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Energy Consumption Prediction Analysis for the Retrofitting of an Urban Area using Artificial Neural Networks – Case Study

D. S. Rusu

Technical University of Cluj-Napoca, Faculty of Building Services. 21 Decembrie 1989 Street, no.128-139, Cluj-Napoca, Romania

Abstract: ***This paper presents an analysis of the retrofitting process of an urban area. The predictions for the energy consumption was made using a series of software programs created using artificial neural networks instead of simulation software or standard computing or numerical methods. The novelty of this method is that energy consumption was determined based on real data collected from numerous real cases instead of standard old norms, leading to a more accurate prediction. This method takes into consideration the nonlinearity relations between all the measurable variables and the final energy consumption value, without being restricted to standards and norms. The construction of the neural networks was presented in previous papers. The main goal of the analysis was to determine the most efficient methods for the retrofitting of the residential buildings and the economic costs.***

Keywords: residential buildings, energy consumption, retrofitting, artificial neural networks, case study, prediction

1. Introduction

When establishing the energy policies of an urban area, one must take into consideration the importance of reducing the energy consumption of the residential buildings. The process of restauration and modernization of these, in a word the retrofitting of the buildings is an enormous energy and money investment for the residents and the town. Before any work can be done in this direction one must analyze all the possible solutions taking into consideration all the variables of the equation because otherwise a lot of money and materials are going to be wasted on inefficient solutions. Sadly, nobody does such an elaborate analysis because it is simply too much work using the existing methods. The simulation of the entire town and all the existing building systems would take an enormous amount of time, not to mention the simulation of all the methods of retrofitting. Even if all this would be possible and feasible what we get out of these methods is how much energy it should be consumed and not how much it will be. This is so because the energy consumption in residential buildings is predicted today by a series of calculation methods that start with some physical data of the building itself and a lot of normated values extracted from standards and norms.

In this sense a new method was designed by the author for predicting the energy consumption of a specific urban area using artificial neural networks as an alternative method. The main advantage of this is that the new software programs developed will accurately determine the outcome of any retrofitting methods almost instantly without the need of mathematical modeling or standards and norms. All that is needed is a series of data collected over time for all the components used and the real energy consumption values of the residents of that specific area.

In this regard, a series of artificial neural networks were designed, trained and tested for the following tasks:

- Prediction of heat loss through various wall structures
- Prediction of heat loss through various pipes
- Prediction of thermal energy consumption for heating
- Prediction of thermal energy consumption for hot water production
- Prediction of electrical energy consumption for lighting and home appliances
- Predictions of overall energy consumption for residential buildings.

The process of designing, training and testing of these was presented and published by the author in previous papers. In order to prove the importance of these new tools a case study was conducted on the town of Brad situated in Hunedoara County, Romania.

The purpose of this case study was to determine the most effective retrofitting methods for this town and to determine the costs and benefits of these. The case study was conducted over a period of 5 years in which important data was measured and analyzed for the creation of the data base for the training of the artificial neural networks.

Once the software programs were ready, the total time needed for making all the predictions for most retrofitting methods took only a few seconds. Not only that, but now, these software programs are able to make such predictions on all the similar towns from that specific area in a matter of seconds.

The author chooses to publish all these results in order to demonstrate the usefulness of this method and to encourage other researchers to develop such powerful tools.

2. Analysis of the Existing Situation

2.1 General Information

The town of Brad, Hunedoara County, Romania, was chosen for this case study for a very important reason. It is the town with the most expensive energy in the country due to poor management and bad energy policies. During the past years the price for energy production during the cold season was around 190 €/Gcal, making it almost double that the average price in Romania.

The town is situated in the 3rd climatic area and the 4th aeolian area, meaning that the winter outside standard temperature is -18°C.

2.2 General information about the buildings

Most buildings have the category of importance C (average importance) and the class of importance III (buildings that represent a hazard for public safety in case of collapse). The town has around 120 residential buildings connected to the central heating system, numbering 3989 flats and housing 9472 people.

Most buildings are more than 45 years old and are made out of bricks or concrete. At present time only 5% of them were restored and were equipped with thermal insulation. Most windows and access doors are not airtight, so cold air infiltrates inside the buildings.

The buildings heating systems are vertical in nature, making it impossible to meter them separately. The total radiant surface of the radiators is 41147 m^2 and the total installed power is 17.69 MW or 15.26 Gcal/h.

2.3 Energy consumption measurements and predictions

The first step of this analysis was to measure the exact energy consumption for heating and to correctly build up the data base for the artificial neural networks training files. In this regard 35 random buildings were monitored over a period of 3 years. Overlapping these results, a model was created for the average building of the town. The annual specific energy consumption data for this building is presented in Table 1.

Table 1: Annual energy consumption for the model building

Annual energy consumption [kWh/m²year]	
Heating	251.80
Hot water	73.76
Artificial lighting	13.43
Total	339.01

Using the artificial neural network softwares built and trained with these sets of data, a prediction was made for every building of the town in order to determine the total energy consumption for the residential buildings and the total cost. [1],[2],[3] These results are presented in Table 2. A similar study was made for the energy production plant, for the distribution system and for all the district heating plants. These results don't make the subject for this paper and will be published in the future.

Table 2: Total annual energy consumption

Units	Surface m^2	Energy consumption		Energy costs €
		MWh/year	Gcal/year	
Total	242502	61062	52503	9742476
Connected	194001	48849	42003	7793981

3. Analysis of the retrofitting methods

3.1 Choosing the most efficient insulation

Because of the specifics of each area and the multitude of materials and properties, choosing the right insulation method for the buildings can be a difficult task. In this regard an artificial neural network was designed, trained and tested by the author, presented in Figure 1. The training file contained 60 sets of data for different types of walls, different type of insulation materials and different thicknesses. [7]

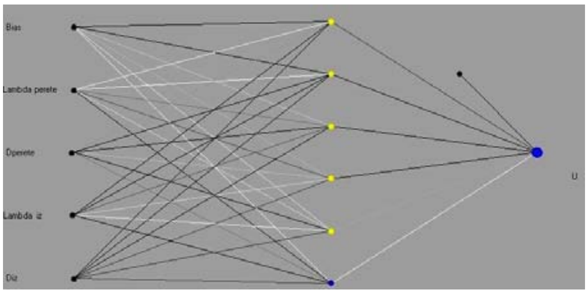

Figure 1: The ANN designed for the insulation

The testing results of the neural network are presented in Figure 2. The blue and green lines represent the measurements and the modeled values and the red line represents the error between them.

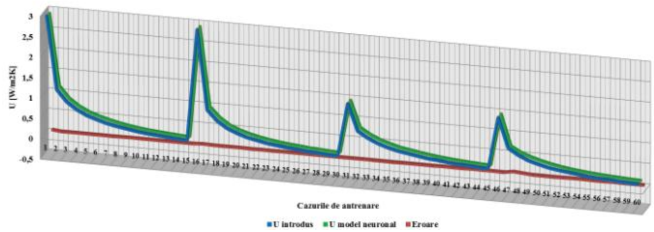

Figure 2: Testing of the ANN

A.15	C.15			*Optimal solutions*
B.12	D.11			
A.7-A.15	C.6-C.15			*Efficient solutions*
B.6-B.15	D.5-D.15			
A.1-A.6	B.1-B.5	C.1-C.5	D.1-D.4	*Inefficient solutions*

Figure 3: The results of the ANN prediction

The next step was to apply the artificial neural network to the actual buildings and to extract the optimal insulation characteristics for each one. An example of the result is given in Figure 3. Each letter represents an insulation material and each number the corresponding thickness. [6]

Using this process, a total of 4 ANN were created, trained and tested for all the components of the buildings: walls, windows and doors, roof and the floor above the basement.[7]

Appling those to the actual data of the buildings offered the most efficient method of rehabilitation for each case. After the careful analysis of results the following proposal was made for the rehabilitation of the residential buildings:

- Thermal insulation of the walls with 15 cm of type A material;
- The replacement of the existing windows and doors with insulating ones, having the thermal resistance over 0.65 m^2K/W [8]
- Thermal insulation of the roofs with 10 cm of type C material;
- Thermal insulation of the floor above basement with 10 cm of type A material;

4. Prediction of the rehabilitation effects on the energy consumption and the economic analysis

The main objective of this study was to find a feasible solution for the town's energy crisis and that includes the production and distribution of energy. In order to evaluate different energy production methods one needs to know how much thermal energy will be required after the rehabilitation of the buildings takes place.

With this goal in mind, a different artificial neural network was designed, built, trained and tested to take into consideration the new values. Its configuration is presented in Figure 4 and the testing results in Figure 5. [6]

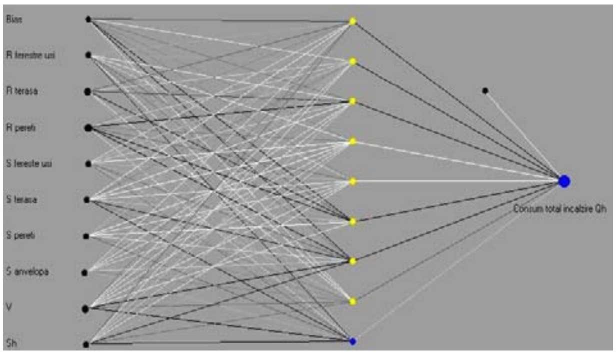

Figure 4: The ANN for energy consumption prediction

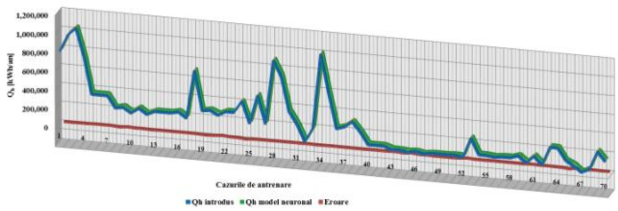

Figure 5: The testing results of the ANN

This ANN was trained using 70 sets of data containing measurements for different retrofitted buildings, similar with the ones in Brad. [6]

After the ANN was tested and approved as a tool for the accurate prediction of actual energy consumption, it was used on all the initial 120 residential buildings of the town. The energy consumption was recorded and the building model was reproduced. The new values are presented in Table 3.

Table 3: Annual energy consumption for the model building

Annual energy consumption [kWh/m²year]	
Heating	61.20
Hot water	73.76
Artificial lighting	13.43
Total	148.39

The energy values for the production of hot water and lighting did not alter because at this stage, the study was conducted only for the use of thermal energy designed for heating. The total value of the energy consumption prediction for the whole town is presented in Table 4.

Table 4: Annual total energy consumption prediction

Units	Surface m^2	Energy consumption		Energy costs €
		MWh/year	Gcal/year	
Total	242502	14793	12719	2360171
Connected	194001	11834	10175	1888137

The total energy savings that will be made by applying these retrofitting methods are presented in Table 5.

Table 5: Annual energy savings prediction

Units	Energy costs €	Energy savings		Money savings €
		MWh/y	Gcal/y	
Total	2360171	46269	7552014	7382306
Connected	1888137	37016	6041611	5905844

In order to determine the feasibility of the investment the costs of the rehabilitation needs to be examined. The economic analysis for the measures to increase the model building energy performance for the thermal rehabilitation process results in a total investment value of 73145 €.

The cost for the all the buildings that are connected to the centralized heating system is therefore evaluated to the sum of 7021901 € and the time needed for the rehabilitation process is estimated to 3 years. [9]

The proposed solutions for thermal rehabilitation of the building have good technical and economic indicators leading to energy savings of 331.53 Gcal/year (385,578.18 kWh/year) and in terms of payback 1.19 years.

It is worth noting that applying all the suggested solutions generates a reduction of the heat consumption by 75.69 % evidenced by the reduction of the annual energy consumption from 42003.10 [Gcal / year] to 10175.49 [Gcal / year] for all units connected to the centralized heating system.

A very important aspect of knowing the prediction for the future energy consumption is that future strategies can be performed in regard to the other components of the energetic system. Raising the insulation capacity of the buildings is not enough for a sustainable development.

After knowing the future energy consumption values, the distribution system can be redesigned in order to be more efficient.

Another important part that needs to be analyzed is the energy production plant. Now that it is known how much energy is really needed after the retrofitting stage, a modern heating and power plant can be designed to satisfy the new needs of the urban area.

The future stages of this study will do exactly that.

5. Conclusions

As the author predicted in previous papers, the artificial neural networks can be a powerful tool for most of energy prediction situations. The study published in this paper proves just that. By creating, training and testing the neural networks on accurate and relevant data they can be used successfully on future cases. The most important quality of them is that they can be used extremely easy and the results come in a very short period of time compared to other methods of prediction.
The use of the ANN's offered in this case a very accurate and important decision making result regarding the course of action in a very problematic situation.

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Author Profile

Rusu Daniel Sorin received his Phd. Diploma in the field of Civil Engineering from Technical University of Cluj-Napoca in 2012. Currently he is a lector at the Faculty of Building Services, specialized in Computer Aided Engineering and member in different energy policies and professional associations.