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BOOK OF PROCEEDINGS

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Energy Efficiency Assessment of a Youth Hostel Based on Multizone Modeling and Simulation

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ABSTRACT

This paper presents an energy performance assessment of a youth hostel in northern Portugal through multizone dynamic simulation. The study combines on-site data collection, energy billing analysis, and advanced building modeling in DesignBuilder using EnergyPlus as the calculation engine. The model includes the building envelope, occupancy profiles, internal loads, HVAC systems, lighting schedules, and domestic hot water production. The simulation results reveal that heating demand is strongly concentrated on the ground floor, with a total installed capacity of 51.04 kW after applying the required safety factor. Lighting contributes minimally to internal gains due to the exclusive use of efficient LED fixtures with occupancy sensors. Annual CO_2 emissions were estimated at 84.21 tonnes, highlighting the building's environmental impact. The results demonstrate the relevance of dynamic simulation as a decision-support tool for optimizing energy performance, reducing operational costs, and prioritizing future retrofit measures in similar hospitality buildings.

KEYWORDS

Dynamic Building Simulation, Energy Efficiency Assessment, Youth Hostel Retrofit.

INTRODUCTION

The building sector accounts for a significant share of global final energy consumption and greenhouse gas (GHG) emissions, making energy efficiency a central pillar of European and national climate policies. The EU's Energy Performance of Buildings Directive (EPBD) establishes a framework for assessing and improving building energy performance, promoting the reduction of energy demand and the decarbonization of the sector. In this context, dynamic simulation tools have become essential for predicting energy use under realistic operating conditions and for supporting the design and management of efficient buildings.

Multizone dynamic simulation enables the accurate representation of thermal zones, internal loads, and HVAC operation schedules, providing detailed insights into heating and cooling needs, internal gains, and overall energy consumption. This approach allows building professionals to test different design alternatives, optimize system operation, and evaluate the potential of retrofit strategies before implementation.

This paper focuses on the energy performance assessment of a youth hostel in northern Portugal, combining field data collection, energy billing analysis, and detailed modeling using DesignBuilder with EnergyPlus as the calculation engine. The primary objective is to calibrate and validate a simulation model that accurately represents the building's energy behavior, quantify energy needs and associated CO_2 emissions, and identify key areas for improvement. The results provide a foundation for proposing energy efficiency measures that can reduce operating costs and support the transition toward a more sustainable hospitality sector.

WORK CONTEXTUALIZATION

The initial steps toward improving the energy performance of tourism and hospitality buildings in Europe were undertaken during the late 1970s and early 1980s in several countries (e.g., France, Denmark, the then Federal Republic of Germany, and the Netherlands). However, it was only with the adoption of the Energy Performance of Buildings Directive (EPBD) in 2002 that a unified EU-wide policy emerged [1]. This directive was later complemented by the Energy Services Directive in 2006 [2], which was replaced by the Energy Efficiency Directive (EED) in 2012.

The EU’s comprehensive and integrated energy policy framework was further strengthened with the introduction of the ”Clean Energy for All Europeans” package [3]. This legislative package consolidates policies related to energy efficiency, renewable energy, electricity markets, and international cooperation. It includes amendments to the EED [4], the EPBD [5], and the Renewable Energy Directive (RED) [6]. These initiatives aim to reduce the environmental impact of energy consumption while maintaining or improving indoor comfort and air quality and addressing energy poverty issues.

In the tourism sector, the use of renewable energy technologies such as solar panels, biomass heating, and efficient HVAC systems can significantly reduce operating costs and carbon emissions. EU regulations, particularly the RED III and EPBD, emphasize integrating renewables in both new and existing buildings to achieve nearly zero-energy standards.

Although Portugal was relatively late in adopting energy efficiency measures in tourism and hospitality sectors, it has made significant progress in both regulatory frameworks and efficiency programs. Notably, three main energy efficiency initiatives have been implemented: the Home Renewable Programme, the Energy Certification of Buildings, and the Renewable at the Time Programme [7] and [8]. The EPBD was first transposed into Portuguese law in 2006 through three separate decree-laws, covering certification systems, performance in commercial and service buildings, and performance in residential buildings [9], [10] and [11]. In 2013, a single legislative document, Decree-Law No. 118/2013, was introduced to align the national regulations with the requirements of the 2010 EPBD amendment [12]. As a signatory of the Paris Climate Agreement, Portugal has committed to contributing to the European Union’s efforts to mitigate greenhouse gas (GHG) emissions, aiming to limit global temperature rise to well below 2°C compared to pre-industrial levels [13]. Globally, the energy sector is a major contributor to GHG emissions, accounting for approximately two-thirds of emissions in 2014 [14]. In the European Union (EU), buildings represent a significant share of the environmental burden, responsible for around 36% of CO_2 emissions and nearly 40% of total energy consumption. Among these, the residential and hospitality sectors alone accounted for a substantial portion of the EU’s final energy consumption in 2014 [4].

Portugal transposed European Directive (EU) 2018/844 and partially Directive (EU) 2019/944 into national legislation on 7 December 2020 in order to establish the requirements applicable to buildings to improve their energy performance and regulate the Energy Certification System for Buildings in Portugal [15], having been subsequently amended, on 19 February 2025, to partially transpose European Directive (EU) 2024/1275 [16].

Tourism buildings, such as youth hostels, are characterized by their intermittent occupancy, diverse energy usage patterns, and varying thermal comfort requirements. These features make energy efficiency improvements particularly challenging but also highly impactful. In addition, the integration of renewable energy sources, such as solar thermal and photovoltaic systems, is crucial for reducing energy dependency and achieving sustainability goals. In the context of tourism, where energy consumption can fluctuate significantly due to seasonal variations and high occupancy rates, implementing renewable energy systems becomes not only an environmental imperative but also a strategic financial investment.

The building sector holds a prominent position in the EU's energy and climate policy due to its significant potential for energy savings and emissions reductions [14], [17] and [18]. Energy consumption throughout a building's life cycle is predominantly linked to operational phases (80–90%) rather than construction phases (10–20%) [19]. Therefore, strategies for decarbonizing the building sector must address both construction and operational efficiency to achieve sustainable outcomes.

The integration of renewable energy technologies in buildings is also strongly supported by EU legislation. The Renewable Energy Directive (RED III) [6] sets binding targets for increasing the share of renewables in the energy mix, including in the building sector. Additionally, the Energy Performance of Buildings Directive (EPBD) [5] encourages the use of renewable energy systems to achieve nearly zero-energy building (NZEB) standards, particularly for new constructions and major renovations.

Despite progress in energy performance standards, around 75% of the existing EU building stock is considered energy inefficient [20]. This inefficiency is partly due to the age of buildings, as around 40% of residential and hospitality buildings were constructed before 1960, a period marked by minimal regulatory requirements [21]. Given that approximately 75–85% of the current building stock is expected to remain in use by 2050 [22], the renovation of existing buildings, including youth hostels, emerges as a critical strategy for meeting long-term energy and climate goals.

In Portugal, the energy consumption pattern diverges slightly from the EU average, with the transport sector leading at 37%, followed by industry (31%) and buildings (29%), split between residential (16%) and service buildings (13%), including hospitality [23]. However, the country has made significant progress in reducing GHG emissions since the peak in 2005, achieving a decrease of approximately 22.5% by 2017 [24].

Given the substantial role of hospitality buildings in energy consumption and GHG emissions, retrofitting older, inefficient buildings remains a priority.

In particular, youth hostels constructed before the introduction of the first thermal regulation in 1991 present a valuable opportunity for energy performance improvements. This study examines the cost-optimal retrofit investment for a youth hostel located in Bragança, Portugal, utilizing dynamic energy simulation and financial analysis to evaluate various energy efficiency and renewable energy measures.

MULTIZONE DYNAMIC SIMULATION

The determination of the BEPI (Building Energy Performance Indicator), based on the multizone dynamic simulation method according to [5] and [15], for the building under study, must be carried out using software accredited under ASHRAE Standard 140, developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers. These programs are employed for building analysis for various purposes, such as ensuring compliance with energy efficiency regulations, evaluating energy-saving strategies, and performing simulations for sustainable building certification. Such software must, at a minimum, have the capability to model, [15] and [26]:

- More than one thermal zone;
- With an hourly time step over a full calendar year, accounting for 8,760 hours;
- Hourly variation of internal loads, differentiated into occupancy, lighting, and equipment;
- Thermostat setpoints for the thermal zones and HVAC system operation, allowing independent parameterization for weekdays and weekends;
- Heat recovery from exhaust air;
- The thermal mass effect of the building.

The adoption of multizone dynamic simulation in internationally recognized tools (e.g., EnergyPlus) allows the explicit representation of multiple thermal zones, load-building-system interactions, and hourly control strategies, forming the basis for regulatory compliance assessments, energy-saving strategy studies, and sustainable building certification support. The foundational EnergyPlus paper describes the software architecture based on heat and mass balance equations, integration with HVAC system modules, variable time steps (including hourly steps), and the capability to represent phenomena such as system controls, interzone air flow, and building thermal mass effects—features essential for 8,760-hour annual analyses in real buildings [27].

In the European context, the evolution toward hourly methods for the assessment of heating and cooling energy needs—central to EPBD alignment—is well documented in the literature on EN ISO 52016-1. Comparative studies demonstrate the relationship and consistency between the standardized hourly method and detailed dynamic simulations, including the explicit treatment of time-dependent profiles and thermal properties that support year-round hourly analyses [28] and [29].

Hourly modeling of internal loads—differentiated into occupancy, lighting, and equipment—and the parameterization of thermostat setpoints and HVAC operation modes for weekdays versus weekends are critical for accuracy. Literature shows that occupant presence and behavior are stochastic in nature and strongly impact energy use, justifying the application of realistic schedules and stochastic models (e.g., Markov chains). Empirical studies and modeling approaches quantify the sensitivity of results to occupancy schedules and equipment use [30], [31] and [32].

Inclusion of heat recovery from exhaust air (ERV/HRV) in simulations is also well-supported by research. Zhou, Wu, and Wang [33] developed and validated an ERV model within a dynamic simulation environment, showing the influence of setpoint temperatures and climatic conditions on annual energy savings; subsequent studies reinforced these findings through parametric analyses of seasonal ERV/HRV effectiveness under various system configurations [33] and [34].

Finally, correct representation of building thermal mass is recognized as essential in the literature. Classical reviews show its effect in reducing peak loads and smoothing indoor temperature fluctuations, with direct implications for HVAC system sizing and operation when thermal mass is properly modeled in balance equations and hourly discretization [35].

The building energy model was developed using DesignBuilder, a widely used graphical interface for dynamic building simulation that employs EnergyPlus as its calculation engine. DesignBuilder enables the creation of detailed 3D models of the building envelope, internal gains, HVAC systems, lighting, and control strategies, supporting multizone dynamic simulation with hourly time steps over a full calendar year (8,760 hours). This capability allows a detailed representation of thermal zones, internal load schedules, thermostat setpoints (differentiated by weekdays and weekends), HVAC operation, heat recovery, and the thermal mass effect of the building. DesignBuilder is ASHRAE Standard 140 validated, ensuring compliance with international standards for building energy modeling and providing confidence in the reliability of the results [25] and [36].

CASE STUDY

The case study is about a youth hostel located in an inland region in northern Portugal built in 1999 and which is part of a global accommodation network, designed to provide tourist, cultural and social experiences (see Fig. 3).

Fig. 3. Youth hostel building.

Building characteristics

The building has a predominantly rectangular geometry and is oriented towards the north, comprising three floors. The façades combine white-painted masonry on the upper levels with stone cladding on the ground floor, creating a solid base appearance. The eastern section of the site is dedicated to recreational uses, featuring two tennis courts, a small amphitheater, and a landscaped garden. The ground floor accommodates the most functional areas, including administration, dining services, and other support facilities. The upper floors are mainly dedicated to accommodation, with dormitories located on the south side, service areas to the north, and double rooms oriented east–west. Accessibility for people with reduced mobility is ensured by a hydraulic elevator. With a total usable floor area of 2,102.08 m^2, distributed over 3 floors, Table 1, the hostel is classified as a Large Commercial and Service Building (GES) under Portuguese Decree/Law 101-D/2020 [15].

Table 1. Areas of the building floors.

Floor	Area (m^2)
Floor 0	806,00
Floor 0	760,46
Floor 0	535,62
Total	2102,08

Energy consumption overview

The analysis of the building's energy consumption is essential for understanding its operational efficiency and environmental impact. The hostel's energy use is derived exclusively from electricity, which is critical for all services, and propane gas, which is primarily used for space heating, domestic hot water (DHW) production, and cooking. The building has an annual electricity consumption of approximately 50 MWh and is subject to a four time-of-use tariff, which differentiates between peak, mid-peak, off-peak, and super off-peak hours, each with distinct costs. Figure 1 presents the distribution of electricity consumption across these tariff periods, based on 2023 utility bills, providing insight into seasonal variations and the relative contribution of each period to the total annual demand. A marked increase in electricity use is observed during the winter months, mainly due to greater heating demand, extended use of lighting because of shorter days, and HVAC operation to ensure thermal comfort (see Fig. 4).

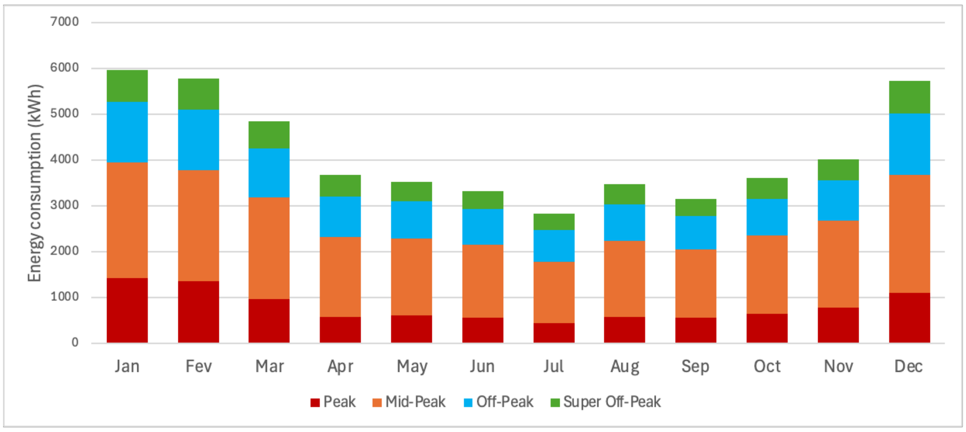

Fig. 4. Annual electricity consumption.

Propane consumption is summarized in Fig. 5. Annual propane gas consumption., which reports a total annual use of 238,257 kWh. It is important to note that the values shown in this figure do not represent regular monthly consumption but rather the deliveries made throughout the year to replenish the external storage tank as needed. Consumption follows a seasonal pattern, with higher demand during winter for heating and DHW production, and lower demand during summer. The combined analysis of electricity and propane data allows for a comprehensive understanding of the hostel's energy needs and supports the identification of opportunities for improving efficiency and reducing operational costs.

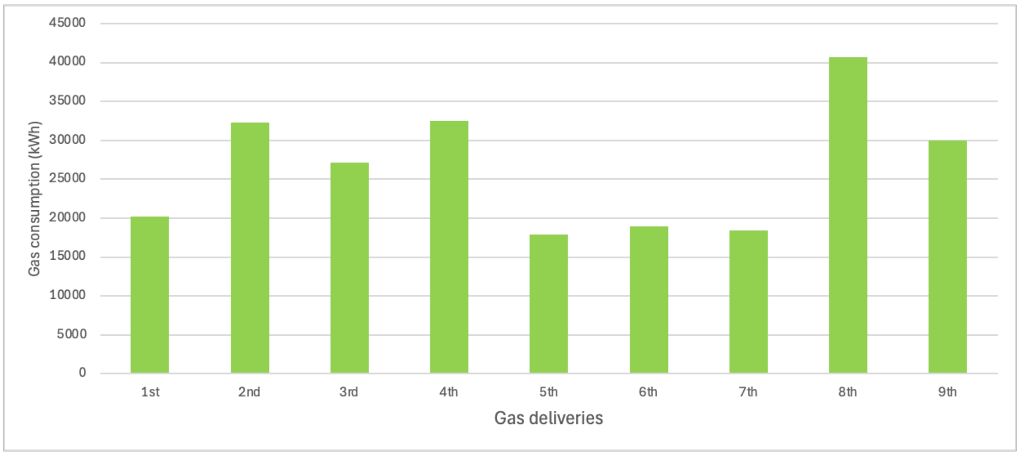

Fig. 5. Annual propane gas consumption.

Climatic zone

The climatic zoning of the country is based on the Nomenclature of Territorial Units for Statistical purposes (NUTS) level III, in accordance with [15]. According to this classification, the building is located in the winter heating climatic zone I3, with a degree-day value of 2,491 °C. For the cooling season, it is situated in zone V2, characterized by an average outdoor temperature of 21.5 °C.

Building occupation

Occupancy density has a direct impact on the building's internal thermal loads. The hostel has a capacity for 88 people and is frequently used by large groups of students, resulting in significant internal gains.

On average, winter occupancy is about 50 people, increasing by approximately 40% in summer. High use of lighting and electronic devices by occupants further contributes to energy demand. A short survey involving 13 occupants was conducted to assess their ventilation preferences. Results showed that over 75% favored natural ventilation, highlighting the importance of air quality and the impact of occupant behavior—such as window opening or shading use—on thermal performance and HVAC efficiency. Periods of high occupancy lead to increased energy demand, while adapting system operation during low-occupancy periods can reduce waste and improve energy efficiency.

Standard schedules were defined in the simulation software to more accurately represent real energy consumption, including system operation, equipment use, and occupancy patterns. Heating systems were programmed to operate only during the winter season, with schedules adjusted according to the severity of the cold: continuous operation on the coldest days, partial daytime operation during mid-winter, and reduced operating hours at the end of the season. Equipment use schedules were based on on-site observations, and occupancy profiles were adapted to reflect daily variations in building use. When fully occupied, the building reaches an occupancy density of approximately 0.042 occupants/m².

Lighting System

A comprehensive inventory of the building's lighting system was carried out to quantify installed power and to evaluate Lighting Power Density (LPD). The survey identified a total of 292 luminaires distributed across all floors, corresponding to an installed power of **3,693 W**. The majority of fixtures are 12 W LED panels (101 units, 1,212 W total) and 9 W A60 bulbs (99 units, 891 W total), complemented by tubular LEDs, GU10 spotlights, decorative ceiling LEDs, and a smaller number of CFL "corn" lamps. This confirms that the building is equipped entirely with efficient LED lighting technology, many of which are fitted with occupancy sensors to minimize unnecessary use.

The detailed distribution of lighting power by space was used to calculate LPD values for each room and aggregated for each floor, Table 2. Results show that most spaces have very low LPD values—typically below 2 W/m²—reflecting the use of efficient LED technology. Higher values are observed in functional areas requiring increased illuminance, such as kitchens, storage rooms, sanitary facilities, and circulation atria. The highest densities occur in the first-floor distribution atrium (**7.54 W/m²**) and the second-floor atrium (**8.35 W/m²**).

Table 2. Lighting Inventory and Installed Power.

Fixture Type	Power (W)	Quantity	Total Power (W)
LED Panel	12	101	1,212
GU10 LED Spotlight	6	11	66
LED Tube 1.2 m	18	7	126
LED Tube 1.5 m	22	34	748
LED A60 Bulb E27	9	99	891
LED CFL "Corn" Bulb	20	10	200
Decorative Ceiling LED	15	30	450
		Total	3,693

Table 3 presents the total installed lighting power and average LPD per floor, resulting in a **global average of 2.17 W/m²**for the building. These results demonstrate that lighting represents a relatively small share of total energy use and internal heat gains, but its contribution is relevant for accurate simulation. The data were implemented in the dynamic simulation model using hourly schedules consistent with occupancy profiles, ensuring realistic representation of lighting loads in the energy performance assessment.

Table 3. Installed Lighting Power and LPD per Floor.

Floor	Installed Power (W)	Total Area (m²)	Average LPD (W/m²)
P0 (Ground Floor)	1,524	753	2.02
P1 (1st Floor)	1,161	589	1.97
P2 (2nd Floor)	1,008	358	2.82
Total	**3,693**	**1,700**	**2.17**

HVAC Systems

Space heating is provided by wall-mounted radiators connected to an 80 kW propane-fired boiler. Burner operation is automatically controlled by a service thermostat and a safety thermostat based on boiler water temperature. Heating is available in bedrooms (1.7–2.5 kW each) and sanitary facilities (0.6–2.5 kW each).

Cooling is provided by ceiling-mounted cassette split units. Thermal load calculations considered the building envelope, orientation, and expected occupancy schedules. Installed capacities are 23 kW (cooling) / 18 kW (heating) for the multipurpose room, 17.4 kW / 17 kW for the dining hall, and 16 kW / 16 kW for the lounge, reception, and lobby areas. Currently, only the units in the multipurpose room and dining hall are operational, and they are switched on only when necessary.

Domestic Hot Water (DHW) System

DHW production is ensured by a dedicated 104 kW boiler, supported by a plate heat exchanger connected to a 2,500 L storage tank. The primary circuit uses a circulation pump and a modulating three-way valve, with temperature sensors controlling water temperature. The secondary circuit includes a dedicated pump managed by a thermostat. The boilers can operate in cascade mode, running sequentially or in parallel to meet seasonal demand more efficiently.

Other Equipment

The building contains various appliances and equipment related to its daily operations, accounting for a total installed capacity of 300.15 kW. However, precise operating schedules for these devices could not be determined, which introduces uncertainty in the estimation of their contribution to total energy consumption.

Building Energy Systems: Installed Power Overview

To accurately represent the energy performance of the building, the installed power of all major systems was surveyed and quantified, Table 4. This includes HVAC (heating and cooling), domestic hot water (DHW) production, lighting, and other electrical equipment. Incorporating these values into the dynamic simulation model allows for a realistic representation of internal heat gains and system loads, supporting a more reliable assessment of the building's overall energy performance and the identification of potential efficiency improvement measures.

Table 4. Installed Lighting Power and LPD per Floor.

System / End-Use	Installed Power (kW)
Heating (HVAC)	131
Cooling (HVAC)	56.4
DHW Production	104
Lighting	3.7
Other Equipment	300.15
Total Installed Power	≈ 545

SIMULATION AND RESULTS

Dynamic simulation is a key technique for analyzing building energy performance, allowing the quantification of potential energy consumption under specific usage and operational conditions. This approach makes it possible to determine heating and cooling demands, as well as internal gains from occupancy and external factors, and is therefore essential for testing alternative design and operational strategies.

Following the collection of all characteristic and energy data, a detailed model of the building was developed in DesignBuilder, incorporating the gathered information to closely replicate real operating conditions and construction features. Fig. 6 shows the 3D model of the youth hostel in DesignBuilder, including the envelope colors, shading elements, and other relevant details, together with the solar diagram indicating the sun's position. This visualization allows the assessment of solar gains and shadowing effects from nearby buildings, which significantly affect the building's energy needs.

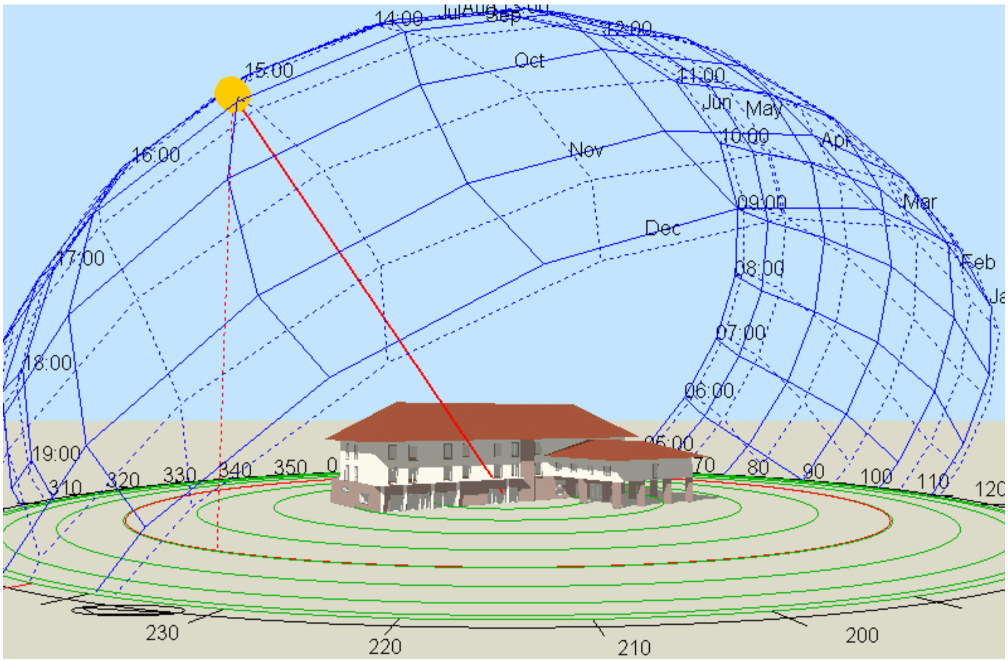

Fig. 6. Youth hostel model created in DesignBuilder, at 3 pm on May 20.

The energy model of the youth hostel was calibrated to ensure that simulated energy consumption closely matched real data. Using 2023 electricity and propane bills as a reference, the model was considered validated when simulated annual consumption deviated by less than ±10% from measured values. The final results showed a difference of –1.5% overall, with electricity consumption underestimated by 3.5% and propane by 1.1%, which falls well within the acceptable tolerance.

The simulation also determined the building's heating needs, resulting in a total required heating capacity of 51.04 kW after applying a safety factor of 1.25, with the ground floor representing nearly half of the demand. The main entrance was identified as the area with the highest heating deficit (5.18 kW), suggesting a potential area for improvement. Cooling needs were not analyzed in detail since several air-conditioning units are non-operational and rarely used.

Internal gains were broken down by source, showing that lighting contributes very little to thermal gains despite significant energy use, mainly due to the efficiency of LED fixtures.

The model also estimated annual CO_2 emissions at 84.21 tonnes, considering emission factors of 0.685 kgCO_2/kWh for electricity and 0.195 kgCO_2/kWh for propane.

DISCUSSION AND ECONOMIC ASSESSMENT

The critical interpretation of the results must be framed within the current Portuguese regulatory context for building energy performance. Decree-Law No. 101-D/2020, later amended by Decree-Law No. 11/2025, establishes the requirements for improving energy performance and regulates the National Energy Certification System (SCE). According to this legislation, the improvement measures proposed in energy certificates must demonstrate technical and economic feasibility, presenting information on investment cost, expected benefits, and payback period. The dynamic simulation approach used in this study provides direct technical support to this legal requirement, allowing the quantification of real consumption patterns and estimating the economic impact of the proposed interventions, in line with the objectives of the SCE and the Portuguese National Energy and Climate Plan 2030 (PNEC 2030).

At European level, the Energy Performance of Buildings Directive (EPBD) — Directive 2010/31/EU and its revision, Directive 2018/844/EU — reinforces the need for buildings to be assessed under realistic operating conditions, favouring hourly calculation methods and calibrated simulation models. The present case study clearly illustrates this principle: the concentration of heating demand on the ground floor highlights failures in air-tightness and envelope performance, aspects explicitly addressed in the minimum performance requirements adopted by Portugal following the transposition of the EPBD. These observations align with the “cost-optimal” principle defined in Commission Delegated Regulation (EU) No 244/2012, which requires Member States to select measures that provide the best balance between investment cost and energy savings, particularly in existing hospitality buildings.

Furthermore, the significant dependency on propane for space heating and domestic hot water (DHW) production contradicts the decarbonisation targets set by both PNEC 2030 and the Long-Term Strategy for Carbon Neutrality 2050 (RNC50), which encourage the gradual replacement of fossil fuels by high-efficiency or renewable-assisted systems. The adoption of air-to-water heat pumps, solar thermal systems for DHW, or photovoltaic systems for self-consumption would be consistent with the Renewable Energy Directive (RED III), which increases binding targets for renewable penetration in buildings and promotes decentralised generation.

The economic analysis carried out within this study also complies with the SCE requirement that qualified experts must indicate technically feasible improvement measures accompanied by cost estimates and payback period. The three selected interventions — replacement of the existing boiler with a condensing boiler (~€16,000), installation of variable-speed circulation pumps (~€4,500), and roof insulation reinforcement (~€14,000) — represent cost-effective actions for service buildings, enabling a predicted reduction of 15–22% in heating demand. The estimated annual savings of €5,500–€7,200 result in a simple payback between 4.5 and 6 years, a value clearly aligned with the economic criteria established in Decree-Law No. 101-D/2020 and the EU cost-optimal framework.

Beyond direct consumption reduction, these measures also contribute to improving the building’s energy certification rating, which is relevant for compliance, market value, and eligibility for national or European funding programmes. When combined with renewable systems — particularly solar thermal for DHW and photovoltaic self-consumption — the building could approach nearly zero-energy building (nZEB) requirements, a central concept of the EPBD and already mandatory for new constructions and major renovations.

Therefore, the combination of dynamic simulation, critical result analysis and economic assessment demonstrates that the proposed measures are not only technically sound but also legally consistent with Portuguese and European energy policy. This confirms the role of simulation as a decision-support tool within the SCE framework and highlights the relevance of energy renovation in hospitality-oriented buildings to meet national and EU-level efficiency and decarbonisation targets.

CONCLUSIONS

This study conducted a comprehensive energy performance assessment of a youth hostel in northern Portugal using multizone dynamic simulation in DesignBuilder/EnergyPlus. The calibrated model demonstrated high reliability, with a deviation below ±10% relative to measured electricity and propane consumption. The results confirmed that heating demand is strongly concentrated on the ground floor, driven by air infiltration and envelope performance limitations, while lighting contributes minimally to internal gains due to the exclusive use of LED technology and occupancy-based controls.

Beyond the technical findings, the study highlights that dynamic simulation is not only a diagnostic tool but also a legally relevant instrument within the Portuguese regulatory framework for building energy certification. In accordance with Decree-Law No. 101-D/2020 and its amendment by Decree-Law No. 11/2025, improvement measures must demonstrate both technical feasibility and economic justification. The simulation outputs provided a quantitative basis for this requirement, enabling the definition of cost-effective interventions aligned with the “cost-optimal” methodology established in EU Regulation 244/2012.

The economic and regulatory analysis shows that relatively simple retrofit measures — such as installing a condensing boiler, variable-speed pumps, and roof insulation — can reduce heating needs by 15–22%, leading to annual savings of €5,500–€7,200 and a payback period between 4.5 and 6 years. When complemented by renewable energy integration, such as solar thermal for DHW or photovoltaic self-consumption, the building could move toward nearly zero-energy building (nZEB) requirements foreseen in the EPBD and supported by the Renewable Energy Directive (RED III). These outcomes reinforce the relevance of retrofitting existing hospitality buildings in meeting national decarbonisation targets under PNEC 2030 and the Long-Term Strategy for Carbon Neutrality 2050 (RNC50).

Future work should expand the analysis to include hybrid and renewable-assisted HVAC solutions, lifecycle environmental impacts, and multi-criteria optimisation of energy performance, comfort, and economic return. Broader application of calibrated dynamic simulation in the Portuguese building certification context could further support decision-making, reduce uncertainties in energy modelling, and accelerate the cost-effective renovation of existing building stock.

Overall, this research demonstrates that dynamic simulation, combined with economic and regulatory assessment, provides a robust and policy-consistent pathway for improving energy efficiency, reducing operational costs, and supporting the decarbonisation of hospitality buildings.

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