Multiple regression model for fast prediction of the heating energy demand

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ABSTRACT

Nowadays, heating energy demand has become a significant estimator used during the design stage of any new building. In this paper we are proposing a model to predict the heating energy demand, based on the main factors that influence a building's heat consumption. It was found out that these factors are: the building global heat loss coefficient (G), the south equivalent surface (SES) and the difference between the indoor set point temperature and the sol-air temperature. In the second part of this paper, multiple dynamic simulations were carried out in order to determine the values of the inputs and output data of the future prediction model. Using the obtained database, a multiple regression prediction model was further used to develop the prediction model. In the last part of this paper the model results was validated with the measured data from 17 blocks of flats. Moreover, in this article it is also shown the comparison with the results calculated using the building's energy certification methodology. A detailed error analysis showed that the model presents a very good accuracy (correlation coefficient of 0.987).

In conclusion, the proposed model presents the following characteristics: three inputs and one output, simplicity, large applicability, good match with the simulations and with the energy certification calculations, human behavior correction.

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1. Introduction

In a report realized by the European Commission for Energy, the major issue of EU citizens is the energy security, which was translated by shortages of fossil fuel supplies compared to an increasing world demand [1]. Buildings sector is the largest energy and CO_2 emitter in the EU and it is responsible for 40–45% of energy consumption in Europe and about 30–40% world-wide [2]. The most important constituents of the energy consumption are the heating/cooling of the building, the hot water production and electricity consumption. Among them, the heating energy demand of existing buildings accounts for more than 50% of the primary energy demand of residential and service buildings in the EU [3]. It is obvious that this sector has a significant potential for mitigating problems associated to energy demand and its consequent environmental and economic issues. Nowadays, the development of low energy buildings is currently one of the most important goals in many environmental programs worldwide that try to emphasize the need of a higher level of envelope insulation or systems rehabilitation. The correct design of a building is one of the very first solutions toward a low energy building. Estimating a building energy demand is a big challenge knowing that it is almost impossible to model a true level of occupancy, lighting and equipment heat gains. The ways in which a building and its services operate in practice are extremely complex and a modeling for obtaining an accurate estimation of the energy consumption is difficult to accomplish [9].

There are various simplified methods to evaluate the heating demand, like the degree-day method but are not so accurate and they do not take into consideration the dynamic heat transfer of the building. During the last decade different software tools have been developed such as TRNSYS, EnergyPlus or SIMBAD and they are considered to be the most reliable solutions to estimate the impact of design alternatives on the energy demand.

These tools are widely used for analyzing energy consumption and for developing standards, however, they demand a considerable amount of detailed input data, tedious expert work and in some cases, powerful informatics equipment. For these reasons many researchers have proposed simpler models to offer an alternative during the building design stage. Compared to physical models, which are based on the analysis of physical processes such as heat transfer, these fast prediction models are developed using a survey database and have a lower number of inputs. Moreover, these prediction models are particularly suitable for doing parametric studies, where the actual methods are very time-consuming and even challenging in some cases. There has been almost a decade since buildings in European countries are legally bound to conform to appropriate minimum requirements regarding energy efficiency following the European Directive 2002/91/EC [4]. Since then, many energy certifications have been issued in all countries and recently the legal authorities must verify the correctness of these documents. This task is almost impossible as the number of data to be

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Nomenclature

A	area (m^2)
c	specific heat (J/kg/K)
G	global building heat loss coefficient (W/m^{3}K)
h_o	external surface heat transfer coefficient (W/m^{2}K)
I_h	global solar irradiance on horizontal (W/m^2)
q_{LS}	the specific heat consumption that takes into account the heat losses and the solar gains (kWh/m^3)
n_a	air change rate (ach)
R	thermal resistance (m^{2}K/W)
U_{ma}	average transmittance of the building envelope (W/m^2/K)
V	volume (m^3)

Greek letters

Φ_h	supplied heat by means of the indoor heating system (W)
Φ_i	indoor thermal gains (W)
Φ_s	heat gains from the solar radiation (W)
Φ_L	heat losses of the building (W)
α	solar absorptance (–)
β	temperature correction coefficient (–)
$\Delta\theta$ (K)	indoor–outdoor temperature difference (°C)
θ_i	indoor set-point temperature (°C)
θ_o	heating season outdoor average temperature (°C)
$\theta_{sol-air}$	sol-air temperature (°C)
φ_i	internal heat gains (W/m^2)
η_s	heating system distribution/emission efficiency (–)
ρ	density (kg/m^3)
τ	time (s)

verified is high and recalculating everything is clearly not a viable and a fast solution.

Using a simple mathematical model obtained from a simulation database to rapidly check the energy consumption and compare it with the data from the energy certificate is therefore an appealing idea. These models are not meant to perfectly match the data from simulations or from the European Directive methodology calculations, but to direct out the authorities toward the major errors where more detailed checking is mandatory. Moreover, these models could be the start point of decision support tools that will assist the designers and architects to take decisions upon the optimum economic, environmental and energy solution.

Numerous methods and models for the energy demand forecasting have been proposed during the last decade including: Fourier series models [5], regression models (RM) [6,7] and neural network (NN) models [8].

Tsanas [10] developed a statistical machine learning framework to study the effect of eight input variables (relative compactness, occupation surface area, wall area, roof area, overall height of the building, orientation, glazing area, glazing area distribution) on two output variables which are heating load and cooling load of residential buildings. The use of artificial neural networks to predict the energy consumption was the work of Ekici [11] who considered as inputs for the model: the physical environmental parameters and artificial designing parameters like the transparency ratio, building form factor, orientation and thermo-physical properties of the materials of the building envelope. Kwok et al. [12] discussed the use of the multi-layer perceptron (MLP) model to estimate the cooling load of a building. Soteritis [13] has constructed and developed an ANN model to estimate the heating-loads of buildings and for forecasting the energy consumption of passive solar buildings.

A recent paper realized by Jaffa et al. [14] on the use of regression technique to acquire an accurate and practical model showed that polynomial models are suited for this kind of study and the accuracy is good.

Other studies [15] concluded that the heat consumption is influenced mainly by: (1) external vertical walls surface and thermal resistances, (2) windows surfaces and thermal resistances, (3) indoor and outdoor temperatures, (4) indoor heat sources and (5) the air change rate. Other parameters with a smaller influence upon the yearly heat consumption are: the surface and the thermal resistance of the roof, indoor walls toward unheated spaces, floor or absorption coefficients. Along the main parameters that influence the heat consumption we can add the compactness factor [16–18], which represents the ratio between the heat transfer surface and the indoor air volume. We conclude that in order to learn a statistical model to predict the yearly heat consumption we need to take into account as input data all these parameters that highly influence the yearly heat consumption or those other parameters that regroup the effect of these main parameters, similar to the principal component analysis. The European and national standards present two such coefficients: (1) the building global heat loss coefficient G (W/m^3/K) [19,20] and (2) the building global heat transfer coefficient H (W/K) [21], the latter being equal to the first one multiplied by the indoor air volume of the building.

Regardless the interest and the considerable work done so far, there is no common consensus among the researchers on which are the best inputs to be used in the models or what is the most suitable model to be used by the designers. Thus, obtaining a fast and accurate method to evaluate the energy demand is clearly a difficult task. The simplicity of the model is an important characteristic because it will enable the integration with other more general models like: the Indoor Environment Quality prediction [22], or the building permeability measurement model [23].

In this article, with the development of a new forecast model, we want to advance the knowledge in this direction by highlighting the importance of the climatic conditions, the model accuracy, the validation with on-site data, the errors analysis and probably the most important for the designers, the practicality of the model. The final objective is to support integrated building design by providing rapid and simple assessment of the energy demand with accuracy close to that of dynamic simulations. The article presents the main parameters influencing the heating energy consumption, the simulation database development, the model learning and the model validation with on-site data.

1.1. Heating energy consumption

The phases of building's design, development, commissioning and the management of the building should be carried out by focusing on finding optimal energy, environmental and economical solution, tailored to the specific building and to its specific architectural characteristics. Numerous factors may influence the energy performance in buildings, such as: the outdoor weather conditions, building's architecture, building's thermal characteristics, the operation of sub-level components like HVAC systems and the way the building is used by the occupants. There are two main variables influencing the energy demand for the heating and cooling of the building [24]: climatological conditions and building's architecture along with its structure properties. Many studies have been carried out during the last decades showing how the energy performance of buildings can be improved with a properly insulated building envelope and that the building's heating loads depend mainly on the thermal transmittance of envelope components [25]. Therefore, identifying these most important building components is critical from the perspective of the building designers and owners as they want to examine the possibilities of reducing building energy