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Dynamic integrated method based on regression and averages, applied to estimate the thermal parameters of a room in an occupied office building in Madrid

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ABSTRACT

A room facing north in a fully monitored office building located in Madrid (Spain) has been studied. Data corresponding to a period of more than two years, recorded while the building was regularly used, have been employed.

A regression analysis method based on averages has been applied. Although the used equation is analogous to the steady state, dynamic features of the test have been considered. A dynamic energy balance equation is first stated. Then this equation is integrated for a time interval long enough to make the accumulation term much lower than the other terms. Finally averages are used to estimate integrals. The minimum integration period that allows this simplification has been identified, studying integration periods from 1 to 20 days.

It is concluded that integration period and variables needed depend on test conditions and the building. Daily averages are insufficient for this analysis in these test conditions. Heat supplied by the HVAC system was modelled avoiding flow measurements. Suggested terms including occupancy and door status improve the model remarkably. A spread in the Overall Heat Transmission Coefficient (UA) estimated under 10%, was found for a 7-day integration period. This narrow interval allows to hand this parameter as intrinsic.

1. Introduction

The high energy consumption for heating and cooling of buildings is one of the current main problems of the energy sector and has an important environmental impact. This sector has a high saving potential taking into account the implementation of passive saving strategies since the early stages of design and also combined with solar systems for heating and cooling. For this reason a growing interest to promote energy efficiency in the building sector has led to several European Directives [1] and progressive implementation of regulations related to this topic. It has also pointed to the necessity of increasing the knowledge of buildings and constructive systems and has pushed research activities in this field.

In the field of regulation, the "Código Técnico de la Edificación (CTE, Ref. [2])" has been approved in Spain. This is the Spanish regulation for thermal conditions in buildings and is "the regulation framework that established the basic quality criteria that buildings must conform to, including their installations, to satisfy the basic requirements about safety and habitability" as implementation of the Spanish building law (LOE, 1999) 38/1999. The CTE includes a basic document on energy saving HE, and the document HE1 about limitation of energy demand.

The criteria given by the CTE represents an important step forward regarding the regulations about energy quality and energy savings in heating and cooling of buildings. However these criteria are based on simplified simulations and theoretical calculations using design values, and sometimes incorporate high uncertainties. Sometimes these tools do not allow the user to take into account some of the passive systems that are most useful regarding energy saving and consequently they do not allow the user to quantify these savings.

Thermal performance of buildings usually depends on the interaction of complex physical processes and their simplified analysis or analysis under unreal conditions can lead to uncertainties in the results. The inclusion of thermal evaluation based on testing can significantly contribute to solving problems caused by simplified analysis and also to improving the certification criteria for energy efficiency of buildings. Dynamic data analysis methods based on

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Nomenclature

A	area of the tested building component, m^2
C	effective heat capacity of the test room, J/K
d	integer representing the day of the year, –
D	status of the door: $D = 1$ if door is closed and $D = 0$ is door is not closed, –
g	Solar energy transmittance, –
G_h	global horizontal solar radiation, W/m^2
G_d	diffuse solar radiation, W/m^2
$\dot{m}_c$	water flow in the cooling pipe of the HVAC system, l/min
$\dot{m}_h$	water flow in the heating pipe of the HVAC system, l/min
N_c	integer associated to intervals of temperature difference between inlet and outlet water in the cooling pipe of HVAC system, –
N_h	integer associated to intervals of temperature difference between inlet and outlet water in the heating pipe of HVAC system, –
N_a	integer associated to intervals of temperature difference between air in the room and air supplied by the HVAC system, –
N_p	number of occupants in the room, –
N_d	$N_d = 1$ if G_h is higher than the threshold and $N_d = 0$ if G_h is below the threshold, –
P_{Aux}	electric active power consumed by all devices in the room (computers and lights), W
$P_{HVAC+Aux}$	power supplied by the HVAC system added to P_{Aux}, W
P_{people}	power supplied to the room due to the metabolic activity of the users, W
$P_{leakage}$	power losses of the room due to air leakage, W
P_p	status of occupancy: $P_p = 1$ if room is occupied and $P_p = 0$ if room is empty, –
T_e	outdoor air temperature, °C
T_i	indoor air temperature of the studied room, °C
T_j	indoor air temperature of any adjacent room j, °C
ΔT_{ie}	Temperature difference between indoor and outdoor air, °C
$\Delta T_{c_{io}}$	temperature difference between inlet and outlet water in the cooling pipe of the HVAC system, °C
$\Delta T_{h_{io}}$	temperature difference between inlet and outlet water in the heating pipe of the HVAC system, °C
ΔT_{AC}	temperature difference between the air in the room and air supplied by the HVAC system, °C
ΔT_{i_hall}	temperature difference between the air in the room and air in the hall, °C
U	heat transmission coefficient, $Wm^{-2} K^{-1}$
v	air velocity in the duct of the HVAC system supplying air to the room, m/s
W	wind speed, m/s
Y	number of days of the year, –

system identification techniques can be applied to thermal characterisation of buildings. In this sense, this research line is very promising, and it could help to develop empirical models that may be used to quantify the energy savings achieved with passive solar building components.

The interest in thermal performance analysis of building components and whole buildings based on Dynamic Full Scale Testing has increased recently, and several activities in this field of research are in progress [3,4].

There is a wide variety of approaches to dynamic analysis all of which have different levels of complexity and accuracy, and need prior system modelling and system identification to obtain the required parameters [5]. Some of these approaches have been applied to estimate the thermal properties of real buildings [6,7], building components using in situ measurements [8], and to find their U and g values from outdoor test cells ([9], etc.). Generally, according to the purpose and characteristics of the test and also on the characteristics of the test object, applied analysis is chosen ranging from averaging methods to dynamic approaches.

Averaging methods were widely used in the past. These average methods applied to the thermal analysis of real size building components tested under dynamic outdoor weather conditions allow the application of steady-state equations which significantly simplify analysis. However these methods are valid provided that some hypotheses are satisfied. The conditions under which average methods are valid to obtain the U value of building components from in situ tests are mentioned in Ref. [8]. These conditions limit the applicability of this method usually leading to a very long period of testing.

Ref. [10] reports on the application of multiple regression using daily averages to the energy performance analysis of 10 single family houses located in different European countries. The results showed higher inaccuracy in mild weather locations, mainly in Spain.

In some works, a first order correction is mentioned as an alternative to solving some of the problems related to the application of linear regression method based on averages to dynamic tests of building components, leading to pseudodynamic models although dynamic methods are indicated as more appropriate for such applications [11]. Ref. [12] proposed a pseudodynamic analysis tool based on multiple regression using daily averages to estimate the energy performance parameters of dwellings.

Ref. [13] reports on the study of the errors in the U-value estimates for different walls, using the steady-state equation and simulated measurements under dynamic conditions. This study is done for instantaneous measurements as well as considering integrals. It concludes that instantaneous measurements cannot provide accurate estimates of the U-values but its accuracy is significantly improved if time integrated variables are used. It is also shown that the error in the U-value estimation is minimised by using a multiple of 24 h as the integration period. It affirms that the minimum valid integration period depends on the characteristics of the wall and weather conditions. It also demonstrates that longer integration periods are required when temperature fluctuations are higher, temperature difference between indoors and outdoors are lower and walls are heavier.

Steady-state equations using daily averages are also used in coheating tests to obtain the heat loss coefficient of full size buildings from field measurements [14]. These tests are carried out in empty buildings, in the heating season, setting a constant indoor air temperature (typically 25 °C), and using electric heaters. Although this methodology is not a new concept, it is currently the subject of much research and debate.

Dynamic methods are very useful for overcoming some of the problems arising when average and linear regression methods are applied. The activity carried out in the European PASLINK Group in empirical test procedures for different types of building components under real weather conditions with the application of dynamic analyses based on system identification techniques is highlighted [15].

Traditionally, these dynamic methods have taken into consideration linear models with linear and time invariant parameters. Recent studies have shown the flexibility and usefulness of dynamic nonlinear models, particularly for dealing with problems related to warm sunny weather [16]. Nonlinear models have successfully