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Setting up and validating a complex model for a simple homogeneous wall

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ABSTRACT

The present paper describes modelling of the thermal dynamics of a real wall tested in dynamic outdoor weather conditions, to identify all the parameters needed for its characterisation. Specifically, the *U* value, absorptance and effective heat capacity are estimated for the wall using grey-box modelling based on statistical methods and known physical dynamic energy balance equations, related to the heat flux density through a simple and homogeneous wall. The experimental test was carried out in a hot-temperature climate for nine months. This study aims at proposing a dynamic method improving the regression averages method for estimation of parameters which describe the thermal behaviour of the wall. Solar irradiance and long-wave radiation balance terms are added in the heat balance equation besides modelling of wind speed effect to achieve a complete description of the relevant phenomena which affect the thermal dynamics of the wall. The method is applied using different frequency data samples looking for the best to study this wall. The *U* value obtained characterising the wall is consistent with the one given by the regression averages method.

1. Introduction

There is a growing need in our society to evaluate and quantify thermal properties of the buildings and their components, to save energy and to develop better ways to characterise them. The aim is to increase comfort conditions, reduce the energy consumption and enable buildings to become interactive components in an energy system increasingly based on renewable energy production.

In a previous study a linear regression method based on averages was used to evaluate thermal properties of the same simple opaque and homogeneous wall [1]. The wall is part of a test cell, and it is tested under real weather conditions [2–4]. This method can be applied to buildings and buildings components. Its main drawback is that it requires long test periods depending on the test component and weather conditions, and in some cases may become too much time consuming or leading to unaffordable long test campaigns. Thus, previous work gave a reference regarding the *U* value estimates that can be used as additional validation criteria, and regarding accuracy, length of test, needed variables, etc., to evaluate the improvements achieved when another method is used.

This paper applies techniques based on modelling the dynamics of the system which are also able to describe non-linear effects. Grey box modelling using stochastic differential equations (SDEs) [5], is applied for estimation of *U* value, and it is also used to estimate absorptance and effective heat capacity, which were not able to be estimated when averages were used to characterise thermal performance of the wall [1]. Parameters obtained with the SDE models based on energy balance equations are employed for identifying these physical parameters [6].

Different experiments applying this modelling approach have been studied. From the thermal characterisation of building components using outdoors test cells [7], over the modelling of building integrated photovoltaic modules [8,9], and to the analysis of full size buildings [10].

Dynamic modelling in the present study [11], considers a different experiment and SDEs regarding previous works using data for a significantly longer test period to have a better description [6,7]. Furthermore, it considers a more detailed description for surface effects allowing the capability to take into account these effects in this analysis approach, giving a very valuable background for further studies on building systems.

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Nomenclature

Measured quantities

T_e	outdoor air ambient temperature (K)
T_i	test room indoor air ambient temperature (K)
T_{se}	external surface temperature (K)
Q_i	heat flux density through the building component (W/m^2)
G_v	global vertical solar irradiance (W/m^2)
G_{lw}	vertical long wave irradiance (W/m^2)
w	wind speed on the wall (m/s)

Non-measured quantities

T_{sky}	sky temperature (K)
T_{ground}	ground temperature (K)
T_{sg}	surroundings temperature (K)

Parameters

U	total heat transfer coefficient of the wall (W/m^2 K)
g	solar energy transmittance
$C_{1,2}$	effective heat capacities of part of the test component per unit surface (W min/m^2 K)
C	effective heat capacity of the test component per unit of surface (J/K)
α, ϵ	wall absorptance and emittance
$U_{1,2,3}$	heat transfer coefficients of part of the wall (W/m^2 K)
h_{se}, h_{si}	external and internal surface heat transfer coefficient (W/m^2 K)
h_{ce}, h_{re}	external surface convective and radiative heat transfer coefficient (W/m^2 K)
$h_{r,ws}, h_{r,wg}$	external surface radiative heat transfer coefficient wall-sky, and wall-ground (W/m^2 K)
$h_{r,wsg}$	external surface radiative heat transfer coefficient wall-surroundings (W/m^2 K)

Constants

F_{ws}, F_{wg}	view factors wall-sky and wall-ground
F_{wsg}	view factor wall-surroundings
σ	Stefan–Boltzmann constant (W/m^2 K^4)

State variables

$T, T_{1,2}$	inside wall temperatures (K)

The text is organised as follows: in Section 2 the test component is described. In Section 3 the experiment set up is presented. Data used for the analysis are presented and discussed in Section 4. In Section 5 the methodology is presented. Finally, the results are outlined and discussed in Section 6 and the conclusions are drawn in Section 7.

2. Test component description

The data used in this paper stems from a test of a simple lightweight, opaque and homogeneous wall [12].

This wall is made of ceramic bricks which size is 32 cm × 16 cm × 11.5 cm, joined using sand and concrete mortar, Fig. 1. Exterior is plastered with mortar, 2 cm thick. Interior is gypsum plastered 1.5 cm thick. The wall total thickness is 15 cm made of 2 cm mortar, 11.5 cm brick and 1.5 cm gypsum.

The interior surface of the wall is 276 cm height by 298 cm width.

Fig. 1. Exterior view of the wall tested.

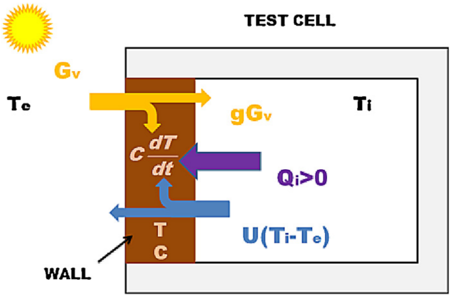

Fig. 2. Test cell scheme.

3. Experiment set up

3.1. Boundary conditions

This wall was tested in a test cell, Fig. 2, at the LECE laboratory at Plataforma Solar de Almeria,[1] in the South East of Spain (37.1° N, 2.4° W). The weather at this test location is dry and extremely hot in summer and cold in winter. The temperature difference varies considerably between day and night. Daily global vertical solar irradiation is significantly higher in winter, 22 MJ/m^2, than in summer, 12 MJ/m^2, for sunny days.[2] The sky is usually very clear.

The test was carried out under outdoor weather conditions. Set point for indoor air temperature is about 18 °C in summer and 40 °C in winter. A ventilator was used to avoid indoor air temperature stratification.

3.2. Measurements

This section describes the measurement equipment and relevant information regarding the measurement accuracy [7].

The following list summarizes the used measurement transducers and sensors, Fig. 3:

- Air temperature (T_e, T_i[°C]): Platinum thermoresistance, PT100, 1/10 DIN, directly measured using a four-wire connection, with a solar radiation shield and ventilated for outdoor measurements. Accuracy 0.1 °C.
- Surface temperature (T_{se}[°C]): Analogous sensors and connections as those used for air temperature, in this case embedded in the corresponding surface. Accuracy 0.1 °C.

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[1] http://www.psa.es/webeng/instalaciones/lece.php#lece.

[2] Source: PSA-LECE Laboratory.