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A Comparative Study on Discrepancies in Residential Building Energy Performance Certification in a Mediterranean Context

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Abstract: Energy Performance Certification (EPC) systems are pivotal in addressing the global energy challenge, particularly in the building sector. This study evaluates the efficacy of the EPC offered by the Simplified Building Energy Model interface designed to indicate compliance with the Cypriot building regulations, widely known as iSBEM-Cy Version 3.4a, by examining a typical residential unit in Cyprus. Data on construction features and electromechanical systems were collected, and actual monthly electricity and oil bills were analyzed to determine the total primary energy consumption. Various factors were considered, including energy efficiency and operational parameters for heating, cooling, lighting, auxiliary systems, and domestic hot water. The building energy performance was simulated using iSBEM-Cy, allowing for comparison with real-world energy consumption. Notable discrepancies were observed, particularly in cooling, with deviations reaching 377.4%. Conversely, domestic hot water consumption exhibited minimal variance at 7%, while heating and lighting showed moderate discrepancies (24.3% and −113.9%, respectively). This study underscores the need for rigorous evaluations to shape effective EPC and provides insights into building energy performance in Mediterranean Cyprus. This research contributes to the broader discourse on sustainable construction practices by aligning simulation results with real-world energy consumption.

Keywords: sustainable buildings; energy efficiency; building energy upgrade; building energy consumption discrepancies; building sustainability evaluation; climate change adaptation; resilience; Cyprus

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1. Introduction

In recent decades, global discussions have increasingly focused on regulations aimed at reducing energy consumption and improving energy efficiency in buildings [1–3] and high intensity economic sectors [4–6]. The urgency of these discussions is underscored by the fact that in Europe, buildings alone account for 40% of total energy consumption [7–9], with heating, cooling, and domestic hot water contributing up to 80% of this usage [10–13]. Moreover, the significant energy use in buildings is a critical contributor to climate change, accounting for 36% of total greenhouse gas emissions associated with energy production; this situation is driven by the fact that 75% of the current building inventory is deemed energy-inefficient [14,15]. Energy-efficient buildings not only play a crucial role in reducing greenhouse gas emissions but also enhance the comfort of occupants and reduce operational costs [16–18].

The majority of different technologies and types of energy sources have contributed to this situation [19,20], with the choice of energy sources being significantly influenced by political and economic factors [21,22]. The dual substitution policy has been effective in promoting the transition to cleaner heating, with income, energy costs, and education playing key roles [23,24]. In Europe, methods of power generation and political and institutional constraints have historically shaped fuel use, with a shift towards market regulation and refurbishment of existing plants [25,26]. Liberalization of the electricity market and government policies have influenced investments in combined heat and power plants, with subsidies and fuel prices playing a significant role [27,28]. Climate policy, including emissions trading and taxes, has also impacted heat and power capacity investment decisions, increasing the value of flexibility in energy investments [29,30].

The European Energy Performance of Buildings Directive (EPBD), introduced in the 2000s, is the cornerstone of the efforts to achieve high energy performance in buildings and educate citizens on energy-saving practices to lower costs [31,32], a holistic approach that plays a crucial role in navigating the complexities of diverse energy technologies and sources. The initial version of the EPBD made the energy performance certificate a mandatory requirement for all European members, applicable to buildings under construction or undergoing selling and renting procedures [33,34]. The latest iteration of the EPBD, introduced in 2018, has amended previous directives, addressing aspects such as the long-term renovation strategy, technical building systems, electromobility, smart readiness indicators, inspection of heating systems, and building automation and control systems [34,35].

As a member of the European Union, Cyprus provides an intriguing case study for examining the energy efficiency of buildings, given the island's distinctive climatic characteristics and the opportunity for upgrading its existing building stock [36,37]. The majority of residential buildings in Cyprus were constructed between 1980 and 2000 [38,39], a period during which no regulations on the energy performance of buildings were in place, resulting in a low average energy efficiency rating [40,41]. Furthermore, despite the current state of the building stock, Cyprus boasts a growth rate twice the average of other EU member states, reaching 4% [42].

In Cyprus, the building sector accounts for over 30% of total energy consumption [43,44]. Addressing the high energy consumption in the existing building stock has become one of the key challenges for the government in recent years [45,46]. A primary software tool utilized for EPCs is the Simplified Building Energy Model interface, which is designed to indicate compliance with the Cypriot building regulations, widely known as iSBEM-CY [47,48]. iSBEM-Cy is an EPC designed to certify both residential and non-residential buildings by evaluating their energy usage in accordance with Cypriot requirements [49,50].

Previous research has identified significant challenges and discrepancies in building EPC processes. For example, Li (2015) [51] revealed that building energy models have limited reliability in assessing the performance of energy conservation measures, citing factors such as assumed occupancy data and cross-energy conservation measures estimation. Similarly, Raslan (2010) [52] highlighted predictive inconsistencies among accredited building energy performance compliance demonstration software in the UK. Later, Kelly (2012) [53] raised concerns about the effectiveness of the standard assessment procedure in estimating building energy efficiency, suggesting the potential for perverse incentives. Brady (2017) [54] emphasized the need for improved energy management techniques, particularly in existing buildings, due to high uncertainty in estimates of energy consumption. More recently, Li (2019) [55] concluded that next-generation EPC should rely on building information modeling technology, benefit from big data techniques, and use building smart-readiness indicators to create a more reliable, affordable, comprehensive, and customer-tailored instrument. Additionally, both Berg (2019) [56] and Mattoni (2018) [57] focused on the role of user behavior, with the first discussing the challenges of refurbishing historic apartment buildings and the need for a bottom-up approach, and the latter providing a critical review of international green building rating tools, emphasizing the need for a deeper understanding of the aspects included in these tools. Collectively, these studies highlight the urgent need for more accurate and reliable tools and processes in building EPC, tailored to user and case-specific needs. A reliable solution for assessing the energy performance of buildings of any typology is represented by dynamic simulation models [58,59]. Different tools are available on the market as commercial software [60,61]; however, the adoption of the these software options is often not flexible because they are linked to specific weather data files [62] or are not capable of simulating novel technologies that can be integrated into the building envelope [63]. To cope with these issues, the adoption of in-house building energy performance simulation tool is a key strategy [64–66]. Despite prior research shedding light on associated challenges and the utility of software tools, there remains a lack of clarity regarding their real-world performance and reliability, especially in Mediterranean regions like Cyprus.

Consequently, the principal aim of this study is to evaluate the accuracy and effectiveness of the iSBEM EPC, a widely utilized tool in Cyprus. This comparative analysis serves to uncover the reliability of the iSBEM EPC in practical applications and addresses an additional research gap pertaining to software precision. While recognizing that iSBEM EPC is not designed for direct measurements, being algorithmic in its approach to continuous comfort conditions, its widespread use in public and private sectors necessitates a thorough examination of its trustworthiness.

This study holds significant implications for policymakers, practitioners, and stakeholders in the building sector. By evaluating the accuracy and effectiveness of the iSBEM EPC, this research fills critical gaps in the wider understanding of building EPC, particularly in Mediterranean regions like Cyprus. Insights gained from this study can inform policy decisions, guide improvements in building energy efficiency regulations, and contribute to the development of more effective and sustainable building energy certification practices. Ultimately, this research aims to support efforts toward achieving energy efficiency goals, reducing greenhouse gas emissions, and enhancing the overall sustainability of the built environment.

To achieve the objectives set, the current research is structured in six sections. Following the introduction, the paper delves into existing research on EPC, underscoring the significance of considering user behavior and regional factors in building energy simulations. This comprehensive analysis sets the stage for the empirical section, which begins with the methodology. Here, the study's approach is outlined, detailing data collection methods and the selection of a representative building sample for comparison. Subsequently, the results section provides a comprehensive outline of the disparities between measured and simulated energy consumption using the iSBEM-Cy software, with a particular focus on household appliances and user habits. Following this detailed examination, the paper transitions to the discussion section, which reflects on the implications of the findings. Specifically, it emphasizes the necessity for adaptive methodologies that better accommodate diverse user behaviors and regional conditions, calling for collaborative efforts among policymakers, researchers, and industry experts to advance energy performance certification practices. Finally, the conclusions section succinctly summarizes the key findings and underscores the importance of continual improvement in energy performance prediction models to ensure they accurately reflect real-world energy usage, thereby contributing to sustainable construction practices and effective energy management in the built environment.

2. Literature Review

EPC is part of a rating scheme that delineates the energy efficiency of buildings and devices [55,67]. Within the building sector, three general categories describe the approach to building certification and energy efficiency improvement: asset rating, operational rating, and combined rating [68,69]. Asset rating centers on the primary energy required to meet predetermined theoretical energy efficiency standards, while operational rating assesses the consumed energy over a defined period compared to other buildings of a similar type [70,71].

2.1. EPC Global Significance and Challenges

EPC serves as a valuable global tool, providing engineers and consumers with insights into building energy performance and strategies for cost-effective enhancements [55,72]. A plethora of studies utilizing EPC software tools have concentrated on improving building energy performance through diverse scenarios, comparing and evaluating data derived from EPC [55,67,73,74]. Furthermore, certain studies have scrutinized EPC methods by juxtaposing measured and calculated energy ratings [75–77]. For instance, Charalambides et al. (2019) [78] conducted surveys across twelve European countries, revealing the significant role of EPC in guiding both renovation and property acquisition decisions, with 72% of the respondents acknowledging its importance.

EPC functions as an indicator of building energy performance, typically under EPBD guidelines [79]. However, while the directive outlines these guidelines, Member States have the flexibility to employ their calculation methods for energy performance and energy label designs, leading to a lack of uniformity across the EU [80]. This variation is particularly evident in the approach to energy performance assessment, with operational rating relying on actual energy use (measured) and/or asset rating based on assumed standard usage (calculated) [81]. Research by Semple and Jenkins (2020) [80] investigated EPC schemes in six countries, revealing how different methodologies can yield disparate conclusions about building stocks, while Ferrantelli and Kurnitski (2022) [82] found that EPCs issued using four distinct methodologies resulted varying, and at times unrealistic, renovation rates for Estonian building. These findings underscore the necessity for a standardized EPC energy labeling system.

Gonzalez-Caceres et al. (2020) [83] examined the recommended measures in EPC schemes and noted a lack of consistent design for engaging building owners, with limited information on implementation discouraging renovations. Previous research has highlighted the technical language and lack of user-friendliness in many EPC schemes [84–86]. Nonetheless, EPC has demonstrated its importance in improving energy efficiency and sustainability by evaluating building energy efficiency and carbon emissions as well as monitoring the EU's building stock [74,87].

Li et al. (2019) [55], in their analysis of the current EPC landscape in the EU, concluded that EPC information can be valuable for energy performance monitoring and building renovation planning. However, they note challenges that hinder its reliability as a tool for large-scale building renovations. Specifically, the lack of access to trustworthy information and financial support contributes to hesitations, resulting in a low refurbishment rate in the EU.

While the EPC has demonstrated its effectiveness globally, its implementation in the Mediterranean region presents unique challenges [88]. With diverse climatic conditions and architectural styles prevalent in countries surrounding the Mediterranean Sea (see [89]), the applicability and accuracy of EPCs require special consideration [32]. Research by Mediterranean-focused studies has highlighted discrepancies in energy performance assessments due to factors like high temperatures, extensive use of air conditioning systems, and architectural designs optimized for passive cooling [76,90–92]. These factors often lead to significant deviations between calculated and actual energy consumption, affecting the reliability of EPCs in the region [93,94]. Moreover, socioeconomic factors and varying levels of technological infrastructure further complicate the adoption of EPCs and hinder energy efficiency improvement initiatives [95,96]. Understanding these regional nuances is crucial for enhancing the effectiveness of EPCs and promoting sustainable building practices across the Mediterranean basin.

2.2. Discrepancies between Real and Simulated Data

The frequently observed poor quality of EPC limits its effectiveness in supporting building renovations because it may not accurately reflect actual energy performance, which can be influenced by user behavior [55,97]. Despite the establishment of EPC databases and quality control measures in most member states, the uncertainty in quality underscores the importance of quality control and the need for consistent input data [98,99].

Pérez-Lombard et al. (2009) [69] recommend that existing buildings utilize both calculated and measured ratings to assess energy performance. They advocate for a preference for measured rating to mitigate risks such as uneconomical retrofit investments or credibility issues. Measured ratings involve on-site energy metering, further categorized into asset and tailored ratings. For new buildings, the authors (*ibid*) recommend employing asset rating compared to reference values stipulated by regulations, which relies on standard usage patterns, independent of occupant behavior, actual weather, and indoor conditions.

Herrando et al. (2016) [100] employed the Calener GT energy simulation software to evaluate the energy performance of buildings based on specified general operating conditions. Their study, focusing on 21 faculty buildings in Spain, revealed an average 30% deviation between real and simulated energy consumption results. This discrepancy is attributed to the use of standard operating conditions in the software, which differ from actual conditions. A significant discrepancy, reaching up to 83%, was observed in some cases, where real consumption surpassed the simulated results. The study underscores user behavior in (public) buildings as a primary factor contributing to the gap between real and simulated data.

Fokaides et al. (2011) [101] conducted a study comparing the measured and calculated energy consumption of ten residential units in Cyprus. Employing a combination of questionnaires, energy consumption records, and the SBEM software, they found that, in some cases, the ratio of the average calculated to measured energy consumption exceeded 4. Furthermore, calculated primary energy consumption consistently surpassed measured consumption in all ten cases, indicating the significant impact of user behavior on measured energy consumption.

In a separate study in Cyprus, Dimitriou et al. (2020) [102] evaluated the energy and economic viability of various scenarios for a public office building, utilizing iSBEM and Design Builder. This research underscores the integration of energy and economic considerations in research, a well-established theme in energy-related discourse [103,104], often accompanied by policy analysis [105,106]. Their findings revealed that cooling, lighting, and equipment collectively contribute up to 85% of the total energy consumption in a typical office building in Cyprus. The study also concluded that while minimum energy performance requirements in Cyprus can reduce heating needs by 85%, the reduction in cooling needs is less effective at 50%.

Another study in Cyprus by Foikaides et al. (2014) [40] explored scenarios aimed at achieving zero-energy consumption residences following the implementation of EPBD regulations. Their results demonstrated a 40% reduction in energy consumption, underscoring the significance of European directives in promoting energy efficiency. The research team further concluded that technologies such as photovoltaics, solar thermal, and biomass for space heating directly contribute to reducing energy production from fossil fuels.

2.3. Research Gap and Objectives

While the existing body of literature extensively delves into EPC, a critical gap persists regarding studies scrutinizing the EPC accuracy vis-à-vis real-world data. These discrepancies often hinge on regional variations and building-type factors. This research endeavors to address this identified gap by providing a focused examination of the precision of the energy certification system in Cyprus, an aspect hitherto unexplored in current scholarship.

The paramount aim of this study is to conduct a meticulous comparison between measured and calculated ratings of an existing building, utilizing the Cyprus Government's building energy certification software, iSBEM-Cy. The evaluation of results will be conducted with scientific rigor, emphasizing consumption compliance by categorizing energy loads into specific end uses. This research, concentrating on a typical residence in Cyprus, aims to contribute valuable insights into the nuanced interplay between real-world energy consumption and iSBEM-Cy's computational outputs, thereby advancing our understanding of the practical efficacy of energy certification systems in the Cypriot context.

3. Methodology

The study aims to evaluate the energy performance of a typical residential unit in Cyprus through a comprehensive methodology employing both simulations (iSBEM-Cy) and real-world data. A representative partially insulated, 180 square-meter, four-bedroom residential unit in Limassol is selected to characterize the prevailing Cypriot building stock. Examination of passive envelope components and collection of construction and electromechanical system details precede the analysis of monthly electricity and oil bills. Using iSBEM-Cy, simulations are conducted under standardized operation schedules and climatic conditions, categorizing results into primary energy consumption for Heating, Cooling, Lighting, Auxiliary, and Hot Water. A subsequent comparison between real and simulated data enables the identification of deviations, essential for assessing the efficacy of the iSBEM-Cy system.

3.1. Cyprus Building Stock

Based on data from the Cyprus Statistical Service [www.cystat.gov.cy], the average floor area of dwellings in the last decade is 190 square meters and decreasing, with the majority being two-story structures [102]. Most of the Cypriot building stock was constructed before 2008 without any thermal insulation measures. Since 2008, the thermal insulation regulations have been gradually implemented in Cyprus, with the requirement that all new residences must be nearly Zero Energy Buildings (nZEB) from 2020 onwards [107]. The thermal insulation characteristics of most Cypriot residences are presented in Table 1 and are compared with the modern requirements of 2020, which apply to new residences.

Table 1. Comparison of the Cyprus' current building stock typical thermal conductivity coefficient values to the nZEB standards. Source: [107,108].

Thermal Conductivity Coefficient Values W/(m^{2}k)		
Element	**Cyprus Building Stock Typical Thermal Conductivity Coefficient Values (before 2008)**	**nZEB Standards (after 2020)**
External Walls	1.400	0.400
Roofs	3.300	0.400
Load Bearing Structures	2.800	0.400
Floors	2.000	0.400
Windows	6.000	2.250

Considering that 34% of the Cypriot building stock lacks any thermal insulation measures in its envelope [107], and only a small percentage of the existing building stock is nZEB, the selected building for this study should represent the transition from the pre-2008 era and the absence of thermal insulation measures to nZEB structures, serving as a sample of the current Cypriot building stock. Thus, for the assessment of iSBEM-Cy, a representative partially insulated, 180 square meters, four-bedroom residential unit in Limassol, Cyprus, is chosen, aiming to typify the residential building stock in Cyprus. All constructional details of the residence, as well as the type and efficiency of the electromechanical systems, are gathered. The total energy consumption of the residence is determined through monthly electricity bills from the Electricity Authority Cyprus (EAC) and oil bills, translated into primary energy. By considering the energy efficiency of the electromechanical systems and estimating the operation time for each system, the total energy consumption for Heating, Cooling, Lighting, Auxiliary, and Hot Water is recorded. Subsequently, all collected data on construction and electromechanical characteristics are input into the iSBEM-Cy software. Using standardized operation schedules and climatic conditions, energy performance calculations are conducted, categorizing results into primary energy consumption for Heating, Cooling, Lighting, Auxiliary, and Hot Water. The final step in the methodology involves a comparison between real and estimated consumptions, pinpointing deviations between real and simulated data for the same residence.

3.2. Data Collection

The subject of this study is a two-story, four-bedroom residential building located in Limassol, with a total usable area of 180.00 m^2 (155.84 m^2 thermal zone area, as entered in iSBEM). The initial phase of data collection focuses on the passive components of the building, commencing with the envelope. The building's envelope comprises insulated brick walls, columns lacking thermal insulation, and an insulated concrete roof. The windows are of the typical double-glazed variety without thermal improvement. The U-Values and the Cm of the elements of the building were calculated based on the official guide; Cyprus Building Energy Performance Calculation Methodology [109]. Table 2 presents the features of the existing envelope elements.

Table 2. Existing Building Masonry.

External Masonry		
Element	**U-Value W/(m^2k)**	**Cm (kJ/m^2K)**
External Wall (Insulated 29 cm)	0.684	116.000
Roof (Insulated 28.9 cm)	0.469	240.000
Load Bearing Structure 1 (No Insulation 29 cm)	1.667	228.000
Load Bearing Structure 1 (No Insulation 24 cm)	3.448	228.000
Windows	2.800	
Internal Masonry		
Internal Wall 1 (No Insulation 24 cm)	1.250	116.000
Internal Wall 2 (No Insulation 14 cm)	1.818	86.000
Internal Doors (5 cm)	2.155	18.000
First Floor Slab (No insulation 29 cm)	0.740	93.000

In juxtaposing the simulated and actual consumption, the total energy consumption for one year is documented using bills obtained from the Electricity Authority Cyprus (EAC). The chosen timeframe spans from December 2012 to the end of November 2013, with total consumption grouped every two months. The recorded consumption, as provided by EAC, is then converted into primary energy and expressed in primary energy per square meter to ensure comparability with the iSBEM-Cy results. These values are detailed in Table 3.

It is essential to highlight that the residence utilizes a diesel boiler with a performance factor of 0.90 for both heating and domestic hot water purposes. Throughout the investigation period, a total of 450 liters of diesel is consumed for heating and hot water. Consequently, the overall primary energy consumption for heating and hot water is calculated to be 5305.85 kWh, equivalent to 34.05 kWh/m^2. Of this total, 26 kWh/m^2 pertain to heating, while 8.05 kWh/m^2 are attributed to hot water.

Table 3. Recorded Consumption.

Period	Recorded Consumption from EAC (kWh)	Primary Energy Consumption (kWh)	Primary Energy Consumption (kWh/m^2)
December 2012–January 2013	890.06	2403.16	15.42
February–March 2013	761.1	2054.97	13.19
April–May 2013	643.09	1736.34	11.14
June–July 2013	786.03	2122.28	13.62
August–September 2013	661.02	1784.75	11.45
October–November 2013	696.06	1879.36	12.06
Total	4437.36	11,980.87	76.88

4. Results

Following a comprehensive analysis of the collected data, the results are presented herein. A meticulous examination of all electricity-consuming devices, encompassing both indoor and outdoor installations, was conducted throughout the selected timeframe. Device consumption is assessed on an annual basis, with classifications based on energy consumption levels by estimating the operational durations for each device. The ensuing graphical representation categorizes consumption into distinct segments, including lighting, cooling, and home appliances. This analytical breakdown is paramount, particularly given the omission of home appliances in iSBEM-Cy, as depicted in Figure 1, highlighting their significant role in overall energy consumption.

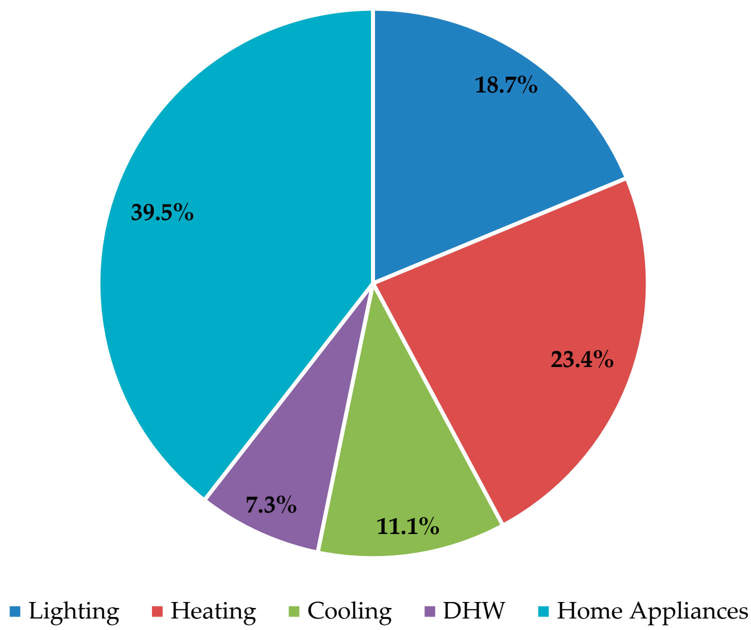

Figure 1. Energy Consumption Percentage Per Use.

The percentage analysis of household energy consumption reveals that the use of household appliances accounts for 39.5% of the total household energy consumption. This finding is noteworthy as this energy consumption is entirely user-dependent and not readily replicable, posing a challenge in transparently representing the energy footprint of each building.

Subsequently, Figure 2 presents the total energy consumption for lighting, heating, cooling, hot water, and home appliances per square meter of the building.

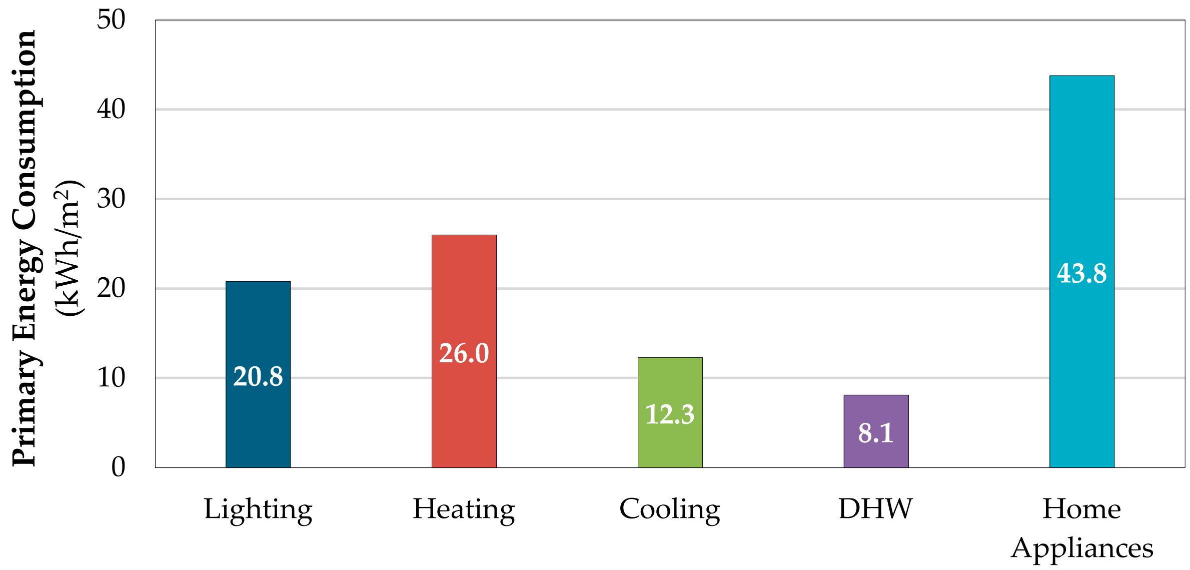

Figure 2. Primary Energy Consumption of the Actual Building.

The total energy consumption of the actual building amounts to 111 kWh/m^2, of which 43.8 kWh/m^2 is attributed to household appliances. Since household appliances are not considered in iSBEM-Cy, a comparable figure for analysis is adjusted to 67.2 kWh/m^2. Notably, the lowest energy consumption is observed for Domestic Hot Water purposes, while heating registers the highest energy consumption after household appliances, accounting for 26 kWh/m^2. It is noteworthy that the actual cooling consumption is lower than the heating needs, a seeming paradox considering the climatic conditions in Cyprus. This observation may be interpreted by the incorporation of fundamental bioclimatic elements in the building's design and adequate, though not complete, thermal insulation. Furthermore, the usage of air conditioning systems is influenced by the user's subjective perception, significantly impacting the final energy consumption of the building.

Comparison with iSBEM

iSBEM-Cy computes the total primary energy consumption for cooling, heating, lighting, and domestic hot water. The simulated building's total annual primary energy consumption is calculated at 320 kWh/m^2. As depicted in Figure 3, a significant deviation exists between the actual primary energy production and the simulated results, reaching up to 377.4%. The actual building's energy consumption is 67.2 kWh/m^2, contrasting with the iSBEM-Cy-modeled consumption of 320 kWh/m^2. The discrepancy ratio in annual consumption for lighting, heating, cooling, and domestic hot water amounts to 4.77.

For a more detailed analysis of the results, it is essential to categorize the energy consumption by use, as illustrated in Figure 4. Notably, the deviations for heating loads and Domestic Hot Water are −25% and 7%, respectively. However, there is a significant deviation for Lighting, amounting to 114%, while the deviation for Cooling is exceptionally high, reaching 1908%, with a ratio as high as 20. The smallest deviation is observed in the energy consumption for Domestic Hot Water, with a margin of up to 7%.

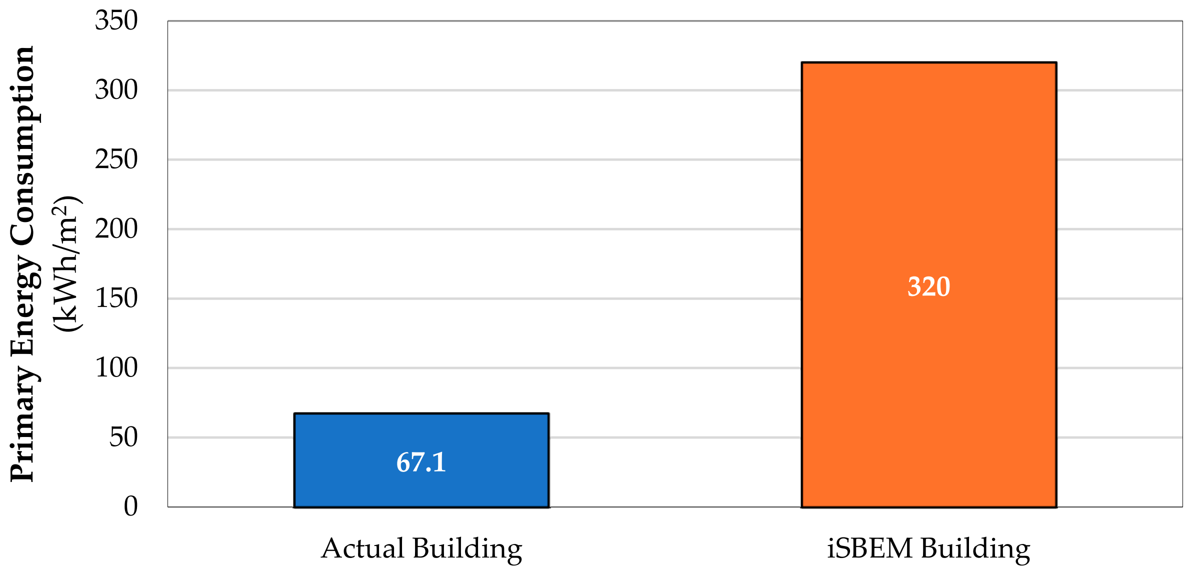

Figure 3. Energy Consumption Comparison between Actual Building and iSBEM.

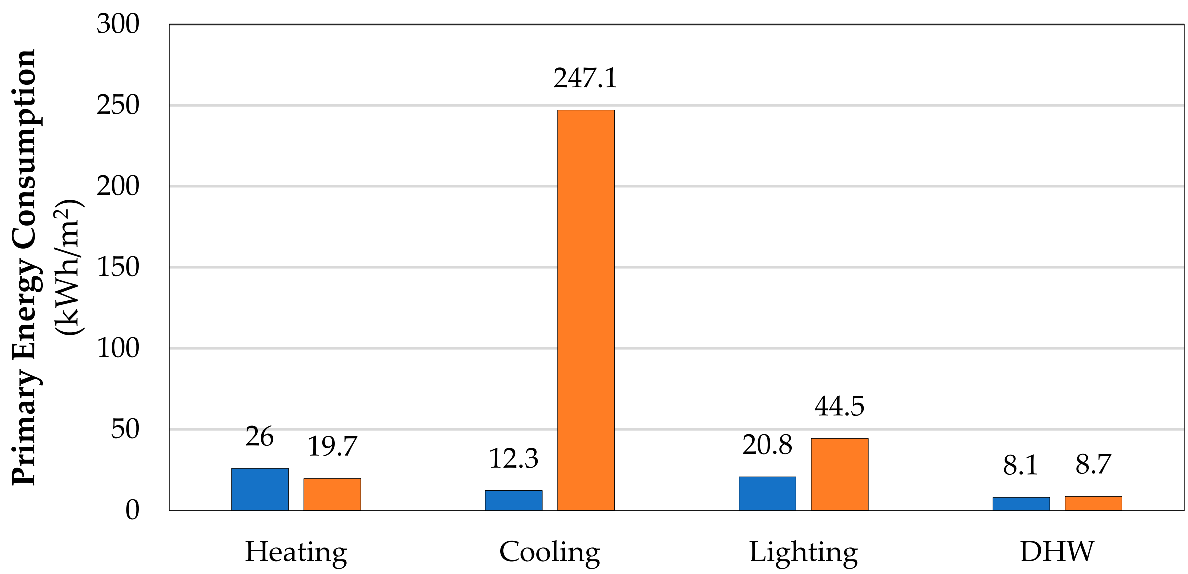

Figure 4. Categorization of the primary energy consumption per use.

5. Discussion

The results of this study bring to light substantial disparities between real-world and simulated data, emphasizing the pivotal role of user behavior and the limitations inherent in the current certification methodologies.

Upon examining household energy consumption, it becomes evident that user-dependent factors, particularly those related to household appliances, account for a significant portion, approximately 39.5%, of the total household energy usage. This finding, on the one hand, aligns with previous studies emphasizing the importance of considering user behavior in building energy simulations [110]. On the other hand, this reliance on user behavior introduces complexities in accurately representing the energy footprint of buildings, as individualized consumption habits are challenging to replicate uniformly within simulation frameworks.

In comparison to iSBEM-Cy, the software exhibits commendable accuracy in certain aspects, such as calculating heating and domestic hot water consumption, with deviations of −25% and 7%, respectively. However, a more profound analysis exposes the software's limitations in predicting user behavior, especially concerning lighting and cooling. Notably, there is a considerable deviation of 114% in lighting and an alarming 1908% deviation in cooling, with a ratio as high as 20. These discrepancies underscore the critical importance of user-specific behavior, such as limited use of cooling systems during the day and adoption of alternative cooling methods like mobile fans, which are not adequately accounted for by the software algorithms. In particular, regarding lighting, deviations can be explained by users' habits and their preferences in lighting fixtures. This discrepancy is less worrisome as such detailed user behavior cannot be inputted into the software, which is primarily designed for energy certification, rather than building design. Conversely, the substantial deviation in cooling can be traced to the software inability to accommodate user-specific behaviors, such as the reduced use of cooling systems during certain times and reliance on mobile fans (averaging 1.7 kWh/m^2) instead of HVAC systems. These factors are not encompassed within the software's algorithms. This elucidation underscores the critical role of user behavior in shaping energy consumption patterns and underscores the necessity for enhanced algorithms capable of capturing such nuanced dynamics for more accurate building energy simulations.

Furthermore, it is essential to note that the iSBEM-Cy certification system operates within specific parameters, such as mandating the introduction of certain systems, like the "Split unit with oil boiler heating source 0.9 and cooling with seasonal efficiency 3.2" into the software for zones without air conditioning. However, in cases where there are no air conditioning units, the software calculates cooling loads based on these conditions. While these characteristics align with the software's intended use for comparative building energy certification, they underscore the importance of applying methodologies that closely align with both certification requirements and the actual energy dynamics in the existing building stock.

The assessment of Cyprus' iSBEM-Cy certification system for a representative four-bedroom residential unit in Limassol reveals critical disparities between simulated and actual energy consumption. These disparities particularly pronounced in the context of household appliances and user habits, emphasize the urgent need for refined certification methodologies. Spherically, the identified limitations of iSBEM-Cy, especially its oversight of household appliances constituting nearly 40% of total energy consumption, underscore a crucial blind spot in current certification frameworks.

Addressing these discrepancies effectively requires a shift towards adaptive systems that integrate real-world data, accounting for diverse user behaviors and regional climatic conditions. Collaborative efforts among policymakers, researchers, and industry experts are necessary to evolve certification systems, fostering a more accurate, adaptive, and user-centric approach.

In specific terms, the actual building's total energy consumption is measured at 111 kWh/m^2, with 43.8 kWh/m^2 attributed to household appliances. This stark contrast with the iSBEM-Cy simulation, which calculates a total annual primary energy consumption of 320 kWh/m^2, reveals a significant deviation of 377.4% from the actual building's consumption. The observed 'paradox' in the balance between cooling and heating further highlights the need for adaptive methodologies that better accommodate diverse user habits.

Moving forward, actionable steps must be taken to enhance the accuracy of energy performance certification. Policymakers should consider implementing adaptive methodologies that better accommodate diverse user habits, while researchers and industry experts collaborate to refine existing frameworks. These advancements are pivotal not only for the effectiveness of energy performance certification but also for broader goals of sustainability and environmental responsibility in the built environment.

While this study has highlighted the disparities between iSBEM-Cy simulations and actual energy data for a building, further research is necessary to identify specific trends in these deviations. A more extensive analysis of additional case studies is planned to identify specific trends in these deviations. Incorporating these trends into iSBEM-Cy results aims to continually improve the accuracy of outcomes and contribute to the ongoing dialogue surrounding sustainable construction practices and energy certification.

6. Conclusions

This study aimed to scrutinize the effectiveness of energy performance certification, particularly focusing on the disparities between iSBEM-Cy simulations and actual energy data for buildings. Through a comprehensive analysis, the study revealed significant discrepancies between simulated energy performance and real-world energy consumption. These findings underscore the necessity for ongoing research to refine predictive models and enhance the accuracy of energy performance certification.

All in all, the study emphasizes the importance of continual improvement in energy performance prediction models to ensure they accurately reflect real-world energy usage. Such enhancements are crucial not only for regulatory compliance but also for advancing sustainable construction practices. Furthermore, the findings underscore the need for broader analysis encompassing diverse case studies to discern overarching trends and refine predictive algorithms, ultimately contributing to environmental sustainability and effective energy management in the built environment.

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