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A daily baseline model based on transfer functions for the verification of energy saving. A case study of the administration room at the Palacio de la Madraza, Granada

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HIGHLIGHTS

- The study developed methodology to obtain energy consumption baseline for buildings.
- Proposed energy baseline is the combination of two inverse characterisation models.
- Energy consumption and thermal comfort have been considered explicitly.
- The model can be applied to a wide range of buildings, regardless of their use.
- The baseline model was verified by comparing with measured data.

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ABSTRACT

Energy consumption in the building sector presents a high potential for reducing it by means of interventions to improve the energy efficiency of the building and/or its installations. After these interventions, it is necessary to ensure the energy impact expected by measurement and verification of savings protocols.

The energy characterization of the starting situation, which takes place from the baseline, is one of the fundamental pillars of the measuring and verification of savings process. The baseline is necessary to determine the savings made after introducing an improvement measure.

In this regard, researchers have provided various solutions for obtaining it. From the literature review, mathematical models stand out, which require very detailed knowledge of the building or a large amount of training data to get a good adjustment in the results. In addition, these models do not have the capacity to adapt to changes not previously considered in the knowledge base of the model.

The baseline methodology proposed presents a combination of two models based on transfer functions. Both models are easily identifiable with experimental data and minimal monitoring is required to adjust them.

The proposed formulation gives the models the ability to characterize the dynamic effects linked to the thermal inertia of the building and the operating conditions of the building by any variables that there may be. In addition, due to the linking of the coefficients of the models with the building's characteristic energy parameters it is possible to perform quality estimates with different input variables from those used in their calibration.

The proposed methodology has been validated experimentally in a building with the use of HVAC systems, and a very variable level of occupation, with average relative daily errors of less than 10% and a monthly maximum relative error of less than 5% in the estimate of HVAC consumption. In addition, to illustrate the usefulness of the proposed methodology, its possible application has been described.

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Nomenclature

Variable	Description (units)
M&V	measurement and verification of savings (–)
IPMVP	International Performance Measurement and Verification Protocol (–)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers (–)
f(t)	target variable of the transfer function (–)
Y_i	independent variables or excitations of the transfer function (–)
a_{ij}	adjustment coefficients of excitations or numerators of the transfer function (–)
d_k	denominator or dependence of the target variable with past moments (thermal inertia characterization) of the transfer function (–)
k	number of excitations of the transfer function (–)
m	number of numerators of the transfer function (–)
n	number of denominators of the transfer function (–)
CI	integrated HVAC consumption over a period of time (kJ)
T_{INT}	average temperature representative of the air inside the building (°C)
GI	gains inside the building (kJ)
$T_{SA}(z)$	sun-air temperature (°C)
a_i	coefficients associated with the sun-air temperature of the consumption model (kJ/°C)
b_i	coefficients associated with the internal temperature of the consumption model (kJ/°C)
d_i	denominators of the consumption model (–)
e_i	coefficients associated with the sun-air temperature of the internal temperature model when turned off (–)
g_i	coefficients associated with the internal gains of the internal temperature model when turned off (°C/kJ)
	denominators of the internal temperature model when turned off (–)
aa_i	coefficients associated with the temperature of the air outside of the internal temperature model in free running (–)
bb_i	coefficients associated with the solar radiation of the internal temperature model in free running (°C·m^2/kJ)
df_i	denominators of the internal temperature model in free running (–)
T_{EXT}	outside air temperature (°C)
RAD	incident global horizontal irradiance (W/m^2)
k	radiation equivalence parameter at temperature (°C·m^2/kJ)
P_{GI}	parameter associated with the internal sources characteristic of the building (kJ)
V	volume of air of the building to be characterized (m^3)
ρ	density of the internal air. Takes a value of (1.18 kg/m^3)
C_P	specific heat of the air. Takes a value of 1. (kJ/kg·K)

1. Introduction

1.1. Background

Energy is the driver and a fundamental requirement for social and economic development. Since the Industrial Revolution, global energy consumption has not ceased increasing. Today, the use of this energy is linked to lifestyle, the more developed a society is, the more power it consumes. Which is why, during the last twenty years the demand for energy products has increased at a rate of 3% per annum globally [1].

This leads to thinking about the current energy situation, where the building sector in the European Union represents 40% of primary energy consumption and 36% of CO2 emissions [1]. Approximately 70% of consumption in buildings for residential use occurs in internal air conditioning areas [2], far exceeding lighting and other uses. The European Commission is seeking more sustainable and efficient HVAC systems for buildings and therefore is focusing its objective on the refurbishment of the stock of existing buildings. These constitute the largest potential for energy savings in the building sector, crucial for achieving the European Union's objective to reduce greenhouse gas emissions by 2050 to between 80% and 95% of the levels produced in 1990 [3].

In Europe, the average energy consumption for heating residential buildings is 200 kWh/m^2, which varies according to the climate [4], environmental factors, the building's characteristics, use [5] and the economic level of the occupants [6]. The future objective is to lower it to 50 kWh/m^2 [7], making qualitative renovations of the stock of existing buildings necessary to increase their sustainability, both in terms of operation and maintenance, considering criteria of energy efficiency, environmental impact, cost-efficiency, comfort and life cycle [8].

Spain's action plan by 2050 proposes refurbishing 10 million main dwellings built before 2001, which will become highly-efficient, more comfortable homes with low greenhouse gas emissions and with a higher economic value [9,10].

1.2. Measurement and verification (M&V)

A critical problem for existing buildings is assessing the energy savings when any improvements are made to them. This process is known as M&V (Measurement and Verification of savings) [11], which is illustrated in Fig. 1.

The chain that makes up the measurement and verification of savings can be summarized in four stages: 1-measure the starting situation for its energy characterization (baseline model); 2-assess the various

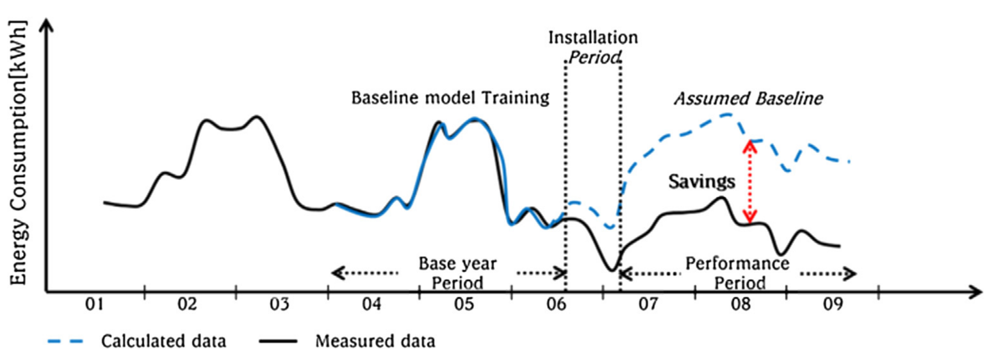

Fig. 1. Baseline concept [33].