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New thermal parameters identification approach applied to the thermal renovation of buildings

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ABSTRACT

In this article, a new technique for identification of the thermal parameters of simplified mathematical model for an existing building is presented. This thermal simulation model allows the performance analysis of a building. The model is based on the electrical analogue with resistances and capacitors (RC) used for the simulation of the unsteady heat flow in the building. The model is validated with the results of a TRNSYS simulation. The obtained accuracy lies within a 7% interval. This tool is then used in an inverse method in order to determine the value of the electrical (RC) equivalent thermo physical characteristics of the building envelope. The model for the determination is based upon the least squares method, between the indoor measured temperatures and the model response, using an inverse iterative algorithm (Reflective Newton).

1. Introduction

If we would like to raise the building performance, with respect to energy consumption and energy management, to the next level, a new way to determine the thermal characteristics of a building will be essential. These characteristics involve the thermal characteristics of the walls, the thermal load, the air in- and exfiltration, to name but a few.

During the last years, researchers have delivered a notable effort to achieve this. In this perspective, the numerical codes are beyond any doubt the most powerful tools to perform a rapid analysis to study the thermal performance of buildings.

The thermal response of a building is often represented by a series of electrical elements (resistances and capacitors) using the electrical analogue [1,2]. Although theoretically it was possible to provide a complete and accurate description of the building and the appropriate boundary conditions, in practice this would be not feasible. The question that arises is about the best way to describe the building adequately with a minimum number of components.

Antonopoulos and Koronaki [3] characterized the dynamic behaviour of a building using a virtual and effective capacitance. Other researchers have shown the role of the position of the insulation layer upon the dynamic thermal behaviour of the buildings (Asan [4,5] and Bojic and Loveday [6]). The latter have analyzed the influence of the order insulation/brick in a three-layer wall upon the consumption of energy for heating and air conditioning.

The importance of the thermal inertia has been studied at length and is well documented in the literature. Balaras [7] has stressed the role of the thermal inertia upon the heat and cooling load of a building. He gives in his contribution a large overview and a classification of the simulation tools allowing the calculation of the thermal load and the indoor temperature, taking into account the thermal inertia. Asan and Sancaktar [8] have shown the impact of the thermophysical properties of the walls on the phase shift and the damping of the thermal front.

Numerous works deal with the optimal insulation and thermal characteristics of the building envelope. Mahlia et al. [10] have established a correlation about the optimization of the insulating layer and its the thermal conductivity using a second order polynomial. Comakli and Yuksel [11] have determined the optimum thickness of the insulating layer in an exterior wall based upon the whole life cycle of a building in the coldest cities of Turkey. Al-Khawaja [12] has determined for each type of insulation matter the best thickness to use in order to minimize the energy consumption in a hot environment. With a dynamic thermal simulation modelling, Al-Sanea et al. [13] have studied the impact of the electricity pricing upon the insulation layer thickness for a building in Saudi Arabia. Lollini et al. [14] carried out research in order to determine the amount of insulation for new build houses from an energetic, economic and environmental perspective. All those studies focus upon the insulation aspects and ignore the thermal inertia.

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Nomenclature

C	thermal capacity (J/K)
e	thickness (m)
Hi	heat transfer coefficient
Hij	radiative exchange coefficient (WK^{-1})
J	functional error
Q	heat flux (W)
R	thermal resistance ($K\,W^{-1}$)
S	surface (m^2)
t	time (s)
T	temperature (°C)
$\triangle t$	time difference (s)
Greek symbols	
Q	heat flux ($W\,m^{-2}$)
Subscripts and superscripts	
0	outer layer of the building structure
1	inner layer of the building structure
b	ground
bl	blowing rate
c	celestial vault
h	roof
in	internal air
m	wall
p	door
re	recovery rate
s	solar
w	windows

McKinley et al. [15] have presented an optimization process for the thermal parameters of a building (thermal resistance and thermal inertia). The direct model is solved numerically, and the optimization is performed through the “Reflective-Newton” algorithm. The Reflective-Newton method is a deterministic method and allows to define the global minimum in an iterative optimization procedure. The method is well described in Refs. [21,22]; it was used successfully in Refs. [23,25]. For the present effort, the unmodified method is applied in the built environment.

The direct model is solved numerically while the optimization is done with the Matlab “Reflective-Newton” function available in a MATLAB toolbox.

Sambou et al. [16] have developed a model based upon the method of the thermal quadripoles coupled with a multi-objective evolutionary genetic algorithm. The purpose of their work was to find a compromise between the thermal insulation and the thermal inertia of a wall. The solutions are presented using a Pareto Front (which is a collection of non-dominant solutions: no solution is systematically inferior to the others for all criteria).

In the eighties of the past century, the European Commission had launched a project named PASSYS [17]. A part of this project consisted in setting up test cells in several countries. The test cell was an instrumented small building located outdoor. One could swiftly alter the south facade: for example, either a standard front panel with a window, or a facade with veranda appended, or a facade with transparent insulation from the outside, to cite but a few. For the work described in Ref. [18], a full-scale test cell build around a wooden frame, for the validation of thermos-hygro-aeraulic tools was conceived. Olivier [19] transformed a test building into an experimental platform, where one could simulate various occupation schemes in order to test the controllers of different hybrid ventilation system components. A numerical model on the basis of this experimental platform has been developed and has allowed, after validation, a rapid assessment of multiple control strategies multi-source and multi-zonal. Ulgen [9] on the other hand made a theoretical and experimental study of the effect of these properties on the phase shift and damping of the thermal response of the building. He suggests using multilayer walls including year insulation layer for buildings that are occupied all day long while mono layer walls are more suited for buildings that are only occupied during limited time intervals.

The goal of this work is to identify some thermal parameters able to describe the overall thermal response of the building. Those thermal parameters are translated into capacities and resistances since the used tool is based upon the well-known electrical analogy. Input data and control data are obtained via TRNSYS. Indeed in TRNSYS we identify the different layers of the envelope and calculate the temperature evolution in the thermal zones over a long period (e.g. a year). The composition of the walls allows also to calculate the electrical analogy as shown in Fig. 2. After this initial procedure, this work can start. Using the temperature evolution and a simplified thermal model, coupled with an inverse methodology, the electrical elements (resistances and capacitances) are determined: and from there the thermal characteristics of the wall can be evaluated. The simplified thermal model takes into account the boundary conditions such as indoor (zone) temperature, outdoor temperature, solar radiation, the internal gains (heating, occupation, lightening) to name but a few. The iterative solution procedure uses the Reflective-Newton approach to speed up the calculations (a typical calculation on a modern PC takes between 15 and 90 s). This approach has been successfully applied to different models of the building (simplified and mono zone) and for different layouts (percentage of fenestration, resistance and thermal inertia of the building envelope). The calculated characteristics are verified against the TRNSYS input data.

To validate this parameter identification process, two experimental configurations equipped with monitoring devices, have been retained. The results of those efforts show a fairly good match between the identified calculated values and those measured: the difference between both of them does not exceed 21%.

The primary motivation is to create a simplified model, allowing to obtain the thermal response of the building swiftly and estimate the thermal characteristics quickly. With such a model, it should be possible to optimize the control of the thermal environment.

2. Direct model

2.1. Thermal model (TM): electrical analogue

The layout of the dynamic thermal simulation model is presented in Figs. 1 and 2. The model is based upon the thermal balance of a zone where the temperature is uniform. For an efficient numerical model, the exterior walls, the ceiling, windows and doors are grouped. The proposed electrical analogue of the thermal model is composed of thermal resistances and thermal capacities. The internal heat gain is delivered directly at the internal temperature T_{in}. A thermal capacity, representing the thermal inertia of the air and the internal walls, is associated by a capacitor C_{in}. The temperature of the air is linked to the outdoor air temperature T_0 via three transfer modes. Different heat transfer coefficients allow modelling the thermal transfers: e.g. for the ventilation H_{bl} (blow) and H_{re} reuse, another value is used to model the conduction through the exterior walls (opaque) and similarly for the radiation through the transparent parts of the walls. The conductive exchange through the windows and doors are represented by two distinct conductances (H_w and H_p). This is an analogue model with one resistance (type 1R). The conductive exchange within the external walls, the ceiling and floor are considered to be in a transient regime. We