Development of a Method for Building Energy Diagnosis ; Application to an Existing Light Weight Building

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ABSTRACT

The goal of this study, carried out on a wooden building, is to apply the methodology of identification in order to obtain the physical parameters which characterize the thermal behaviour of the building. The identification of the system is the methodology of modeling the system starting from the experimental data. It consists in measuring the inputs/outputs of the system, choosing the structure of the model representing this system, adjusting the parameters of the model by an algorithm of identification and finally validating the model.
The method developed in this paper can be applied to all types of buildings. We started by analysing the measured data by using the principal component analysis in order to identify the thermal zones of the building and we also used the cumulated spectra of the system inputs ant outputs in order to determine the need for filtering. Then we estimated the global parameters in static domain; an algorithm for the estimation of the set of parameters was developed, based on the least square method. Finally we estimated the physical parameters of the building in dynamic state.

KEYWORDS

Building, identification method, measured data analysis, PCA, thermophysical parameters, PEM.

INTRODUCTION

Thermal comfort inside a building is achieved by the building envelope and its technical equipments. In order to rate the energy performance of an existing building we need to know its thermophysical parameters but the problem is that the theoretical parameters are generally different from the real ones. Facing this problem, we chose to develop a measurement based approach by using the identification method.

There are a wide variety of approaches to dynamic analysis with different levels of complexity and accuracy, see for example Rabl (1988), Norlen (1989). All these methods require setting up a model representing the analysed system and the application of system identification techniques to obtain the required parameters. One of the problems related to this type of analysis, is the correlation between the physical quantities involved in the tests. Different strategies for analysis and testing have been adopted to deal with this problem in a more general context, depending on the final application of the models. Principal components analysis (PCA) has been used in simulation and prediction to deal with the problem of correlation of input quantities, Urbani (1995).

The main purpose of the present work is to promote a methodology of energy analysis for energy savings and rational use of energy in a wooden building. The methodology of study can be applied to all types of buildings. The principle of this method is to derive the thermal behavior of the building from experimental measures of internal temperature in different rooms in response to outdoor climate (temperature and solar radiation) and internal loads (heating power, electric equipments power). Our methodology of work is essentially composed of three stages: preliminary analysis of recorded data, estimation of the thermal parameters which characterize the building envelope in static state and finally in dynamic state with the help of MATLAB.

BUILDING DESCRIPTION AND MEASURED DATA

The building is located in Jugasin with 44°49' 54'' of northern latitude and 0°41' 30'' of western longitude. This building is used as offices for the “Confort Bois Contruction” company (CBC); it was built in November 1999. The Company CBC designs wooden houses of high environmental quality. As shown in figure 1, the building is composed of four offices, a large room conference, a kitchen, a bathroom equipped with a sauna and finally a WC. The total surface of this building is 110 m^2 and its volume is 350 m^3.

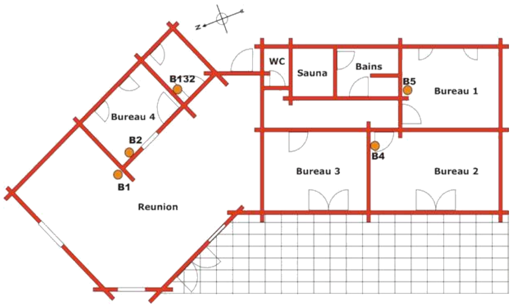


Figure 1: Plan of the building and position of the HOBO sensors

Heating is achieved by electric convectors with manual regulation. Two convectors are placed in the largest room of the building which is the conference room. The bathrooms and each office, except office 4, are equipped with one convector. Concerning the occupation, the building is occupied all the days of the week from 8a.m to 18p.m. There are approximately two persons in the conference room and two persons in each office except the office 4 where we found one person. The weekend, the building is empty, only the bathroom is likely to be used since it is equipped with a sauna.

The type of sensors installed is the HOBO sensors which have their own electrical mains with a very great autonomy. The sensors were located at 1.5m height and on the interior walls which are not in contact with outside and are protected from the sun. The measured data are: indoor temperature in different rooms (Tint), relative humidity of the air in different rooms (RH), consumption of electricity for the heating and the equipment (Pc), power related to the sauna (Ps), outdoor temperature (Text), solar radiation on horizontal surface (RS)

PRELIMINARY DATA ANALYSIS

In order to study the features of the collected information and the possible correlations between the physical quantities involved in the tests, we have firstly submitted the recorded data to a preliminary analysis which allowed us:

- To identify the thermal zones of the building by using the PCA
- To identify the need for filtering and the dynamic implementations by using the spectral density and cumulated spectra of input ant output variables.

The data used for our study correspond to the data of November and December 2004. The sampling interval of measured data is 15 min for the internal temperature, 5 min for the power and 1 hour for the outside temperature and solar radiation on horizontal surface. The outputs of the system are represented by the internal temperature in different rooms. In general, multivariable models, and especially models with several outputs, become complicated because the coupling between several inputs and outputs leads to models with too many parameters. In our study case, we notice that the different internal temperatures are similar that's why we choose to apply the PCA in order to identify the thermal zone of the building.

PCA result

Concerning the contribution to the variance of each internal temperature, Fig 2 shows that the first principal component explains the majority of information (about 85%) for each signal.

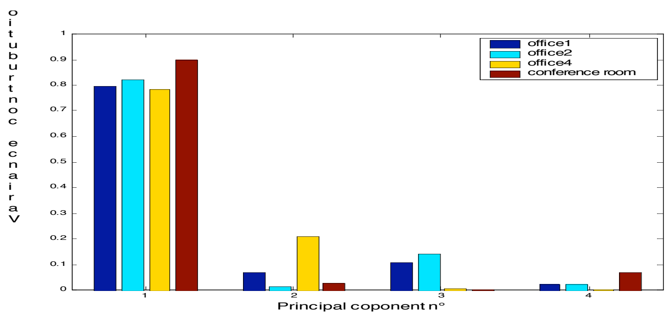


Figure 2: The contribution to the variance of each signal

This analysis thus shows that the output data can be reduced to the mean value of the temperatures of the different rooms, with little loss of information.

Identification of the dynamic settings and the need for filtering

Chowdhury et al (2001) and Ramdani et al (1997) have used cumulated spectra to analyze the dynamic behaviour of system variables. We have applied this mathematical tool to our system. Figure 3 shows that although the heating power has a high frequency request, all the outputs have a low frequency; this means that the system is a low pass filter. Moreover, the three spectra of the temperatures respectively of office 1, office 2 and conference room have the same pace. This means that the building is equivalent to a low filter system and we will not lose information if we increase the step of sampling. So, we decide to sample all the recorded signals with a time step of 1 hour.

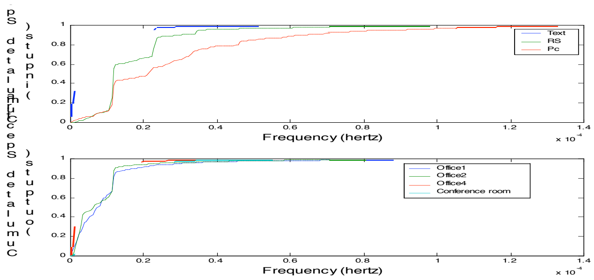


Figure 3: Cumulated spectrum of the inputs and outputs

ESTIMATION OF THE BUILDING PARAMETERS IN STATIC DOMAIN

In order to identify building parameters, we have to choose an appropriate mathematical model, and to establish relations between physical and mathematical parameters. We considered that the building is a linear system submitted to various excitations U_i (solar radiation RS, heating power P and outside temperature Text) and we observe the output of the system (Y) which is the indoor temperature. In this case the equation of the model is represented by the Eqn 1:

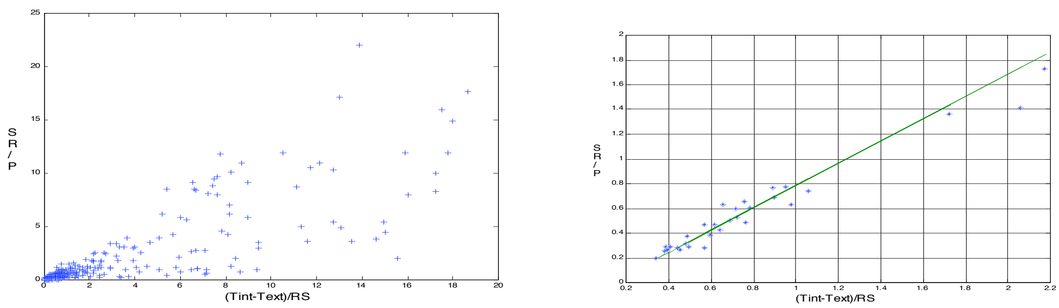
$$P + \eta_{RS} RS - U_{eq} \Delta T = 0$$

η_{RS} being the solar effectiveness, U_{eq} is the thermal loss coefficient, and ΔT the difference between indoor and outdoor temperatures.

We can describe the relation between the inputs and the outputs of the system by the following equations; α_i being the mathematical parameters:

$$Y_i = \sum \alpha_i U_i$$

The thermal parameters will be expressed as a function of the mathematical ones, which are calculated by a least square method.
The first stage was the selection of data corresponding to the static domain by representing the correlation line: $\frac{P}{RS} = f(\frac{\Delta T}{RS})$.
Figure 4a, shows that data corresponding to one hour sampling is scattered, reflecting the dynamic behaviour. However, by using a sampling of one day (figure 4b) we found a correlation coefficient equal to 0.96. This means that we should exploit the data with a sampling of one day to deal with the static mode. We have tested 6 cases by changing the number of solicitations and by exploiting: the data of only working days, all the days of the week, or finally the average value on a number of days.



a)Hourly data b) Daily data

Figure 4: Different data sampling

Figure 5, shows that by using the average value on a certain number of days, the thermal loss coefficient is stable and the solar effectiveness follows practically the same fluctuation, but the effectiveness of the electric components varies. This means that this method allowed us to have a good estimation of the thermal loss coefficient and the solar effectiveness.

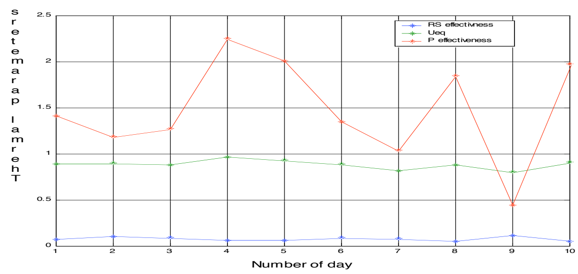


Figure 5: Variation of the thermal parameters

The best results were obtained when we consider the following inputs: RS, P_{eqp}, T_{ext} and P_c and for case number 2 in which we use all the days data. We present in table 1 the calculated thermal parameters.

TABLE 1
Thermal parameters

The data exploited	Solar effectiveness	Thermal loss coefficient [$W.m^{-2}.K^{-1}$]	Effectiveness of the electric components
All the data	0.080 ± 0.0007	0.895 ± 0.0048	1.420 ±0.1371

ESTIMATION OF THE BUILDING PARAMETERS IN DYNAMIC DOMAIN

In order to estimate the thermal parameters of the building in a dynamic system, a reduced state space model was chosen to represent it. We used the prediction error method (PEM) and the state space model implemented in “System Identification Toolbox” of software MATLAB. Validation of the obtained results was based on comparison between the values of indoor temperatures measured and reconstituted by the model, and on the analysis of residues and the test of autocorrelation. We noticed, after validation, that the significant parameters which have a physical meaning are those obtained by using the data of every day with order 4; indeed, according to the autocorrelation test shown in figure 6, we note that the autocorrelation of the residual for the output is in the interval of [-√2⁄N, +√2⁄N] ([-0.066, +0.066] with N=920). Moreover, we obtain a mathematical parameter related to the T_{ext} equivalent to 1. However, the effectiveness of the electric components is physically meaningless (table 2).

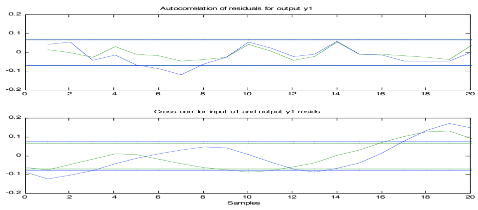


Figure 6: Autocorrelation test

TABLE 2
Thermal parameters (model order 4)

The data exploited	Solar effectiveness	Thermal loss coefficient [$W.m^{-2}.k^{-1}$]	effectiveness of the electric components
All the data	0.158	0.706	2.235

Conclusion

We started with a preliminary analysis of the measured data based on PCA. From these measurements of the inputs and outputs, we have determined the thermal parameters in static domain. We noticed that the most stable parameter in this case is the thermal loss coefficient; the coefficient related to the electric components shows wide variations. That is probably due to the quality of measurements related to consumption of these equipments. Then, we made the same study in dynamic domain. In this part we based our validation on the comparison of the indoor temperature measured and reconstituted by the model and on statistical tests applied to the residual of the model. The results obtained in this case lead us to the same conclusion as in static domain.
In a general way, this study enabled us to obtain the thermal parameters of the building. In prospect, it would be interesting to use these parameters with an aim of reducing the energy cost by keeping a comfortable environment. This is why we propose as continuation of this study, the inversion of the model i.e. the temperature of comfort given by the regulation is imposed like input, and the output of the system will be the power of heating, leading to the addition of a regulator of the type proportional-integral-derivative (PID).

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