# Analysis of building energy performance based on sensor data for building retrofitting

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**Abstract:**
The current building stock is responsible for a large part of the final energy consumption in Europe and most of it presents the greatest potential for energy savings. One of the most important steps in the retrofitting process is to understand its pre-retrofitting stage energy performance, and the building energy simulation (BES) models can play a significant role in that sense. In this paper, a building case study has been monitored during a whole year. A methodology has been developed specifically for the pre-processing procedure of the building monitored data. Then, based on the available detailed building drawings, building operational data and the data sets obtained after data calibration, a first approach of a BES model is carried out. In addition, some window samples have been tested in the Laboratory of Building Quality Control of the Basque Government to measure their thermal transmittance. These samples will be introduced in the BES model in future works, to evaluate the reduction in heating demand after the windows replacement. A sensibility analysis of the recorded data justifies their good quality. In consequence, the accumulated heating energy supplied by the boiler reaches a value of 44.05 MWh in the monitored year and the total electric energy consumption is 16.71 MWh.

**Keywords:**
Building energy simulation model; data pre-processing; energy retrofitting; thermal transmittance calculation.

## 1. Introduction

This paper is developed under the scope of the AGORA project, founded by Next Generation EU. The project aims to bring to the market a holistic smart solution capable of promoting more sustainable energy and water consumption from producer to final consumer. The tool developed will be tested in some pilot buildings, such as the Faculty of Nursing and Health Science “Building 2” of the University of Burgos in Spain.

In recent years, building energy simulation (BES) is playing a significant role for designing and optimising buildings, but also for pre-rehabilitation procedures. A high level of accuracy in BES results can only be achieved through optimization of three factors as determined by Waltz [1]: (1) an intimate understanding of the simulation tool; (2) an intimate understanding of the building to be simulated and (3) a careful analysis and critique of output data. In their research, [2] presented a critical review of data-driven methods for BES modelling and their practical applications for improving building performance. The paper focuses on methods based on larger datasets and demonstrates that the insights obtained from big building data can be extremely helpful for enriching the existing knowledge repository regarding building energy modelling. However, [3] determined that due to the complexity of the built environment and the prevalence of large numbers of independent interacting variables, it is difficult to achieve an accurate representation of real-world building operation. The difference between measured and calculated energy consumption is known as the “energy performance gap” and reducing this gap is an important task to provide confidence in the models for evaluating energy efficiency. Therefore, calibrating the BES model by reducing discrepancies between model outputs with measured data is a key process to achieve more accurate and reliable results.

In their work [4] focus on reducing the technical issues which are one of the main causes of the energy performance gap, e.g., poorly adjusted thermal parameters in the envelope, inefficient boiler operation or lack of adjustment in parameters of heat pumps, baseboard radiators or air handling units, etc. As a result of the

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calibration process, they obtained a whole building calibrated BES model that considers the building's envelope behaviour and incorporates into the simulation the detailed behaviour of its HVAC systems.

Other researchers like [5] proposed a systematic feature-selection procedure for developing the BES model which integrates a statistical analysis, apart from building physics and engineering experiences. This includes data pre-processing based on domain knowledge, implementation of filter methods to remove irrelevant and redundant data and feature grouping through wrapper method to search for the best feature set. In the building context, [6] points out that data pre-processing can be very challenging considering the relatively poor data quality and the intrinsic complexity of building operations. A review done by [7] considers existing case studies and methods for calibrating whole building energy models related to measured data. This research describes a systematic, evidence-based methodology to calibrate these models. In terms of data-driven methods, [8] presented a review of data-driven building energy consumption prediction studies with a particular focus on scopes of prediction, data properties and data pre-processing methods used, among others.

A new method was developed by [9] involving dynamic simulation and on-site measurements aiming to evaluate refurbishment solutions for a historical building. The authors demonstrate how a specific calibration of the dynamic model using only indoor temperature measurements can overcome the problem of in situ measurements of thermal parameters (U-values). In this field, there exist some standardized methods to determine the thermal resistance and thermal transmittance of different building components. Several research studies ([10], [11]) have been carried out to analyse and compare different approaches to thermal transmittance measurements, which pay particular attention to the hot box method.

## 2. Objectives

This paper analyses and models the energy performance of a real pilot building based on available sensor data. A specific data pre-processing approach is developed and applied to obtain clean and useful data to interpret and apply into a BES model by using the DesignBuilder software.

The case study is related to an academic in-use building located in Burgos, Spain, described in detail in section 4. The building was retrofitted some years ago and the effect of the windows replacement over the heating demand wants to be tested. In collaboration with the Laboratory of Building Quality Control (LBQC) of the Basque Government, some window samples have been characterized under standard rules. The obtained thermal transmittance of the windows is used to characterize the BES model.

According to [3], an accurate calibration process relies on the importance of occupant behaviour as well as the need for instrumentation to monitor its behaviour. For that reason, as the occupant behaviour is not been currently controlled in the pilot building, the calibration process will be addressed in future work. However, this article describes the first steps to achieve a calibrated BES model.

## 3. Methodology

The methodology described in this section is applied in the case study presented in Section 4, following the similar calibration procedures found in the literature and divided into two main actions:

- On the one hand, the monitored data of the building is acquired and subsequently processed to implement it into a BES model. Therefore, the building has been modelled using the DesignBuilder software to carry out an energy performance simulation.
- On the other hand, a set of window samples were tested in the laboratory and characterized through their performance in a guarded hot box. As a result, the real heat transmission coefficient (U-value) of these windows was accurately determined. The process and samples are described in detail in Section 3.3.

### 3.1. Monitoring system

An advanced monitoring system was installed in the case study building (see Section 4) whose data were available from the 1st of May 2021 to the 31st of May 2022 and have been registered on a sub-hourly basis. Unfortunately, and due to technical problems, not all monitored parameters have been recorded during some time periods, so some blackouts have been identified and discussed in more detail in Section 3.2. Monitored variables are classified into outdoor conditions, indoor conditions, and general consumptions (including lighting and heating consumptions).

- Outdoor conditions gather two measured parameters obtained from the weather station in the adjoining building: outdoor ambient temperature (ºC) and relative humidity (%). These variables are used to calibrate the climate data file for the BES model.
- Indoor conditions are composed of three parameters: indoor temperature (ºC), relative humidity (%) and $CO_2$ concentration (ppm). The monitoring system consists of THERMOKON WRF04-CO2-RH-LON sensors located in each room (see Figure 1). These parameters are used to compare BES results.
- Heating consumption is monitored by a KAMSTRUP MULTICAL 602, which is a thermal energy meter connected to a KAMSTRUP ULTRAFLOW 54 flowmeter monitoring the return water volumetric flow ($m^3/h$). The MULTICAL 602 also receives the monitored temperature of the delivery and return circulating water


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(ºC) via two Pt500. The monitoring system calculates energy based on the EN 1434-1:2007 formula, in which the international temperature scale from 1990 (ITS-90) and the pressure definition of 16 bar is used. The energy calculation can in a simplified way be expressed as indicated in Eq. (1):

$$\mathrm{E_t}[Wh] = \mathrm{V_{wa}}[\mathrm{m}^3] \cdot k_{wa}\left[\frac{Wh}{m^3 \cdot K}\right] \cdot (\theta_{inlet}[K] - \theta_{outlet}[K]) \qquad (1)$$

where k is the thermal coefficient of water which is a function of the properties of the energy-conveying liquid at the relevant temperatures and pressure. The calculated energy is registered in Wh units and expressed as accumulated energy. These parameters are used to compare BES results and to define heating schedules.

- Lighting consumptions are monitored with eight NICO 8101L clamp ammeters that monitor two electrical parameters: current (A) and accumulated electrical energy consumption (Wh). One of them is located in the boiler and the rest are in each room[1]. These parameters are also used to compare BES results, as well as to define lighting schedules.

Figure 1 depicts the sensors installed in the building.

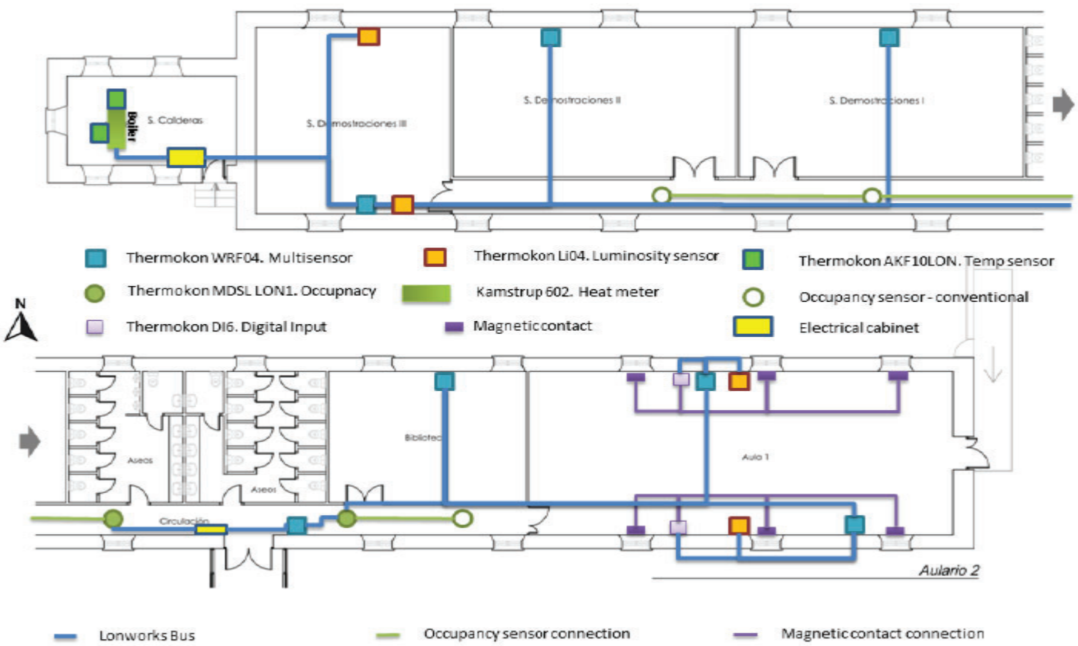


**Figure 1.** Distribution of monitoring devices within the building.

## 3.2. Data analysis

This section describes the initial data calibration procedure after collecting them.

### 3.2.1. Data pre-processing

Data pre-processing is an essential part of any data-driven BES model. This process, according to [12], aims to detect the outliers (i.e., any incorrect or outlier data) that may distort the results. As explained by [8], data pre-processing may include data cleaning, data integration and data transformation.

*3.2.1.1. Data cleaning*

Data cleaning is defined by [8] as the process of detecting and correcting the incomplete, incorrect, inaccurate, irrelevant and/or noisy parts of the data.

To begin with, a specific cleaning procedure was developed by using different filters on the raw data files. This step aims to correct the effect of outliers, e.g., taking away noisy data and detecting resets in the accumulated energy register.

For the particular case of the monitored energy, the heating energy from the boiler and the lighting energy at each time step has been calculated as expressed in Eq. (2):

[1] Note: data are not available for Demonstration Room III.

$$E_t[Wh] = \Delta E_{register}(t) - \Delta E_{register}(t-1) \quad (2)$$

Besides, for the particular case of outdoor conditions, the registered data were cumulated or averaged, respectively, in periods of 30 minutes, to make them coincident with the minimum simulation time interval allowed by DesignBuilder. After that, hourly, monthly and annual data were also obtained. Unfortunately, the monitored outdoor data was incomplete since the data for some periods were not available due to technical problems and were considered as blackouts. Nevertheless, the observed lack of data does not affect the results since they last few hours during the monitored year, and only on four occasions, the interruption period affects two or more consecutive days, as indicated in Figure 2. This process for the identification of blackouts has been repeated for each variable and then superimposed on the annual calendar, and as a result, it has been seen that the interruption periods coincide for all the variables recorded.

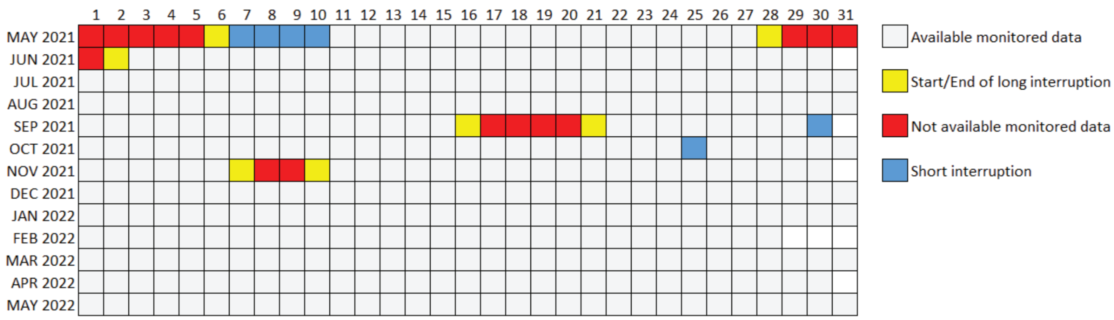


**Figure 2.** Identification of blackouts on the monitored data during one year.

The period of study covers a whole year from June 2021 to end of May 2022, in order to avoid blackouts detected in May of 2021.

*3.2.1.2. Data integration*

According to [8], data integration is the process of combining multiple data from different sources. Therefore, since the variables recorded by each sensor were stored in different monthly files, an essential task was to unify the data in an annual one.

In this work, the blackouts detected in the outdoor conditions file (see Figure 2) were substituted with hourly data taken from Meteostat. To verify the suitability of the Meteostat data, three days on which monitored data were available were randomly selected and compared with the Meteostat data from those days. The results obtained for temperature and relative humidity show minor differences, as shown in Figure 3, so the Meteostat data have been justified as suitable.

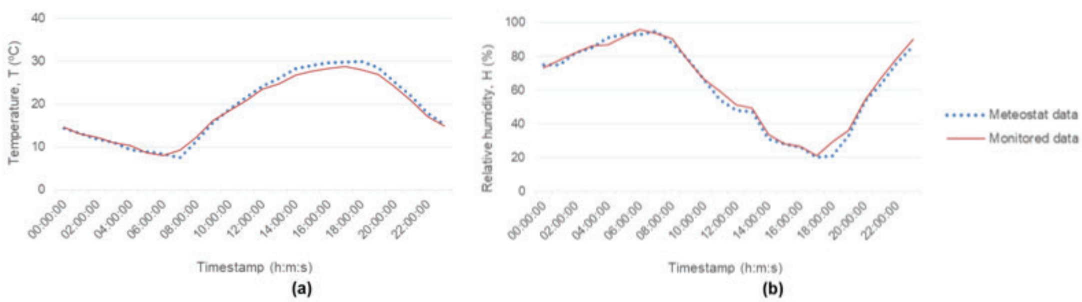


**Figure 3.** Comparison between meteorological data from Meteostat and monitoring data considering outdoor temperature (a) and relative humidity (b).

*3.2.1.3. Data transformation*

As mentioned by [8], data transformation is the process of transforming the data into the required format. Data transformation may include normalization, smoothing, aggregation/ disaggregation, and/or generalization of the data.

In this case, in order to compare the analysis with simulation results, data collected on a minute basis (apart from the previous outdoor conditions data) were averaged and/or cumulated in 30-minute intervals and then hourly data were obtained. However, inasmuch as the data were not homogenously registered (i.e. the time interval between timestamps was not constant) it required further treatment. Fortunately, it was identified that the time-step took values multiples of five in the vast majority of the cases, so, the original data series were converted into 5 minutes step values. For this purpose, the variables have been considered to remain constant between each timestamp. After that, a method based on an analogy with a linear equation has been applied


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in order to obtain average values for sub-hourly, hourly, daily and monthly data series. All the intensive variables have been calculated as averages, but the energy-related parameters, which are the extensive ones, have been calculated as a sum of the values registered within each interval.

Once the database consists of hourly average series and blackouts are fulfilled, the files are prepared for implementation in future work. As an example, the specific case of the outdoor conditions file requires adapting the format to DesignBuilder software. This software operates with EnergyPlus Weather File (EPW) format and integrates a Climate Data File Processor allowing the user to convert an EPW file into another type. Therefore, in this case, the data file was converted into a CSV file, to substitute the "default input data" with the monitored registered data. Another option is to calculate the heating days (HD) during the simulation period according to monitored data and implement the annual values in DesignBuilder, without modifying the standard climate data file.

#### 3.2.2. Data interpretation

After the data pre-processing, the obtained data needs to be interpreted. This process aims to extract useful information from the monitored variables such as operational schedules, occupation schedules and input parameters for modelling the BES model. The more reliable information is obtained, the more input data and model parameters will be available and the higher the accuracy of the calibration will be [13]. Once the data files are correctly organized, operational periods of the building during the year must be established. Then, a typical sub-operational period has been chosen for each season defined in the previous step. The results of the monitoring demonstrate that there are weekly patterns which are repeated during the academic course, so typical weeks were defined for each month to obtain operational schedules of the heating system and lighting system.

### 3.3. Thermal characterization of windows

As is already said, the Laboratory of Control Quality of Buildings (LCQB) of the Basque Government deals with, among others, the characterization of building components to research new construction solutions and enhance the thermal performance of the active and passive systems. Because of that, some windows were tested in order to further implement them in building refurbishment, as can be in the building of this case study.

One of the objectives of future work is to analyse the increase in the efficiency of the building after changing the windows, according to the simulation results. Therefore, in order to describe their thermal behaviour, the most important parameter is the thermal transmittance (U). In this work, the method described by UNE-EN ISO 12567-1 of the hot box method was implemented in the LCQB to characterize the thermal transmittance of the studied windows.

#### 3.3.1. Guarded hot box Method

This test method is carried out under UNE-EN ISO 12567-1:2011 to determine the thermal transmittance of doors and windows. Based on the UNE standard, a sample solution is located between two different spaces called chambers (see Figure 4): the hot chamber where the measurement box is located, and the cold chamber, which is used to simulate the exterior conditions, as [11] explained in their work. Therefore, there is a heating system on the hot chamber and a cooling system on the cold one to create a temperature difference (normally 20ºC). Then, by measuring the temperature difference and the heat flow passing through the sample, the thermal resistance of the window can be calculated. Once there is a steady-state condition in both chambers, the heat flow inside the chamber equals the heat input required to keep the hot side at a constant temperature [11].

In this work, U-values from four different windows are measured thanks to the guarded hot box tests developed in the LQCB, where the temperature difference between the hot and cold chambers is 20ºC and the average temperature of the sample is 10ºC. Multiple sensors are located in the sample, the chamber and the sample holder (frame). The employed metering chamber has a section of 1.63 x 1.88 $m^2$ while the normalized size of the samples is 1.23 x 1.48 $m^2$, with a sample holder of 1.63 x 1.88 $m^2$ (see Figure 4).

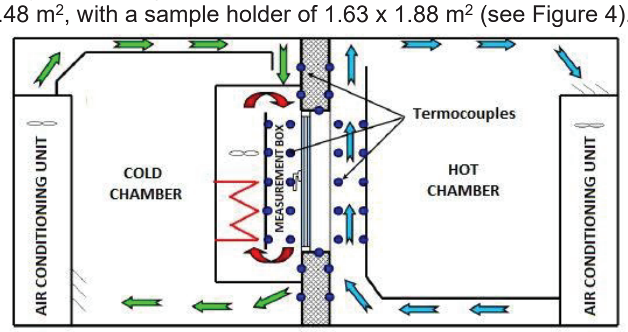


**Figure 4.** Chambers scheme of the guarded hot box employed for window testing. Source: Building Quality Control Laboratory of the Basque Country.

The measured thermal transmittance ($U_m$) of the window system is calculated according to the standard UNE-EN ISO 12537-1:2002 with Eq. (3).

$$U_m\left(\frac{W}{m^2\cdot K}\right)=\frac{\frac{\Phi\,(W)}{A\,(m^2)}}{\theta_{ni}-\theta_{ne}(K)} \quad (3)$$

This measured $U_m$, must be corrected in order to obtain the normalized thermal transmittance $U_w$. Therefore, it is necessary to include the thermal resistances of inner and outer surfaces, see Figure 5 and Eq. (4). The normalized value of $R_{(s,t)st}$ takes a value of 0.17 ($m^2\cdot K$)/W in Europe.

$$U_w\left(\frac{W}{m^2\cdot K}\right)=\frac{1}{\frac{1}{U_m}-R_{s,t}+R_{(s,t)st}} \quad (4)$$

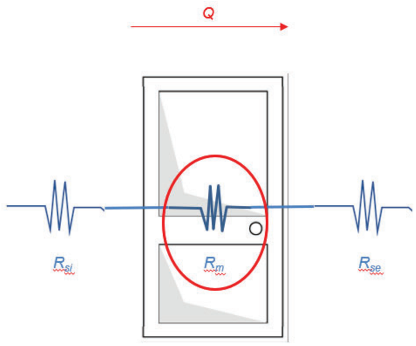


**Figure 5.** Thermal resistances characterization. Source: Building Quality Control Laboratory of the Basque Country.

### 3.3.2. Tested windows

Since the thermal properties of building envelope systems significantly alter the overall energy performance of buildings, so these properties must be accurately determined. In this case, the building façade was previously refurbished so special attention will be paid to the windows replacement. Additionally, four glazing systems have been selected from the experimental test. The normalized thermal transmittance ($U_w$) determined during those tests is shown in Table 1 for each glazing system illustrated in Figure 6.

**Table 1.** Features of the glazing systems with a dimension of 1.23 m x 1.48 m.

| Window | Glazing composition | $U_w$, W/($m^2\cdot K$) | Profile | Shutter box |
|---|---|---|---|---|
| TW-0412-50 | 4+4 / CAM 16 argon / 3+3 | 1.38 ± 0.07 | PVC | PVC isolated with EPS, e = 1.5 cm |
| TW-0412-48 | 4+4 / CAM 16 air / 6 | 1.55 ± 0.08 | PVC with aluminium reinforcement | - |
| TW-0412-7 | Fixed sash: 3+3 / CAM 10 air / 4+4<br>Tit-and-turn sash: 4+4 / CAM 12 air / 4 | 3,07 ± 0.16 | Aluminium, e = 14 cm | PVC, 1.22 m x 0.185 m, e = 18.5 cm |
| TW-0412-21 | Fixed sash and casement sash: 4+4 / CAM 15 air / 10 | 3.14 ± 0.16 | Lacquered aluminium, e = 12.8 cm | - |

**Figure 6.** Tested samples of (a) TW-01412-50, (b) TW-0412-48, (c) TW-0412-7 and (d) TW-0412-21.

## 3.4. Building energy simulation model

To initiate the calibration of the BES model, different data sources have been used such as monitoring, building and construction detail drawings and personal audits. As a result, operational periods and schedules have been obtained for their implementation in the BES model. This includes heating and lighting schedules, weather data and also tested thermal transmittance values. Natural ventilation has not been considered.


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Thermal zones have been determined by considering use and conditioning characteristics, so in this case, each room is taken as an individual thermal zone.

The envelope features have been modelled accurately by considering U-values calculated theoretically during walk-through audits. In the case of windows, the U-value determined during the guarded hot box method has been used.

PV modules have been integrated into façades and roofs as shown in the building drawings and modelled with a constant 15% efficiency.

## 4. Case study

The proposed methodology is applied to a single-floor occupied building, in particular, Building 2 of the Faculty of Nursing and Health Science of the University of Burgos, located in the city of Burgos in Spain (characterized by a moderate continental climate). The building has an academic use, so the occupation is related to the academic schedule and calendar, but in reality, it varies greatly from the expected occupancy. This building is a former Military Hospital built in 1880 with a single rectangular floor of 545.49 $m^2$, composed of five classrooms and two bathrooms, connected by a longitudinal corridor (see Figure 7). Over the years, the building has faced different rehabilitations and after the last one, two façade solutions were installed above the original wall. Table 2, Table 3 and Table 4 show the main construction and thermal characteristics of the building envelope.

The ventilated façade is predominant above the others, only in the Boiler Room have remained the original walls of the building. The non-ventilated panels have a total width of 2.3 m and have been installed between windows. The South orientation contains integrated photovoltaic modules and some ventilated PV modules have been integrated into the westernmost part of the South façade.

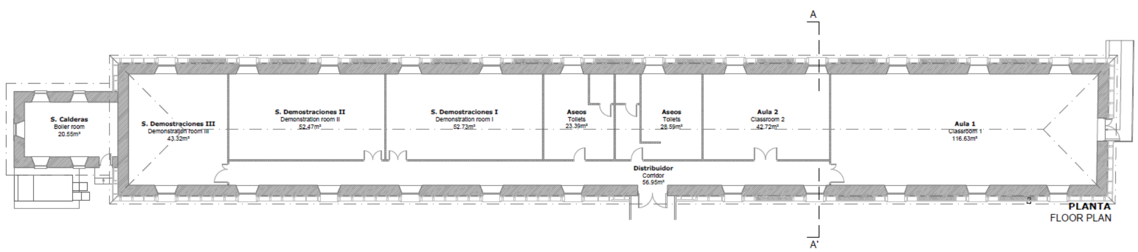


**Figure 7**. Indoor distribution of Building 2.

**Table 2.** Dimensions of building and envelope components.

| | |
|---|---|
| Number of floors | 1 |
| Overhang height | 5.15 to 5.31 m |
| Ridge height | 7.70 m (approx.) |
| Constructed surface | 545.49 $m^2$ |
| Conditioned surface | 431.39 $m^2$ |
| Total façade surface | 789.77 $m^2$; 752.22 $m^2$ (without openings) |
| East façade area | 43.35 $m^2$; 40.55 $m^2$ (without openings) |
| West façade area | 23.83 + 15.64 = 39.47 $m^2$; 38.81 $m^2$ (without openings) |
| South façade area | 323.19 + 21.62 = 344.81 $m^2$; 295.27 + 18.59 = 313.86 $m^2$ (without openings) |
| North façade area | 337.43 + 21.71 = 359.14 $m^2$; 311.61 + 20.39 = 332.00 $m^2$ (without openings) |
| Total openings surface | 64.55 $m^2$ |
| % openings east façade | 2.80 $m^2$; 6,46% |
| % openings west façade | 0.66 $m^2$; 1.67% |
| % openings south façade | 30.95 $m^2$; 8.98% |
| % openings north façade | 27.14 $m^2$; 7.56% |
| Roof area on the ground floor | 623.51 $m^2$ (approx.) |
| Roof inclination | 28º (approx.). |

**Table 3.** Composition and thermal characteristics of the different layers of the opaque envelope.

| | |
|---|---|
| Original wall | Masonry load-bearing wall, e = 62 cm |
| | Garnishing and plastering of gypsum, e = 1.5 cm |
| | U = 1.40 W/($m^2$·K) |
| Ventilated façade (ULMA) | Mineral wool, e = 5 cm |
| | Air chamber, e = 15 cm |
| | Polymer concrete cladding, e = 3 cm |
| | U = 0.518 W/($m^2$·K) |
| Separation between ULMA and STAM panels | Aluminium sheet, e = 0.2 cm |
| Non-ventilated façade (STAM) | Mineral wool, e = 15 cm |
| | EPS, e = 5 cm |
| | Polymer concrete panel, e = 3 cm |
| | U = 0.166 W/(m2·K) * |
| Metallic panel (SOLARWALL) | Mineral wool, e = 5 cm |
| | Air chamber, e = 15 cm |
| | Metallic cladding, e = 3 cm |
| | U = 0.42 W/(m2·K) * |

*Estimated with DesignBuilder in function of selected material and thickness

**Table 4.** Composition and heat transmission coefficient value (U) of opaque envelope and openings.

| | |
|---|---|
| Roof composition | Mixed trusses (metal and wood) |
| | Pine wood decking 800x150mm, e = 2.5 cm |
| | Ceramic flat tile of baked clay. Double side and upper lace |
| | U = 2.40 W/($m^2$·K) |
| False ceiling | Mineral wool rigid panel, e = 8 cm |
| | Smooth laminated plasterboard (accessible roof) 60x60 cm, e = 1.5 cm |
| Slab composition | Metal beam, ceramic vault, compression layer + mesh |
| | U = 2.10 W/($m^2$·K) |
| Non-slip laminate flooring | High density fibreboard, e = 1.25 cm |
| Window type | Wooden pre-frame 70 mm x 50 mm |
| | Mixed carpentry. PVC profiles and Wood finished. |
| | Exterior double low-e glass 4+12+6 mm |
| | Aluminium sheet in window perimeter trims and lower closure in ventilated façade, e = 0.2 cm |
| | U = 2.20 W/($m^2$·K) |

Regarding the thermal facilities, the building has two high-efficiency condensing gas boilers Remeha 65 PRO of 61 kW each, which supply heat through two independent circuits, both to Building 2 and to adjoining Building 3, in which another European project is being developed. The thermal demand only corresponds to the heating system, neither cooling nor DHW systems are operating in the building.

Referring to electricity generation, there are also photovoltaic panels as mentioned before. The PV installation is divided into three systems, independently connected to three inverters as indicated in Table 5. Besides, the lighting of the entire pavilion is composed of 2x32 W fluorescent lamps with a protection box at the entrance.

**Table 5**. Characterization of the PV system.

| PV characteristics | Ventilated façade (ULMA) | Non-ventilated façade (STAM) | Roof (SOLARWALL) | Complete System |
|---|---|---|---|---|
| Power, $kW_p$ | 4.95 | 4.16 | 4.42 | 13.53 |
| PV module model | VS21 C24 P99 | SPS istem 260P plus | SPS istem 260P plus | - |
| Nº modules | 50 | 16 | 17 | 83 |
| Azimuth / Inclination | -26º / 90º | -26º / 90º | -26º / 28º | - |
| Occupied area, $m^2$ | 41.3 | 26.1 | 27.7 | 95.1 |
| Inverter model | Sunny Boy 3.6 | Sunny 3.6 | Sunny Boy 4.0 | - |
| Inverter Power, $kW_{AC}$ | 3.6 | 3.6 | 4.0 | - |

# 5. Results

In this section, the analysed data are interpreted and the preliminary BES model is depicted, which will be fully calibrated in future research. The results of the methodology described in Section 3 are presented below.

From the data analysis, hourly average data and monthly and annual averages were obtained. Besides, operational schedules for heating and lighting systems have also been obtained.

The monitoring of the heating system during June 2021 and May 2022 shows a standard distribution of the heating demand according to the Burgos climate zone. As observed in Figure 8, higher heating demands

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correspond to the cold period from November to April and lower heating demands are required in September, October and May. Summer months from May to the last of August represent a non-heating period. The accumulated heating energy supplied by the boiler reaches a value of **44.05 MWh** in the monitored year, which means an average supply of **80.82 kWh/m²·year**.

Due to the academic use of the building, the operational schedules of heating and lighting systems have a weekly basis and vary according to the academic timetable and calendar. Four typical weeks were selected, see Figure 9. The heating system operates in a defined time period from Monday to Friday, being off during weekends and holidays.

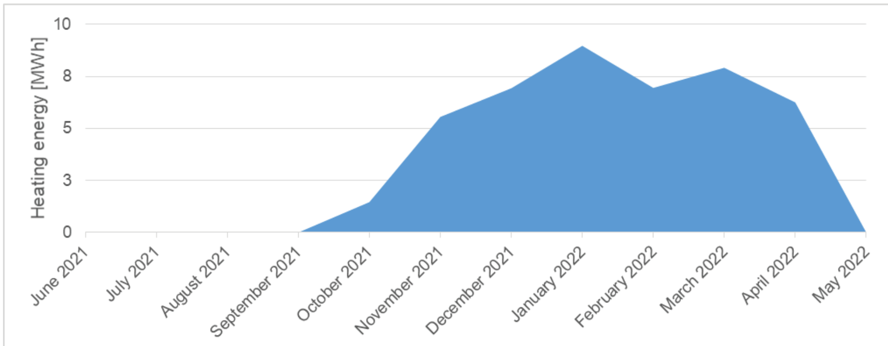


**Figure 8.** Annual distribution of heating energy attending to the measured data in the monitored period from June 2021 to May 2022.

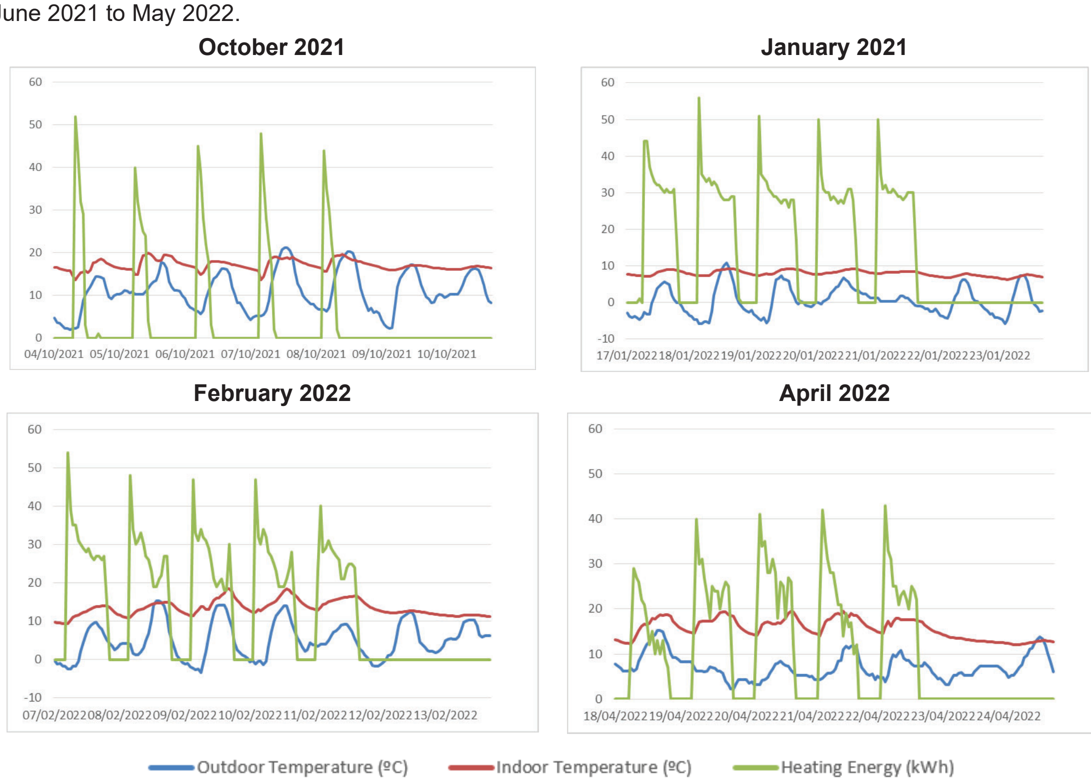


**Figure 9.** Typical week selected for calibrating the operational schedule of the heating system.

As appreciated in Figure 9, the highest recorded energy data correspond to the “start-up” of the heating systems during the morning and decrease during the day as external and internal gains increase. The boiler charge varies during the day according to the indoor conditions, see Figure 10.

In contrast to the heating system, there does not seem to be a clear operating pattern for the lighting system. This is due to a presence sensor in the building, as well as the variability in the occupancy period of the different classrooms. However, it has been identified that the auxiliary energy required by the building and its equipment is around 100 Wh with an electric current of 2 A. The total energy consumption measured in the building in the monitored period is **16.71 MWh** and an average of **30.66 kWh/m²·year,** being gathered in Table 6 the data classified by zones.

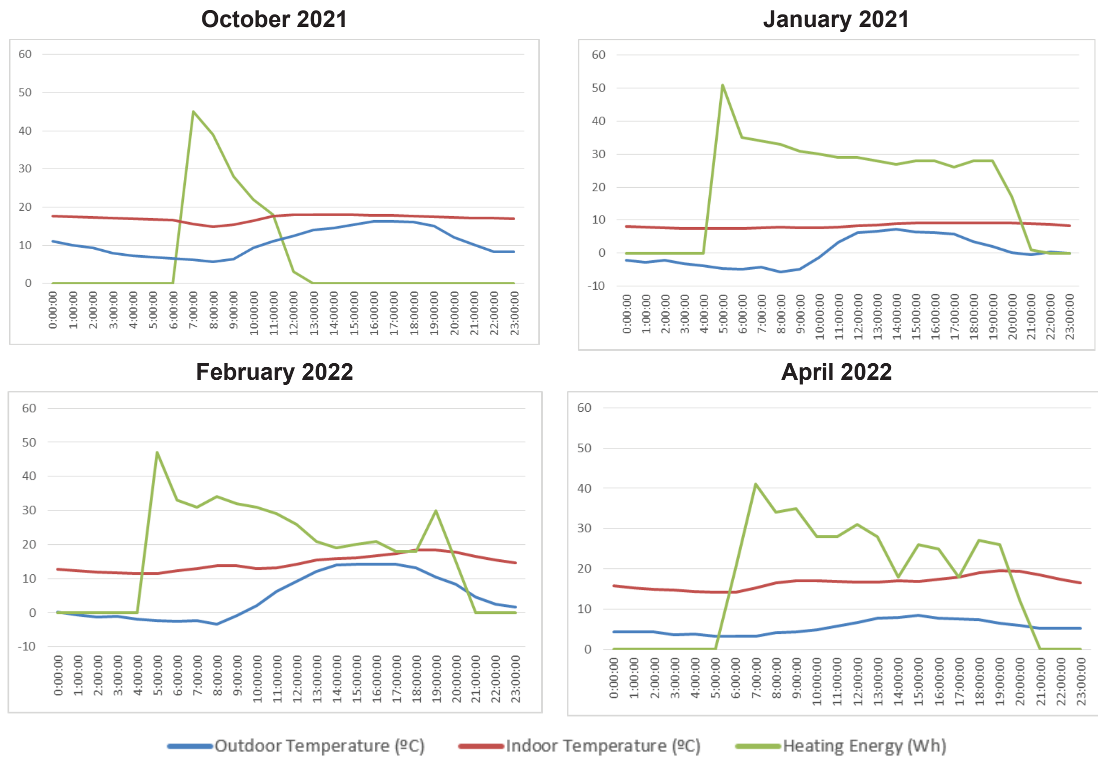


**Figure 10.** Typical days selected for calibrating the operational schedule of the heating system.

**Table 6.** Electrical energy consumption classified by zones in the period from June 2021 to May 2022.

| **Classroom 1** | **Classroom 2** | **Toilets (right)** | **Toilets (left)** |
|---|---|---|---|
| 2556.15 kWh/year | 6762.37 kWh/year | 3099.57 kWh/year | 671.41 kWh/year |
| 21.92 kWh/m$^2$·year | 125.30 kWh/m$^2$·year | 108.41 kWh/m$^2$·year | 28.71 kWh/m$^2$·year |
| 213.01 kWh/month | 563.53 kWh/month | 258.30 kWh/month | 55.95 kWh/month |
| 15.30% | **40.47%** | **18.55%** | 4.02% |
| **Demonstration room I** | **Demonstration room II** | **Corridor** | **Boiler room** |
| 926.11 kWh/year | 125.59 kWh/year | 1261.96 kWh/year | 1307.05 kWh/year |
| 17.56 kWh/m$^2$·year | 2.39 kWh/m$^2$·year | 22.16 kWh/m$^2$·year | 30.17 kWh/m$^2$·year |
| 77.18 kWh/month | 10.47 kWh/month | 105.16 kWh/month | 108.92 kWh/month |
| 5.54% | 0.75% | 7.55% | 7.82% |

From the data shown in Table 6, it can be interpreted that a large part of the teaching activity in the building takes place in Classroom 2 and that most of the occupants of the building are women since the women's toilet (right) has a higher annual electricity consumption. The building has been modelled in DesignBuilder according to constructive detail drawings and walk-through audits as shown in Figure 11.

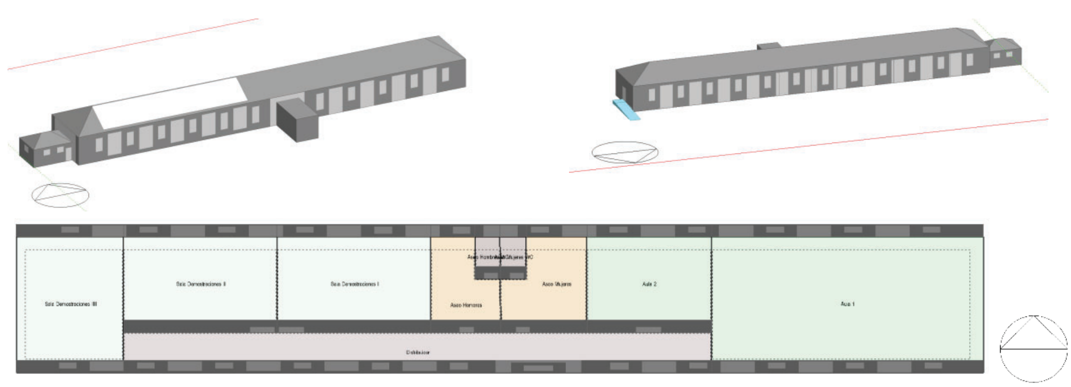

**Figure 11.** Visualization of building model created in DesignBuilder according to constructive details.


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## 6. Conclusions and discussion of results

A data calibration process has been developed in this paper and deployed to implement it in a BES model calibration of Building 2 of the Faculty of Nursing and Health Science of the University of Burgos. It is necessary to define a specific methodology to accurately calibrate the monitored data. Including experimentally tested thermal transmittance values reduce uncertainties and, thus, also the energy performance gap of the BES model. In this study, the available monitoring data have been pre-processed and accurately prepared for implementing them into the BES model, so these data are used in the whole model calibration procedure. In this first part of the research, data have first been used to better understand the in-use operational schedule of the building. In addition, some of the monitored variables have been implemented as inputs to the model and others as outputs to verify the accuracy of the model calibration in future research.

The more complex step consists on the data pre-processing, including data cleaning and transformation, where a specific and accurate methodology was developed for the case study, in order to obtain averaged hourly data for the model calibration. In this sense, it must be highlighted that a whole year monitoring period has been used during this work, which means a more complex analysis process, but it also provides a more accurate BES calibrated model.

After the previous analysis, the BES model will be easily calibrated in further works. This calibrated BES model will encourage the estimation and prediction of reliable energy savings for different retrofitting scenarios of the building, such as this proposed for windows replacement. To fulfil the calibration of the model, occupancy schedules and density must be analysed from monitored data in order to implement reliable inputs in the BES model.

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## Nomenclature

| | |
|---|---|
| $A$ | surface of window sample, $m^2$ |
| $e$ | thickness, cm |
| $E$ | Energy, Wh |
| $k$ | thermal coefficient, $Wh/(m^3 \cdot K)$ |
| $t$ | timestamp, h |
| $R_{s,t}$ | sum of the tested thermal resistances of the outer and inner surfaces, $(m^2 \cdot K)/W$ |
| $R_{(s,t)st}$ | sum of the normalized thermal resistances of the outer and inner surfaces, $(m^2 \cdot K)/W$ |
| $T$ | Temperature, ºC |
| $U$ | Thermal transmittance, $W/(m^2 \cdot K)$ |
| $V$ | Volume, $m^3$ |

**Greek symbols**

| | |
|---|---|
| $\Delta E$ | Accumulated energy, Wh |
| $\Phi$ | Heat flux through the test tube, W |
| $\theta$ | Temperature, K |

**Subscripts and superscripts**

| | |
|---|---|
| *inlet* | delivery boiler circuit |
| *m* | measured |
| *ne* | cold side |
| *ni* | hot side |
| *outlet* | return boiler circuit |
| *t* | timestamp |
| *w* | window |
| *wa* | water |

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