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INFLUENCE OF WINDOWS OPENINGS ON BUILDING THERMAL CHARACTERIZATION USING IDENTIFICATION TECHNIQUE

V.RICHALET, Dr.
Ecole Nationale des Travaux
Publics de l'Etat
Rue M.Audin
F-69518 Vaulx en Velin Cedex

F.NEIRAC, Dr.
Ecole Nationale Supérieure
des Mines de Paris
Rue C.Daunesse
F-06565 Valbonne Cedex

ABSTRACT

Identification techniques have recently found an application in building thermal physics, as they are valuable tools to assess energy performances from on-site measurements. One main problem is still the non-stationarity of the model parameters because of variable air change rate. Especially, long windows openings during the experiment can lead to a failure of identification or non-valuable estimates of the static characteristics of the building (global heat loss coefficient and solar aperture) and its main time constant. This is a severe obstacle for future works in this field when studied buildings are occupied.

We look at this problem using simulated and real data sets with various openings duration and consider some directions to solve it. But at the present time, no satisfactory method is available and it is necessary to impose constraints in the experimental protocol so that variations of the air change rate can be as reduced as possible.

KEYWORDS : Identification, Thermal model, Window opening

INTRODUCTION

There are few means to assess the one site thermal performance of one building. For retrofit purposes, this is done thanks to a long monitoring of its consumption over one heating season. But some recent works have shown other opportunities in this field, for example for heating control purposes. They consist in identifying the parameters of one dynamic model of the building thermal behaviour, thanks to a statistical analysis of some on-site collected measurements (typically during one week). We give more details about these methods and the model that is used in a first section.

One main problem for a practical use of these methods is the non-stationarity of the dynamic model of the envelope if air change rate is varying either because of wind induced infiltrations or because the occupants open the windows of their home. In a second section, we study the influence of variations of the Air Change per Hour (ACH) rate thanks to measured sets of data as well as simulated ones. We conclude in giving some directions for future works in order to limit or suppress the resulting effects of air change rates variations on thermal model of the building.

IDENTIFICATION PRINCIPLE

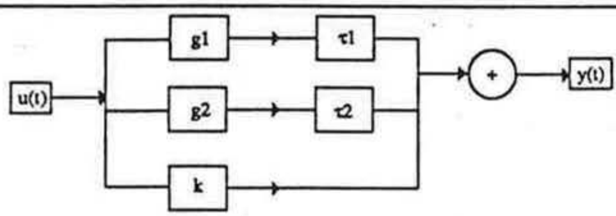
Field of application

Identification techniques are used to fit a model of the dynamic behaviour of any linear system. The system is controlled by input variables u(t) and its response is observed through an output variable y(t). u(t) and y(t) are recorded measured data. This technique can be applied to a thermal characterization of the system «building» in its surrounding environment. Considered inputs are outside temperature, power of the heating system, and solar irradiation. Output is observed through the indoor temperature of the building.

Description of the method

Three main steps have to be performed for an identification:

1. The first one is the choice of one parametric model : we can only consider models including a small number of parameters because information from the experiment is often poor. Different dynamic models have been used by several authors [Rabl,1988]. We chose a second order modal state space model whose mathematical form is validated by modal reduction of large linear physical model [Neirac,1989]. Its expression is given in Figure 1.



$$\begin{cases} y(t) = x_1(t) + x_2(t) + ku(t) \\ \dot{x}_1(t) = f_1 x_1(t) + g_1 u(t) \\ \dot{x}_2(t) = f_2 x_2(t) + g_2 u(t) \end{cases}$$

where x_1 and x_2 are state space variables of the system

$f_1=-1/\tau_1$ τ_1 main time constant

$f_2=-1/\tau_2$ τ_2 fast time constant

Figure 1: Second order modal state space model

2. The second step is the choice of the statistically based method. Depending on the shape and the complexity of the model, several algorithms are available. We chose the classical Levenberg-Marquardt one which is convenient for a large class of problems [Bordier,1984]. Because the method is iterative, it is necessary to give guessed initial values to the parameters.

3. In a third step, one has to realize a suitable experiment. In order to improve the quality of the results it is necessary to impose a few constraints to the experiment, especially some variations of inside temperature must be performed by the heating system. From our experience, we are able to give other recommendations that can be found in [Richalet,1991].

The main hypothesis for the described method are then:

(a)- the behaviour is linear relative to input and output variables (not the parameters)

(b)- a second order is sufficient to model dynamics of the building

(c)- the parameters of the model are constant (this means a stationary model)

(d)- the thermal response of the building can be represented by one temperature

Validity of the identified parameters

The previous method has been developped in a software called «LADY» [Richalet and Neirac, 1991]. For practical reasons (giving initial values to mathematical parameters is not a easy task), the set of parameters has been transformed so that it makes appear physical characteristics: *UA* for overall heat loss coefficient of the enveloppe, *As* for solar aperture, and time constants ($\tau 1$, $\tau 2$) which are linked to parameters ($g1$,$g2$,k). Other parameters give importance of each one of the dynamics for the response to each input. We do not need them in the following discussion, nor the second time constant as it depends on the way all quick phenomena are aggregated so its value is not representative of the building but of the period of data.

In the following, we give results for two examples: the first set of data is a simulated one, the second set is made of measured data.

Simulated data.

We made a simulation of an ordinary house using the ESP code [Clarke, 1987] during 10 days. Time step is 12 minutes and a series of 5 kilowatts heating steps is imposed. Infiltrations are supposed to occur through cracks and ventilation inlets of the envelope as defined in [Clarke, 1985]. A mechanical extract flowrate of 0.5 vol.h^{-1} is assumed. Air flows are calculated by ESP using a mass balance network approach.

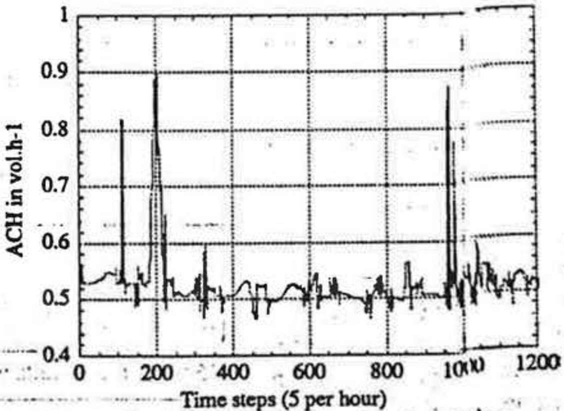


Figure 2 : ACH rate during the simulation

Wind induced pressure boundaries are derived from a set of pressure coefficients [ITBTP, 1987]. In this particular case, the underlined hypothesis (d) of homogenous temperature inside the building is true. Stationarity (c) is quite validated because wind induced variations of the ACH rate are very small (Figure 2), and superficial exchange coefficients are set constant. Moreover, we know reference values for the heat loss coefficient (*UA=205.2 W/°C*), the solar aperture for a south vertical orientation ($As=9.2m^2$) and the main time constant ($\tau 1=51.7\,h$) when the building has a constant ACH equal to 0. 5vol.h^{-1}.

The identified parameters are the following (with standard error into braklets):

UA = 202.3 [1.5] W/°C *As = 9.2[0.3] m2* ; $\tau 1 = 53.0\ [0.7]\ h$

The difference between the output of the model and the measured one is given by the criterion "cri" (degree C) which is the root of the mean square deviations. It is about 0.13°C (with maximum deviations of 0.5°C) showing a good fit between the model and the recorded output. Physical characteristics are well estimated compared to the reference values. These satisfactory results indicate a good validity of hypothesis (b) and (c).

Measured data. The monitored building is a wood frame house located near Bordeaux in France. It is a detached two storey house, non occupied during the experiment from January 18 th to 24 th. A night cut off of the heating system was imposed during the experiment. More details about experimental conditions can be found in [Marchio and Dubernet,1988]. The considered inside temperature is a mean volume ponderation of the measurements from the captors located in several rooms of the building. The identified results for the collected set of data are the following:

UA = 229.4 [2.5] W/°C   As = 6.1 [0.3] m2   τl = 23.8 [1.2] h   cri = 0.20°C

Confidence intervals and criterion are small enough to conclude at a good fit between the model and the recorded output. We have got same accuracy with other single family houses indicating that a monozone, second order, linear, and stationary model is sufficient in most cases to represent the thermal behaviour of unoccupied ordinary houses.

INFLUENCE OF A VARIABLE ACH RATE BECAUSE OF OPENINGS

Identified parameters

Identification is now performed with sets of data from both ESP simulations and experiment for the same houses as previously where windows have been opened.

Simulated data : Bi-directional air flows through large opening (here 2mx2m) can be calculated by ESP. The duration of the opening vary between 1time step (12 minutes) and 1hour (Table 1). The model is still well fitted for short openings as temperature drops are limited, but for longer openings physical parameters are poorly estimated, especially main time constant. Figure 3 shows how the model predicts inside temperature in such cases, by increasing inertia. Note that *UA* values are increased with *ACH* rate but large standard errors prevent from any tempting interpretation.

Opening times	UA (W/°C)	As (m2)	tau1 (h)	cri (°C)
15 h - 15 h 12	204.0 [5.6]	8.9 [0.9]	54.2 [2.2]	0.27
15 h - 15 h 24	206.6 [10.6]	8.9 [1.6]	56.6 [6.8]	0.39
15 h - 15 h 36	210.4 [17.3]	9.2 [2.5]	61.3 [20.3]	0.47
15 h - 17 h	223.3 [30.0]	10.7 [6.5]	72.5 [59.3]	0.59
8 h - 8 h 12 15 h - 15 h 12	216.9 [6.5]	9.8 [1.0]	51.2 [2.4]	0.39

Table 1 : Identified parameters with time varying openings

Measured data. The same real house than previously was monitored when windows were opened each day :

January 25th from 5.30 p.m to 6.00 p.m
January 26 th from 10.20 a.m to 10.45 a.m and 5.55 p.m to 6.20 p.m
January 27 th from 8.00 a.m to 8.25 a.m and 5.25 p.m to 5.50 p.m
January 28 th from 7.20 a.m to 7.45 a.m and 5.10 p.m to 5.53 p.m.

The resulting fall of the inside temperature can be seen on Figure 4. It can reach up to 7°C. An identification performed with these data did not succeed, nor when we lengthen the duration of the monitoring with previous days (January 18th to 24th). Of course, air flows across the building were very important because all windows were opened at the same time. Nevertheless, this case introduces a severe limitation to identification method.

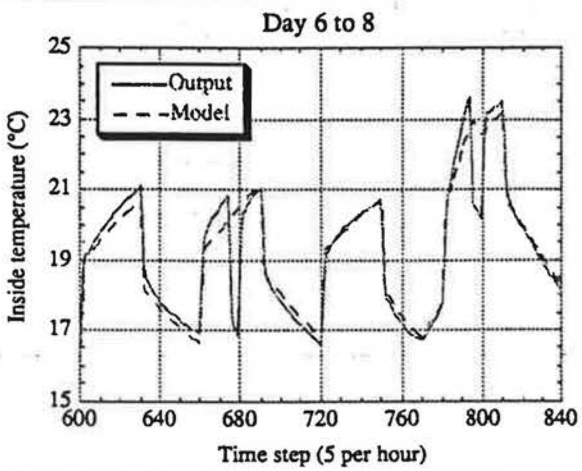


Figure 3 : Identification with simulated data for 1hour openings.

Perspectives for parameters identification in case of windows openings

Two directions can be considered:

1. Try to "filter" the fast falls of the inside temperature because of the openings. This can be done thanks to a pre-filtering of the data by an exponential filter with time constant of one or more hours. Identification then succeeded with a time constant of 6 hours leading to the following results:

$UA = 290.1\ [4.6]\ W/°C \qquad As = 6.2\ [0.4]\ m2 \qquad \tau l = 34.9\ [5.4)]\ h \quad cri = 0.07°C$

Compared with the results for the same real house without openings, we can conclude that reasonable estimations for *UA* and *As* have been found, indicating an increase of the global heat losses and a constant solar aperture during the experimental survey, but the main time constant is about 10 hours higher. Figure 4 shows how the identified model overlaps the temperature fall by increasing inertia as for simulated data. Moreover, the interesting problem is not to fit a model of thermal behaviour including openings of the windows but to obtain a thermal model of envelope without the openings. This model is much more useful for system control purposes.

2. A second direction would be to build a model including the thermal effect of varying *ACH* rates. But then difficulties appear as the non-linearity of the resulting model, the link between time constant and *ACH* rate and measurement problems to get values of *ACH* rates with small time steps (less than half an hour).

We will direct in the next future toward an alternative hybrid approach that would "erase" openings, either by cutting off corresponding periods, or by fulfilling the drops of inside temperature. This involves to solve the difficulty of unknown thermal state of the building during this period, but measurements would be much easier as we only need a detector for time openings.

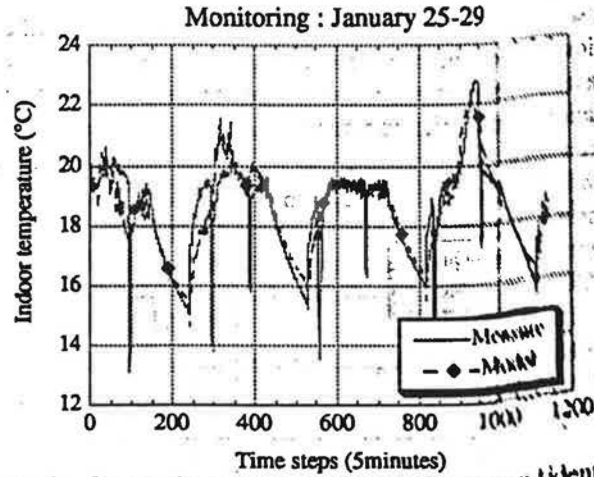


Figure 4 : Comparison between measured output and identified model with filtered data ($\tau = 6h$).

CONCLUSIONS

Thanks to a set of simulated (validated by real measured data) we have shown that identification of the parameters of a second order state space model lead to a good thermal characterization of ordinary houses, except in the case of long windows openings leading to significant falls of the inside temperature. Particularly, an increase of the identified main time constant of the building has been observed.

At now, no real method exists to prevent from, as we do not have any simple way to model theeffect of a varying air change rate on main time constant of the building. But future works will be denied to this problem in order to adapt the method to the case of occupied buildings. There is an important stake in this work for the analysis of consumptions and the control of the heating system of houses.

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