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An original tool for checking energy performance and certification of buildings by means of Artificial Neural Networks

C. Buratti [a,*], M. Barbanera [b], D. Palladino [a]

[a] Department of Engineering, University of Perugia, Via G. Duranti 67, 06125 Perugia, Italy
[b] Biomass Research Centre, University of Perugia, Via G. Duranti 63, 06125 Perugia, Italy

HIGHLIGHTS

- ANN used as a tool for evaluating energy performance of buildings.
- Training, validation, and testing of Neural Network with real energy certificates data.
- Global energy performance index was chosen as a target of ANN.
- A good correlation and a minimum error was found with certificates data.
- A new energy index was defined in order to check the energy certificates.

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ABSTRACT

The Energy Performance Buildings Directive (EPBD) was issued to provide a common strategy for all European countries and to implement several actions for improving energy efficiency of buildings, responsible for 40% of energy consumption. Energy Performance Certificates are provided as a tool to evaluate the energy performance of buildings; however, costly and time-consuming controls are necessary to verify the accuracy of the set and declared data.

Useful tools could be the Artificial Neural Networks (ANN), whereby it is possible to estimate the energy consumptions from specific parameters, to evaluate the accuracy of data in the energy certificates, and to identify the certificates needing accurate control.

In this study, an Artificial Neural Network was developed based on approximately 6500 energy certificates (2700 are self-declaration) received by the Umbria Region (central Italy), in order to evaluate the global energy consumption of buildings from several and specific parameters reported in certificates. Data was checked in compliance with energy standards and only the correct certificates were used to train the Neural Network.

The implemented Neural Network was tested with database data and a good correlation was found; in particular the energy performance calculated with the Neural Network presents an error greater than 15 kW h/m^2 year with respect to the real value of global energy performance index in only 3.6% of cases.

Finally, a Neural Energy Performance Index (N.E.P.I.) was defined, in order to verify the accuracy of the energy certificates; the study reported in this paper shows how the new defined index could be an important tool to identify which energy certificates require controls. A refinement of the Neural Network would allow to minimize the error and to define a N.E.P.I. index that could be used by European public administrations as a tool to perform an initial check of certificates.

1. Introduction

In recent years, one of the targets of European countries in terms of energy saving and of renewable energy development has been to improve the energy efficiency of buildings and to reduce gas emissions; as seen in 1997 many countries, including European ones, signed the Kyoto Protocol with the aim of reducing gas emissions by 5% of the ones recorded in 1990.

Many studies in Europe highlighted how buildings are responsible for 40% of the total energy consumptions, due both to building envelope and heating systems. In order to provide a common strategy for all European countries, the Energy Performance Building Directive (EPBD) [1], issued in 2002,

* Corresponding author. Tel.: +39 075 5853993; fax: +39 075 5853916.
E-mail address: cinzia.buratti@unipg.it (C. Buratti).

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Nomenclature

Abbreviations

ANN	Artificial Neural Network
EPBD	Energy Performance of Buildings Directive
MLP	multi-layer feed forward network/perceptron
MSE	Mean Squared Error

Symbols

A	activation function
CO_2	carbon dioxide
Du	use of buildings
E	error function
Ep_{acs}	primary energy index for hot water
Epi	primary energy index for heating
Epi_{glo}	global energy performance index
Epi_{lim}	primary energy limit index for heating
Epi_{invol}	energy demand of building envelope
FA	floor area
FHS	type of fuel used in heating systems
FHWS	type of fuel hot water systems
GG	degree-day
$NEpi_{glo}$	global energy performance index calculated by Neural Network
N.E.P.I.	Neural Energy Performance Index
PHS	power of heating
PHWS	power of hot water
QE	quality of building envelope
S	dispersant surface
S/V	ratio of dispersant surface and heated volume
T	transfer function
TB	year of construction of buildings
THS	type of heating systems
THWS	hot water systems
V	heated volume
YHS	year of heating system
YHWS	hot water systems
δ_{15}	percentage of certificates for which the calculated output of the network is greater or less than 15 kW h/m^2 year with respect to the target value

provides the guidelines on which national regulations must be based on.

In Italy, the standard was implemented by several regulations [2–6], in which a method for calculation of energy performance of buildings (Epi_{glo}) is defined; an energy class is assigned from the value of global energy performance index, depending on the index *Primary Energy Limit for Heating* (Epi_{lim}) established by the law.

Epi_{lim} is provided by national regulations [3,4] from the definition of degree-day, depending on the location of the building [7], and from the ratio between heat transmission surface (S) and heated volume (V).

For the new building constructions, there are also several checks regarding the global energy performance index and the building envelope, depending on the climate zone considered and based on EPBD [1].

In the other European countries, the national regulations also provide the energy and the building envelope limits for the new building constructions; France, in particular, presents important similarities with Italian regulations. In fact, its standards provide checks of three indices: the first index (CEP) represents the primary energy demand for heating, hot water, cooling and lighting; the second one (Tic) concerns the internal temperature during summer season; the third one (Bbio) assesses the impact that the bioclimatic design has on energy performance. In Spain, the requirements of heating and cooling loads are based on the U-value of building envelope, taking into account windows and doors. Just like Italy, maximum thermal transmission values of building envelope are also provided. The regulations of U.K. have a slightly different approach, but with the same purpose as the Italian one; particularly, the regulations require the design and construction of the building envelope and building services to result in sufficiently low carbon dioxide emissions. These regulations present a major step change in how the energy use of buildings is determined as the government moves towards their aspiration for zero carbon buildings.

Furthermore, the EPBD [1] provided energy certificates as a tool for monitoring and checking energy performance of buildings; however, these certificates need to be verified by the public administration in order to check the declared data.

The revision of certificates represents one of the major problems, because it is costly and time-consuming. In fact, it is very difficult to determine if the declared data is correct without performing an inspection of the building.

This paper presents an interesting study that was carried out in agreement with the Umbria Region (central Italy) in order to develop a new effective method of control on energy certificates; specifically, the Neural Networks approach [8–24] was applied to energy certificates, with the aim of evaluating the correlation between the global energy performance of buildings and some specific data reported in the certificates.

An energy database was implemented containing more than 6500 energy certifications received by Umbria Region (about 2700 of these are self-declarations), in order to collect input data required for the training, validation and testing of the Neural Network; the data relating to the geometry of buildings, the climate zone and the heating and hot water systems were used as input. In order to validate and to test the trained Neural Network, the global energy performance index was used as a target.

Based on the trained Neural Network, an innovative index called Neural Energy Performace Index (N.E.P.I.) was defined to check the correlation between certificates data and energy performance of buildings.

2. Methodology

2.1. ANNs theory

The Neural Networks [25–27] are mathematical models that allow the simulation of the biological neural network behavior. Their most important feature is the ability to learn mathematical models through experience, without having to explicitly determine the mathematical relationships that link the problem solutions. The Artificial Neural Network is then not programmed, but it is “trained” through a learning process based on empirical data.

Artificial Neural Network is composed of a specific number of elementary units, called *neurons*, that allow to process the data mainly operating in parallel; each of them is connected to the other ones by communication links to which a weight is associated.