RESIDENTIAL BUILDING ENERGY ESTIMATION METHOD BASED ON THE APPLICATION OF ARTIFICIAL INTELLIGENCE

Introduction

The energy efficiency of buildings is a major concern in our society. The analytical methods needed to evaluate the energy performance of buildings must therefore be reliable and effective. The methods used for such purposes are simplified methods (rule of thumb, temperature ranges (BIN), degree-days, etc.) and detailed methods, which make use of detailed analytical software (DOE-2, BLAST). The simplified methods are fast and easy to use, but they are not very accurate and the range of their results is limited. The detailed energy analysis methods do not have these drawbacks, but they require some rather tedious data collection work. To remedy this situation, a method that retains the advantages of the simplified methods and that has a degree of accuracy comparable to the detailed energy analyses was developed, thereby filling the gap between the simplified and detailed methods.

Objective of the research project

The objective of the project was to establish a fast energy estimation method for residential buildings. In addition to being fast, the method had to give a wide range of results such as total energy consumption values, power surges, and heating or cooling consumption values. The degree of accuracy of the method had to be comparable to that of detailed building energy simulation software products.

Methodology

To achieve the objective of the research project, we chose to apply neural networks. This application requires a knowledge base that serves to carry out the learning of the neural networks. Since the database for existing buildings was insufficient, we decided to create this base by performing energy simulations of buildings using DOE-2 software. The method developed is applied to residential buildings with 5 to 25 storeys. It comprises the following steps:

1. creation of the database,
2. learning of the neural networks and validation of the learning results,
3. use of the learning results and design of an Energy Estimation Assistance System (EEAS) for residential buildings, and
4. validation of the EEAS.

Creation of the database

In order to take into account the residential building particularities that strongly influence energy consumption, the databases were created at the apartment and corridor levels. This allowed for the determination of energy consumption in relation to several parameters, presented in Table 1.

The quality of the database is crucial to the accuracy of the energy estimation tool. Consequently, we created, in DOE-2 software, 8 apartment models (4 located in the corners and 4 for the principal exposures) and a corridor model per typical storey. The typical storeys are as follows: the ground floor, the storey at the neutral level from the standpoint of the stack effect and the last storey without and with roofing. In addition, we developed and introduced into the DOE-2 software three new features that allow for the simulation of specific operations related to the controls: (1) of the lighting and the curtains, (2) of the opening of the windows and (3) of the operation of the corridor ventilation system.

Table 1. Variable parameters used for the creation of the databases		
Parametres		
Building-related	*Apartment-related*	*Corridor-related*
Climatic region	Exterior wall exposure	Surface area
Exterior wall resistance	Surface area	Ventilation rate
Roofing resistance	Length / width ratio	Lighting
Type of windows	Windows	
Infiltration	Occupancy schedule	
Number of storeys	Use of air conditioning	
Corridor ventilation system operating schedul		

Application of the neural networks

A total of 27 neural networks were used: 3 for the estimation of the energy consumption in the corridors and 24 for the estimation of the energy consumption in the apartments. The learning databases comprise the results of the 500 to 841 simulations. The validation of the learning of the neural networks was done on an independent database containing the results of 200 simulations. The results of the statistical analysis to validate the learning of the neural networks are presented in Table 2. The table shows only the results for the few exposures demonstrating the highest coefficients of variation (CV). The CV values for the other exposures are better.

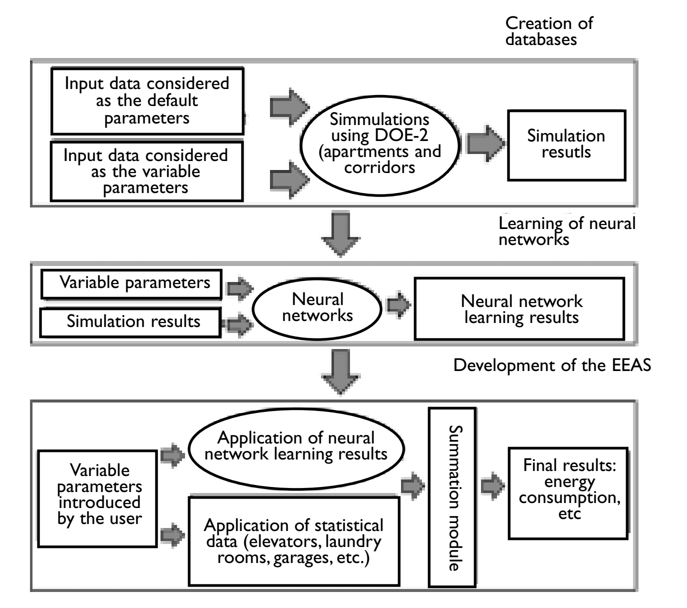
An analysis of the results revealed that the coefficients of variation were very low, except in the case of the apartments with a southern exposure located on the middle storey and the last storey without roofing (*particularly for the heating*). This is due to the magnitudes of the simulation results obtained. An analysis of the coefficients of variation (CV) and standard deviations (SD) by range of energy consumption in these apartments showed that the CV can be relatively high even if the standard deviation is very low (sometimes almost negligible).

Table 2. Neural network learning results

		Basic electricity consumption		*Heating electricity consumption*		*Cooling electricity consumption*	
Floor	*Exposure*	*CV[%]*	*SD [kWh]*	*CV [%]*	*SD [kWh]*	*CV [%]*	*SD [kWh]*
First storey	North	0.49	19.59	1.95	219.16	1.12	8.11
	South	0.55	22.07	1.83	166.26	1.42	14.06
	West	0.39	15.27	1.17	134.71	1.33	13.61
	Southwest	0.77	30.72	2.89	570.85	1.96	22.58
Middle storey	North	Same results as for the first storey	Same results as for the first storey	3.08	29.14	0.81	7.11
	South			6.10	16.74	0.85	9.82
	West			2.35	43.73	1.00	11.99
	Southwest			3.21	67.60	1.39	19.17
Last storey without roofing	North	Same results as for the first storey	Same results as for the first storey	3.88	26.49	0.79	7.21
	South			7.94	12.23	0.93	11.13
	West			4.80	25.31	1.04	12.96
	Southwest			5.58	50.34	1.42	20.19
Last storey with roofing	North	Same results as for the first storey	Same results as for the first storey	1.33	53.99	0.93	6.90
	South			2.44	56.35	1.04	10.59
	West			1.69	59.01	1.15	12.19
	Southwest			2.43	96.47	1.89	23.88

Use of the learning results and design of an Energy Estimation Assistance System (EEAS) for residential buildings

Figure 1.
EEAS Simplified Diagram



To facilitate the estimation of energy consumption, we designed three user interfaces, thereby developing an Energy Estimation Assistance System (EEAS) for residential buildings with 5 to 25 storeys. These interfaces are currently only accessible using MATLAB software, but the EEAS code can be translated into C++ language.

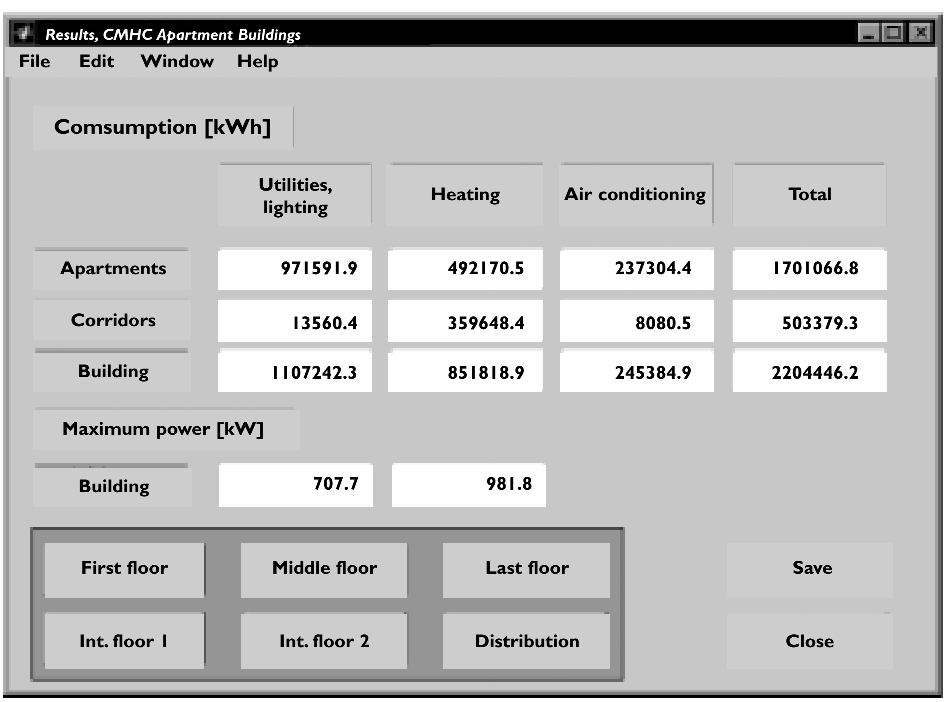
The input parameters used in the EEAS are the same as those presented in Table 1. They allow for the determination of energy consumption levels in the apartments and corridors. The energy consumption values of certain items such as elevators, exterior lighting, underground garages, etc. can come from the statistical data for buildings of this type. The data so provided can be added to the results obtained by the application of the neural networks.
A summation module would then allow for the calculation of the total consumption of the building. Figure 1 presents the development steps and a diagram of the EEAS. It should be pointed out that the summation module currently applies only to the results for the apartments and the corridors.

Figure 2 presents some sample EEAS results. In reality, the results are much more detailed, as they can be presented by apartment type, in relation to their exposure and location (storey).

Validation of the EEAS

A comparison of the results obtained by the EEAS with the energy consumption levels recorded in a building situated in Ottawa reveals that the EEAS is very accurate (the margin of error was 0% for occupancy schedule no. 2 and 5% for occupancy schedule no. 1).
It should be noted, though, that occupancy schedule no. 2 better corresponds to this building, which is a home for seniors.

Figure 2.
EEAS Sample Results (principal window of results)



Conclusions

By changing the variable parameters, the EEAS allows for the determination of the annual heating, cooling and basic (utilities and lighting) energy consumption levels for apartments and corridors in relation to their location. The EEAS also makes it possible to analyze the impact of these parameters on energy consumption in residential buildings while taking into account the interaction between the HVAC (heating, ventilation and air conditioning) systems and the envelope of the building under review.

The EEAS was developed for the climatic conditions in Ottawa. To use it in different climatic conditions, an appropriate correction would have to be made to the heating and cooling consumption values. To avoid these corrections, in the next application of the method developed for this project, it would be necessary to plan to consider certain climatic file characteristics as variable parameters. Obviously, the creation of the database for the learning of the neural networks would have to be modified accordingly.

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Research Report: Residential Building Energy Estimation Method Based on the Application of Artificial Intelligence

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A full report on this project is available from the Canadian Housing Information Centre at the address below.

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