, self-adaptive, fault tolerance, flexibility and real time response. In addition, ANNs can manage complex and ill-defined problems because of their strong nonlinear mapping ability. Neural network models can realize any nonlinear mapping between the input and output, and there is no need to know the mathematical equation describing the load and the influence factors in advance. Thus, it has been popularly applied to predict building energy consumption. Current applications involve investigating the potential of dynamically simulating energy demand of a building using a limited input set [6], dynamically controlling HVAC systems to achieve comfort and energy savings [7,9], predicting electric energy consumptions [8], predicting heat demand based on natural gas consumption [10], standard energy performance of a building using its features as inputs [11,12], and many others. As outlined before, the idea that is investigated in this paper is that of using data potentially available from low-cost monitoring devices, combined with outdoor weather data, to predict optimal energy use for current conditions in a given house and identify any anomalous conditions.

2. Methods

In order to investigate the potential offered by the above mentioned devices and understand whether the adoption of a black-box approach in modelling energy consumptions of a given house is feasible or not, a validated EnergyPlus model of a real house was used to generate the dataset required to train the ANN. Validation was carried out using actual energy consumptions retrieved from energy bills related to a four-year period and by carefully matching user behaviors with the relevant schedules used in the simulation tool.

2.1. The case study

The apartment used to create the EnergyPlus model is located in Bari (Italy), in a densely populated neighborhood; it is at the first floor of a 5-story building built in 1960. The overall floor surface is 80 m^2 and the internal height is 2.9 m. Its East and West walls are shared with other apartments and with the stairway that is