Energy and Buildings 119 (2016) 256–266

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# In-use office building energy characterization through basic monitoring and modelling

A. Erkoreka*, E. Garcia, K. Martin, J. Teres-Zubiaga, L. Del Portillo

*ENEDI Research Group, Department of Thermal Engineering, University of the Basque Country (UPV/EHU), Alda. Urquijo s/n, 48013 Bilbao, Spain*

ARTICLE INFO

*Article history:*
Received 21 October 2015
Received in revised form 18 February 2016
Accepted 11 March 2016
Available online 15 March 2016

*Keywords:*
ISO 9869
Co-heating
In-use office buildings
Heat Loss Coefficient
Solar aperture
Building Key Performance Indicators

ABSTRACT

Due to the European Union energy reduction strategy, many in-use buildings will be energetically monitored in the coming years to obtain their main thermal characteristics to improve or prove their energy efficiency. This is difficult to do with a reduced set of sensors and a robust data analysis methodology. This paper is focused on proposing some modifications on the existing ISO 9869 method and co-heating method to make them usable with basic energy monitoring data of in-use buildings and obtain their main thermal characteristics: the Heat Loss Coefficient (HLC considers heat losses through envelope plus infiltration) and the solar aperture ($S_a$ or gA-value) of the whole building.

Under the FP7 project A2PBEER an occupied big office building has been energetically monitored. This monitoring system has been designed and installed while the building was in operation. Using this monitored data a modified ISO 9869 method has been applied to some specifically selected cloudy and cold winter periods to obtain the HLC of the building. Taking this HLC as a reference, a modified co-heating method has been used to estimate both the HLC again and the $S_a$ of the whole building. Although monitoring was carried out under very difficult conditions since the building was occupied, the proposed modifications on those two existing methods have delivered very reliable results with these two Key Performance Indicators (HLC and $S_a$) of the building under real operation conditions.



## 1. Introduction

According to the European Commission, buildings are responsible for the 40% of energy consumption in Europe. The goal proposed by the EU is decarbonisation in Europe by 2050 by reducing its $CO_2$ emissions by 80% and energy consumption by 50%. Bearing this goal in mind, one of the central aspects to deal with is reducing the energy consumption of buildings. Most of the buildings in Europe (both residential and tertiary buildings) have been constructed without considering the energy efficiency of the building as a main issue. This has two consequences: on the one hand, most buildings are very inefficient, and on the other hand, the real energy consumption of the buildings differ by up to 100% [1,2] compared to the design case. This is why, searching for performance indicators and monitoring techniques for energy-efficiency of occupied buildings is a priority nowadays. Thus, in the coming years, harmonised protocols supporting tools and systems to characterize the performance in real operational conditions will be developed. This is the main scope and innovation of this paper since two existing methods, the ISO 9869 and co-heating method, are modified to make them usable with data sets monitored on buildings operating under real conditions to obtain their main two thermal Key Performance Indicators (KPI): the in-use Heat Loss Coefficient (HLC) and the in-use solar aperture ($S_a$).

There are currently several groups involved in whole building modelling based on monitored data using advanced mathematical modelling techniques such as state-space modelling [3–6], ARMAX modelling [7,8] or RC modelling [9,10], which usually need for very specialized testing procedures such as the PRBS [3] and ROLBS [11]

*Abbreviations: HLC (Heat Loss Coefficient)*, considers the whole building heat losses through envelope plus infiltration per degree difference between indoors and outdoors temperature. HLC = UA + $C_v$ [kW/ºC]; $C_v$, infiltration and/or uncontrolled ventilation heat losses coefficient [kW/ °C]; $H_{sol}$, horizontal global solar radiation [W/m$^2$] or [kW/m$^2$]; *K*, all the other heat gains inside the building (illumination, all other electrical devices consumption and heat gains due to people, solar gains and Q not included) [kW]; *KPI*, Key Performance Indicator, in this work referring to HLC and $S_a$; Q, all heating and ventilating systems energy inputs inside the building [kW]; $q_{i,s}$, heat flux density through the opaque building component, measured usually in the interior surface [W/m$^2$]; $S_a$ *(Solar aperture)*, south vertical perfectly transparent surface, which lets coming in the same solar radiative energy as the whole building referred to the south vertical global solar radiation. Units [m$^2$]; $T_i$, indoor temperature [ºC]; $T_o$, outdoor temperature [°C]; *UA*, whole building envelope heat transfer coefficient [kW/°C]; $V_{sol}$, south vertical global solar radiation [kW/m$^2$]; $\Delta T = T_i - T_o$, air to air inside to outside temperature difference [°C].

* Corresponding author.
*E-mail address:* Aitor.Erkoreka@ehu.eus (A. Erkoreka).

http://dx.doi.org/10.1016/j.enbuild.2016.03.030
0378-7788/

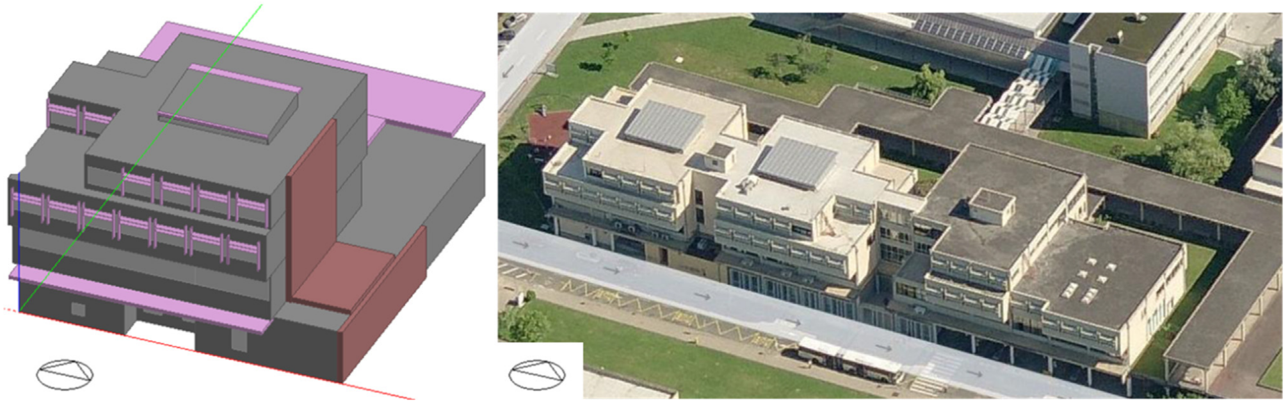

**Fig. 1.** South façade of the whole building (right). Drawings of the monitored west block (left).

heating or cooling test sequences. These test sequences will provide uncorrelated data signals between interior and exterior conditions that are suitable for these data treatment and data analysis techniques. Of course, these testing procedures require the building to be emptied. If not emptied, building heating sequences are usually correlated with the exterior temperature and makes identification procedure harder as discussed by [6]. Some of these techniques (i.e. ARMAX modelling [7,8]) do not directly identify physical parameters such as the UA, HLC or $S_a$ value, they identify some parameters that during the post-processing can be used to estimate those physical parameters after some complex transformations. Sometimes, if the order of the model is not correctly chosen [3,6], illogical parameter estimations without physical meaning (i.e. negative solar apertures or transmittances) might be obtained. As it can be checked in [6] and [3], the model order selection is a complex process requiring specialized professionals to carry it out for each of the analysed buildings. The chosen two methods can be easily understood and applied by non professionals in stochastic mathematics. Furthermore, the proposed methods do not lose the physical meaning of the estimates during the calculating process.

The proposed methods provide simpler characterization techniques but these present other limitations. Specifically, the ISO 9869 and co-heating methods are simpler but also require the building to be unoccupied for monitoring. The ISO 9869 'In-situ measurement of thermal resistance and thermal transmittance' is a standardized method focused on testing building components' thermal transmittance, and among others [12–15], has successfully used the ISO 9869 to make in-situ measurements of building components thermal transmittance (U value); although these tests have been developed in-situ, they have been carried out in unoccupied buildings.

The co-heating method [16] is a step forward on the ISO 9869 and under some very strict conditions [17], it is able to obtain the building Heal Loss Coefficient (HLC) in [kW/°C] and the solar aperture ($S_a$) [$m^2$] of the building. Most of the study cases on the co-heating method have been focused on unoccupied residential buildings such as [18–20]. The main drawback of this method is that it requires the building to be emptied for the thermal study for at least 3 winter weeks.

This paper will focussed on the ISO 9869 and co-heating method and proposes some additional modifications that allow using them to obtain the two main thermal characteristics of occupied buildings using a reduced set of sensors, namely: the whole building Heat Loss Coefficient (HLC) and solar aperture ($S_a$). None of these methods have been developed for use in, 'in-use' dynamic conditions, but the proposed modifications allow obtaining accurate results with energy monitoring data from an in-use office building. A set of real building monitored data will be used to test the proposed modified methods to estimate the aforementioned KPIs of an occupied building considering in them the building in-use effects.

## 2. Material and method

### 2.1. Description of the building and objectives of the project

The energy characterization presented in this document was carried out in a public building of the University of the Basque Country. It is a complex building made up of three blocks (east, central and west), with four-storeys each. The building has a narrow plant

**Table 1**
Summary of monitoring devices used in the west block of the building.

| Measurement | | Device identification | Accuracy |
|---|---|---|---|
| Energy consumption | Heating system | Calorimeter: Kamstrup Multical 602 + Ultraflow (different diameters) and ZENNER Zelsius (DN20) | ET ± (0.4 + 4/ΔT)% (for the set of sensors) |
| | Lighting system | Power meter: ABB EM/S 3.16.1 (I < 20A)/ABB A41/A43 (I > 20A) | ±2% |
| Indoor Conditions | Brightness Level (lux) | Brightness sensors: Siemens 5WG1 255-4AB12 | – |
| | Air Quality (ppm $CO_2$) | Air quality, Temperature and Humidity Sensor: ARCUS SK04-S8-CO2-TF | ±20 ppm, ±1% Meas. Error |
| | Temperature (°C) | | ±0.5 °C |
| | Relative Humidity (%) | | ±3% RH |
| Outdoors Conditions | Brightness Level (lux) | Weather Station: ELSNER 3595 | – |
| | Temperature (°C) | | ±0.5 °C |
| | Relative Humidity (%) | | ±3% RH |
| | Rain (yes/no) | | – |
| | Wind Speed (m/s) | | ±25% at 0...15 m/s |
| | Global Horizontal Solar Radiation (W/$m^2$) | Pyranometer: ARCUS SK08-GLBS-MES | ±5% |