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COMPARISON OF DIFFERENT METHODS FOR ESTIMATING THE BUILDING ENVELOPE THERMAL CHARACTERISTICS

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ABSTRACT

The aim of this work is to evaluate the reliability of different methods allowing the estimation of global envelope thermal parameters, the heat loss coefficient and the main time constant, using short term monitoring. Energy signature, steady state calculation, and identification methods have been tested on a new experimental passive house. A specific heating scenario was adopted. It consists to create a transient state between a heated period and an unheated one. The possibility of identifying the main time constant and the global heat loss coefficient of the building is evaluated using respectively the transient period and the measurements over the heating period.

INTRODUCTION

Increasing demand for energy efficiency requires a more precise knowledge of building performance parameters. The total heat loss coefficient and the main time constant are two such fundamental performance parameters, which provide information about the envelope thermal performance. Estimating these parameters for existing buildings is challenging.

In the literature, there are a variety of methods allowing the estimation of these parameters. They depend on the available data and can be classified in two approaches. The first one is the statistical approach based upon regression model or steady state formulas [Ashrae, 2009]. The second approach is the dynamic modeling approach based on a suitable model taking into account the physical phenomena in the building. It requires detailed data on material and building characteristics.

Regression approaches use simplified static models for estimating building thermal characteristics. For instance, the energy signature has been largely used for evaluating the energy performance of a building in terms of the global heat loss coefficient [Sjögen et al., 2007], [Yu et al, 2005] and [Ghiaus, 2006]. This coefficient can be also calculated from the information about the building characteristics including the thermal properties of materials using a steady state formula [RT, 2005]. However, in general it is difficult to obtain detailed physical properties of a given building. So this procedure of calculation is very sensitive to the estimation of the physical properties of the building. In this paper, the studied building is a new experimental passive house, so we assume that the building characteristics parameters have some degree of precision. Therefore, the steady state formula can be used to calculate the global heat loss coefficient.

Model identification approaches aim at estimating a suitable model based on observed data collected from the building. This can be done using a number of different techniques as the Prediction Error Method (PEM) which is the most used estimation method for model parameterization. The identification process can be applied using different types of models, for example transfer functions [Youmin et al, 2000] or thermal network models [Déqué et al, 1997], dynamic system models derived from actual building performance data [Jimenez et al, 2008] or continuous time models based on the maximum likelihood method [Madsen et al, 1995].

Olofsson et al ([Olofsson et al, 1999], [Olofsson et al, 2000]) and Lundin et al [Lundin et al, 2004] estimate some characteristics of the envelope (total heat loss coefficient, total heat capacity and solar gain factor) using a neural networks model that is trained on measured data for the indoor -outdoor temperature difference, the supplied heat and the available internal and solar gains.

In this paper, a model identification procedure has been applied using a black box model and a dynamic thermal model, Pleiades+Comfie [Peuportier, 1990]. The adopted model form is the state space form.

The main aim of this work is to investigate the possibility, based on a short term measurement period, to evaluate the energy performance of an experimental passive house by estimating its main thermal characteristics.

The work consists in comparing different methods estimating the global heat loss coefficient and the main time constant. Assuming that the available data regarding the characteristics of the walls, windows and air tightness of the experimental passive house are precise, we can consider that the reference value of the global heat loss coefficient is given by the steady state formula. Concerning the mean time constant, the reference value is given by the dynamic simulation model Pleiades+Comfie because the corresponding model represents the physical phenomena in the building.

Firstly, this paper presents a brief description of the studied building and the measured data. Then, the adopted methods for estimating the thermal characteristics are listed. The obtained results for both the global heat loss coefficient and the main time constant are presented. This paper finishes with conclusions of this study and considerations of further research.

BUILDING DESCRIPTION AND MEASURED DATA

The studied building is a part of an experimental platform called INCAS which is built in the National Institute for Solar Energy (Chambéry, France). It is an experimental passive house with two floors. Its net floor area is about 100 m². The envelope is made of 20 cm of heavy concrete and 20 cm of insulating material.

The building is equipped with an electrical heating integrated in the mechanical ventilation system (with a heat recovery system).

The building has been monitored; we exploit the measured data from 19 January to 08 March 2011. Measures quantities are: (a) the indoor temperature in different rooms (rooms 1 and 2, first floor and living room) (b) the outdoor air temperature, (c) the solar radiation. The total heating power is given by the dynamic thermal model Pleaides+Comfie.

In this study, the building is approximated by a single zone and its thermal behavior is presented by the indoor air temperature which is defined by the mean temperature of the first floor (room 1 and 2) and the ground floor (living room).

In order to test the simplified method allowing the estimation of the main time constant, a specific heating scenario has been adopted. It consists to create a transient state between a heated period and an unheated one. More precisely, the variation of the indoor temperature was measured during a first period in which the building is heated and then the heating source was off during 10 days. This can only be done in an experimental building, therefore in a second step we will reduce the length of this period, or use a free floating period in mid-season.

Figure 1 shows the indoor air temperature. Period 1 corresponds to the period from 05 February to 14 February 2011 (2 weeks) during which the heating was stopped and the shutters were closed. Period 2 corresponds to the period of heating with open shutters.

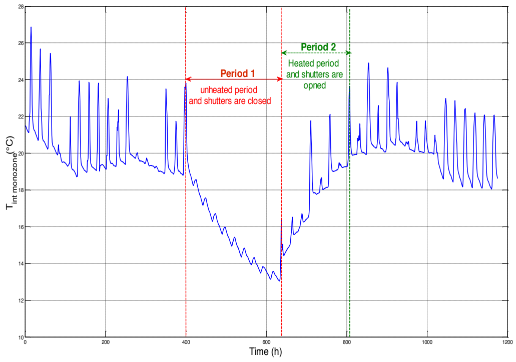

Figure 1 Time evolution of the indoor air temperature

Figure 2 represents the time evolution of the heating power, outdoor air temperature and solar radiation. We notice that the heating power ranges from 0 to around 1200 W and the outdoor temperature varies from −9°C to 13°C.
The maximum value of solar radiation is about 600 W.

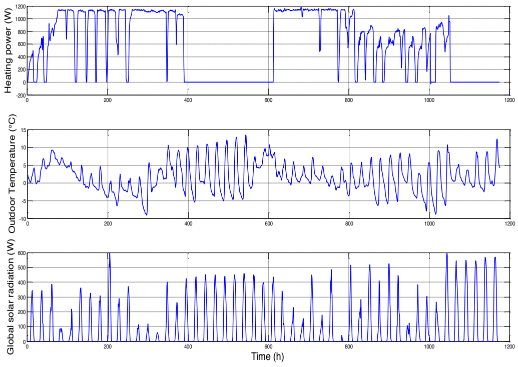

Figure 2 Time evolution of heating power, outdoor air temperature and solar radiation

METHODOLOGY

We focus on estimating thermal performance parameters of a building using limited observation data. The tested methods are respectively the energy signature, steady state calculation/simplified method and the identification method. We present in Table 1 the data source and the estimated characteristics using each method.

Table 1
The tested methods for estimating the thermal characteristics of the envelope

Data source	**Method**	**Estimated characteristics**
Heating power and Outdoor air temperature	Energy Signature	Global heat loss coefficient
Detailed building characteristics	Steady state formula	
Indoor and outdoor air temperatures, solar gain, global heat loss coefficient and heating power.	Simplified method	Main time constant
Simulation data (indoor and outdoor air temperatures, solar radiation and heating power)	Identification based on dynamic model	
Measured data (indoor and outdoor air temperatures, solar radiation and heating power)	Identification based on a black box model	

To estimate the global heat loss coefficient of the passive house, we use two methods which are respectively the energy signature and the steady state formula.

- ***Energy signature***

It consists in using the regression of energy consumption over the climatic data (outdoor air temperature) [Westergren et al, 1999, Bauer et al, 2005]. For more details about this static method see [Ghiaus, 2006].

- ***Steady state formula simplified method***

The steady state formula for calculating the total heat loss coefficient noted H is given by the following equation:

$$H = UA_{walls} + UA_{doors} + UA_{windows} + \sum \psi_i L_i + \dot{v} C_{ventilation} \qquad (1)$$

To estimate the main time constant of the passive house, we compare the results obtained by respectively the steady state method (simplified method) and the identification method for both the dynamic model and the black box model.

In this paper, we present only a brief description of the simplified method allowing the estimation of the main time constant of the building using a short monitoring period. For more details about the identification procedure see [Mejri et al, 2011].

- ***Steady state calculation (simplified method)***

The used data correspond to the transient period; the heating was off and the shutters were closed during 10 days.

The simple dynamic equation describing the behavior of the building is given below:

$$Q_{sol} + Q_{int} - H(T_{int} - T_{out}) = C \times \frac{\partial T_{out}}{\partial t} \qquad (2)$$

Equation (2) can be written as the following:

$$\frac{\partial T_{int}}{\partial t} = \frac{Q_{sol} + Q_{int} + HT_{out}}{C} - \frac{H}{C} T_{int} = aT_{int} + b \qquad (3)$$

with:

$$a = \frac{H}{C} = -\frac{1}{\tau}$$
$$b = \frac{Q_{sol} + Q_{int} + HT_{out}}{C} \qquad (4)$$

where τ is the main time constant of the building.

The resolution of equation (3) leads to the following equation:

$$T(t) = \left(T_{in} + \frac{b}{a}\right) e^{-\frac{t}{\tau}} - \frac{b}{a}$$
$$\Updownarrow$$
$$Log\left[\frac{T(t)+\frac{b}{a}}{T_{in}+\frac{b}{a}}\right] = -\frac{t}{\tau} \qquad (5)$$

The above equation is noted the time constant function. The main time constant of the building is then deduced from the negative inverse of the slope of the above curve which is equal to $-1/\tau$.

RESULTS AND DISCUSSION

Heat loss coefficient

To estimate the global heat loss coefficient of the passive house, a heating period of 16 days is used (first period before the transient one). The value of the global heat loss coefficient calculated by the general formula (equation 1) is equal to 76 W/K.

The studied building is a new experimental passive house, for which precise data is available regarding its geometrical, optical and thermal characteristics, so that the global heat loss coefficient obtained by the simple formula can be considered as a reference value.

The energy signature using the hourly data is depicted on Figure 3, while the one using daily data is shown in Figure 4. The energy consumption is plotted against the outdoor air temperature. We plan to refine the energy signature by considering the solar radiation. The global heat loss coefficient is deduced from the slope of this curve. Hourly data does not allow the estimation of this coefficient because of a too large dispersion. The daily energy signature provides a value of the global heat loss coefficient equal to 92 W/K. This latter is 20% higher than the reference value of 76W/K obtained from the simple formula.

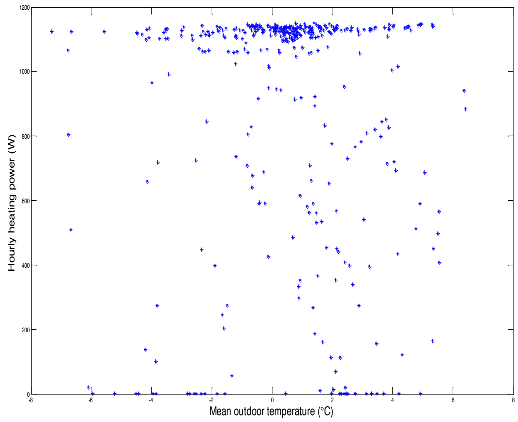

Figure 3 Energy consumption versus outside air temperature using hourly data

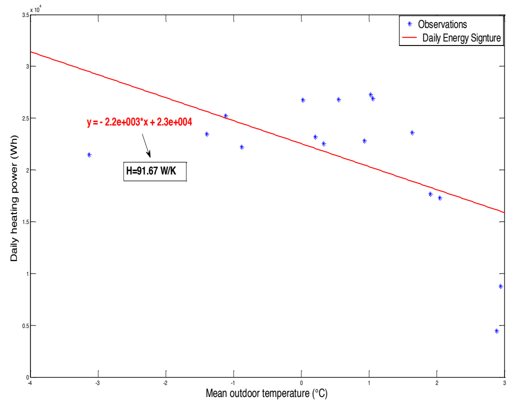

Figure 4 Energy consumption versus outside air temperature using daily data

We propose to determine the value of the global heat loss coefficient based only on measurement data during the night. This was chosen in order to minimize the perturbation in the thermal behavior of the building envelope due to the solar radiation. It provides a value of H = 82 (W / K). This value is 7% higher than the reference one.

We can confirm that the energy signature is a simple way to calculate the global heat loss coefficient but it is more precise if a longer period of data is used.

Main time constant

Concerning the main time constant of the experimental passive house three methods have been compared in this study. The first one is based upon the simplified method given above. The second one concerns the identification method using a black box model and the third one is the identification method using the dynamic thermal model. The considered data correspond to the measured data during the transient period (without heating source for 10 days).

The characteristics of the studied building are well known and the dynamic thermal model represents its main physical phenomena. We can therefore consider that the reference value of the main time constant is given by the identification method using the dynamic thermal model. It is equal to 245 (h).

Figure 5 shows the curve of the time constant function of the experimental passive house (equation 5). The value of the main time constant deduced from this curve is equal to 303 h. Comparing this value with the reference one, we note that the simplified method overestimates the thermal mass of the passive house. It is 25% higher than the reference value.

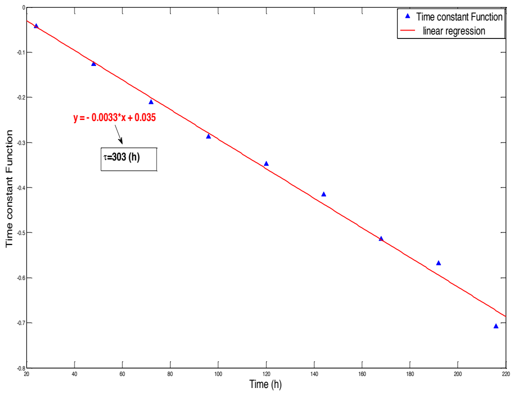

Figure 5 Time constant Function curve (simplified method)

The second method tested to evaluate the thermal mass in the passive house is the identification method. Since the simulated model has been validated, the next step in the identification procedure is to estimate the thermal characteristics. The selected model is the order 3 model. Simulated and measured indoor air temperatures are represented in Figure 6. We conclude that there is a quite good agreement between the measured and the simulated temperatures. The identified value of the main time constant is equal to 208 h which is close to the reference value. This means that in this case study the estimated model provides an appropriate description of the thermal mass of the passive house.

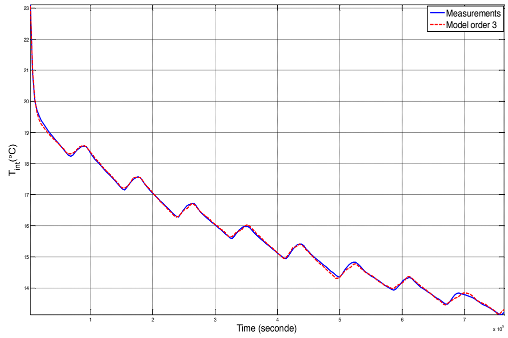

Figure 6 Comparison between measured and simulated indoor air temperatures (Measurements/black box model)

Both the simplified method and the identification method have been tested by varying the number of considered days. The obtained results are summarized in Table 2. The results corresponding to the estimated value of the main time constant from the simplified method are noted τ_{curve} and from the identification method are noted τ_{ident}.

We note that only over a period of 5 days, the simplified method is able to estimate a time constant close to the reference value, while the simulation with the identified model gives a value closer to the reference one only using the data corresponding to the whole period. For a few days data, the estimated value does not reflect the thermal behavior of the building. This later result confirms that identified models are generally more accurate if a period longer than 5 days is used.

Table 2
Estimated values of the main time constant of the passive house

Considered period		$\tau_{curve}(h)$	$\tau_{ident}(h)$ **(BBM)**
Unheated period	whole period	303	0.30 3.23 208
	Fisrt week (5 days)	263	0.86 1.17 176.83
	Second week (last 5 days)	250	1.80 585.37 604.94

CONCLUSION

There are many different methods and models for the analysis of energy use in existing buildings. No single one is universally the best. Rather the choice in a given situation depends on what one wants to calculate and which input data is available [Rabl, 1988]. In this paper, we have presented a comparison between different methods allowing the estimation of the global heat loss coefficient and the main time constant of a monitored experimental passive house.

Simplified methods are usually not the most appropriate to evaluate the energy performance of a low energy building. In fact, we have shown that the simplified method of calculating the main time constant of a building is very sensitive to the variation of the time period and it is only valid for an unheated period.

Regarding the energy signature, the important problem in applying this method is that on short time intervals the data may be less correlated due to the influence of random like the ventilation rates and solar gains [Ghiaus, 2006]. For this method we must have a long time period of monitoring data.

The steady state formula can provide a suitable estimation of the global heat loss coefficient only when the building is new and well known. However, it may not be feasible for existing buildings because detailed data on physical properties and geometrical characteristics are often not available or uncertain.

The identification method was also very sensitive to the variation of the used short time period. We can obtain a good fit between simulation and measurements even with wrong parameters. This is why we should have a sufficiently long time period of measured data to use the identification procedure. Hence, monitoring the building becomes crucial for a more precise assessment of the energy performance.

As a further research, it will be important to evaluate the effect of parameter uncertainty on the reliability of the dynamic thermal model.

NOMENCLATURE

BBM = black box model
H = global heat loss coefficient [W/K]
τ = main time constant [h]
U = heat loss coefficient throught the element i (doors, windows and walls) in [W/m^2.K].
A_i = surface of the element I in [m^2].
$\dot{v}$ = air flow rate in [m^3/h]
ψ_i = *heat* loss coefficient per unit length in [W/m.K] and
L is its corresponding length in [m].
$C_{ventilation}$ = specific heat capacity of the air in [Wh/m^3.K]
C = the apparent heat capacity of the building [Wh/m^3.K]
Q_{sol} = solar gain [W]
Q_{int} = internal gain including the heating sources inside the building (e.g. domestic appliances) [W]
T_{int} = indoor air temperature [°C]
T_{out} = the outdoor air temperature [°C]

Tin = initial indoor temperature [°C]

t = time [h]

a = constant (slope of the time constant fuction curve)

b = constant

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