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A Rapid Calibration Method for Energy Models of Rural Guesthouses: A Case Study from Zhejiang, China#

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ABSTRACT

Rural-residence-converted guesthouses often suffer from high energy consumption and a lack of effective energy-saving measures, indicating a significant potential for efficiency improvements. This study proposes a practical and rapid calibration method for energy simulation models tailored to such buildings, where guestroom occupancy status is treated as an optimization variable. By minimizing the monthly deviation between simulated and actual energy consumption, efficient initial calibration is achieved. Using a typical guesthouse in Zhejiang Province as a case study, the optimization results show monthly energy deviations ranging from 0.05 to 23.75 kWh, with corresponding occupancy rates between 20% and 80%. The calibrated model achieved a Normalized Mean Bias Error (NMBE) of 0.067% and a Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) of 0.947%, both satisfying the accuracy criteria of ASHRAE Guideline 14. The proposed method provides an efficient and practical approach for calibrating energy models in guesthouse buildings, serving as a foundation for subsequent energy retrofit planning.

Keywords: Guesthouses, Building energy simulation, Energy model calibration, Occupancy-based, optimization

NOMENCLATURE

Abbreviations	
BES	Building Energy Simulation
GA	Genetic Algorithm
HVAC	Heating, Ventilation, and Air Conditioning
NMBE	Normalized Mean Bias Error
CV(RMSE)	Coefficient of Variation of the Root Mean Square Error
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Symbols	
E_{sim}	Simulated monthly energy consumption (kWh)
E_{actual}	Actual monthly energy consumption (kWh)
x_i	Occupancy status of the *i*-th guestroom (1 = unoccupied, 0 = occupied)

1. INTRODUCTION

The rapid growth of the homestay industry has become a key driver of rural revitalization in China. As defined in the *Basic Requirements and Evaluation of Tourist Homestays (LB/T 082-2021)*, homestays utilize private or idle residences to accommodate travelers [1]. By 2022, the national online transactions in the homestay sector exceeded 20 billion yuan, with Zhejiang Province leading the market—hosting over 25,000 homestays and generating nearly 10 billion yuan annually [2]. However, the widespread conversion of rural homes into guesthouses often lacks energy-efficient design, resulting in significantly increased energy consumption [3]. This highlights the urgent need for effective strategies to improve energy performance in homestay buildings.

Building Energy Simulation (BES) is a proven tool for assessing retrofit strategies in rural buildings [4,5]. Yet, many studies neglect model calibration, which is essential for ensuring the accuracy and practical reliability of simulation results [6]. In the context of homestays, proper calibration not only enhances

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prediction accuracy but also supports energy-saving design and improved indoor comfort.

This study presents a rapid calibration method for energy simulation models of rural guesthouses, addressing the challenge of missing occupancy data. By estimating occupancy from monthly energy bills and evaluating model accuracy using NMBE and CV(RMSE), the method enables efficient calibration under data-limited conditions. A case study in Zhejiang demonstrates its effectiveness and applicability for energy-efficient retrofitting and sustainable operation.

2. METHODS

Due to the informal and inconsistent management of rural homestays, operators typically lack accurate records of monthly occupancy rates. However, most are able to obtain historical monthly energy consumption records from the State Grid. These energy bills are a practical and feasible data source for calibrating building energy simulation (BES) models in the rural homestay context.

Accordingly, this study proposes a rapid calibration methodology specifically designed for rural homestay buildings. The procedure comprises the following four main steps:

(1) **Data Collection**: Monthly energy consumption records and key building characteristics are collected to support model development and calibration.

(2) **Modeling and Parameter Setup**: A building energy simulation model is constructed using the collected data, with relevant physical and operational parameters set accordingly.

(3) **Occupancy Rate Estimation and Analysis**: The occupancy status of each guestroom (occupied/unoccupied) is treated as an optimization variable. Monthly occupancy rates are estimated by minimizing the deviation between simulated and actual monthly energy consumption, and the inferred results are compared with real-world usage to verify consistency.

(4) **Monthly Accuracy Calculation**: The accuracy of the model is evaluated by calculating NMBE and CV(RMSE) for each month's energy use, following ASHRAE Guideline 14, to ensure the model meets acceptable accuracy thresholds.

This rapid calibration approach improves the reliability of BES models for rural homestays, offering a practical tool for evaluating energy performance and informing future energy-efficient design and retrofitting strategies.

2.1 Data Collection

2.1.1. Case Location and Climate Data

The chosen case study is situated in Zhijiang Village, Jiande City, in Zhejiang Province, as depicted in Fig. 1. The region experiences an average annual temperature of about 18.6 °C. January is typically the coldest month, with an average temperature of approximately 6.6 °C, while July is the warmest month, with an average temperature reaching around 30.4 °C. To improve the simulation's accuracy, weather data from the nearest meteorological station, located approximately 32 km from Zhijiang Village, is used as input for the simulation.

Fig. 1 The location of Zhijiang Village

2.1.2. On-site Measurement Data

The subject of this case study was a three-story rural homestay, originally built in 2009 as a residential house with a brick-concrete structure. The homestay was managed by an elderly operator, approximately 60 years old, who was responsible for daily operations but did not reside in the building. Due to relatively informal management, she was unable to provide precise monthly occupancy data and could only indicate that the homestay experienced peak occupancy during the winter and summer holiday seasons.

A detailed site survey was conducted, resulting in the floor plans shown in Figure 2. The total building area was calculated to be 426.76 m². The ten guest rooms were distributed across the first, second, and third floors. Table 1 presents the basic information on the building envelope, obtained through interviews and on-site observations. Since all major energy-consuming appliances—such as air conditioners and water heaters—had been uniformly procured and installed in recent years, relatively detailed equipment specifications were available and are summarized in Table 2.

Fig. 2 On-site case photos and floor plans

Table 1
Basic Information of the Building Envelope

Item	Description
Roof	(From outside to inside) 1. Roof Tiles 2. Wooden Trusses 3. Ceiling 4. Reinforced Concrete (100 mm)
Exterior Walls	(From outside to inside) 1. Paint and Mortar (10 mm) 2. Fired Brick (240 mm) 3. Mortar and Paint (10 mm)
Exterior Floor	(From outside to inside) 1. Cement Mortar (10 mm) 2. Reinforced Concrete (100 mm) 3. Mortar and Paint (10 mm)
Interior Floors	1. Mortar and Paint (10 mm) 2. Reinforced Concrete (100 mm) 3. Mortar and Paint (10 mm)
Window Type	Single-glazed with Aluminum-Plastic Frame
Shading Type	Concrete Overhang Panel (200 mm extension)
Exterior Door	Single-glazed Aluminum Door

Table 2
Main Energy-Consuming Equipment and Lighting

Item	Location	Performance
Air Conditioner 1-10	Guest Room 1-10	Cooling + Heating, Annual Energy Efficiency Ratio (EER) 3.30
Air Conditioner 1	Living Room	Cooling + Heating, Annual Energy Efficiency Ratio (EER) 3.00
Electric Water Heater	Bathroom	50 L, 80% heating efficiency
Lighting	LED	Performance details unavailable

Although the homestay owner could not provide accurate occupancy rate data, she was able to obtain complete monthly energy consumption records from the State Grid through identity verification. Figure 3 shows the monthly energy consumption record for the year 2023, as provided by the owner.

Fig. 3 Monthly Energy Consumption List

2.2 Modeling and Parameter Setup

The optimization process in this study was conducted in Rhino using the Grasshopper plugin. First, parametric modeling and visualization of the building form were completed using Rhino and Grasshopper. Subsequently, a performance simulation model was developed within Grasshopper, integrating the Honeybee and Ladybug plugins. The simulation results were then linked to the Wallacei plugin for optimization.

Table 3 summarizes the key input information required for the building energy simulation. The data sources and references are based on the findings presented in Section 2.1 and relevant regulatory standards[7–9].

Table 3
Initial Parameter Setup

Parameter		Description
Climate Data		CHN_China/ZJ_Zhejiang/CHN_ZJ_Chunan-Qiandao.Lake.585430_TMYx.epw
Total Building Area / Air-conditioned Area		426.76 m²/224.99 m²
Airtightness		0.0006
U-value	Roof Exterior Walls Exterior Floor Interior Walls	Modeling and Calculation using Honeybee Plugin Based on Table 1

Interior Floors Exterior Door External Window U-value (SHGC)	6.0 W/(m²·K) (SHGC = 0.75)
Lighting Power Density	5.0 W/m²
Equipment Power Density	3.8 W/m²
Air Conditioning Set Temperature	Heating: 22 ℃ Cooling: 24 ℃
Air Conditioning Operating Time	Heating: Active when indoor temperature < 22°C Cooling: Active when indoor temperature > 24°C
Air Conditioning APF	3.0 [(W·h)/(W·h)] / 3.3 [(W·h)/(W·h)]
Domestic Hot Water System Efficiency	80% heating efficiency
Domestic Hot Water System Operating Time	07:00–09:00, 20:00–22:00

2.3 Occupancy Rate Estimation

The case study includes a total of ten guest rooms, with the occupancy status of each room defined as an optimization variable. Each room has two possible states: "occupied" and "unoccupied." To ensure that the simulated monthly energy consumption closely matches the actual consumption, the optimization objective is to minimize the absolute difference between the simulated and actual monthly energy use. This process is formulated as a single-objective optimization problem, which can be expressed mathematically as follows [10]:

$$\min |E_{sim}(x) - E_{actual}| \quad (1)$$

$$\text{Subject to: } x_i \in \{0,1\}, \ i=1,2,...,10$$

In Equation (1), x_i=0 indicates that the i-th guest room is in the occupied state, while x_i=1 indicates that it is in the unoccupied state. $E_{sim}(x)$ represents the simulated energy consumption based on the optimization variable (i.e., the occupancy status of the guest rooms), and E_{actual} denotes the actual energy consumption.

To efficiently obtain the optimal solution, this study employed the Genetic Algorithm (GA) as the optimization method. GA is a type of evolutionary algorithm that simulates the principles of natural selection and genetics, seeking optimal solutions by mimicking the evolutionary process in nature [11]. In this study, the optimization process was implemented within Grasshopper using the Wallacei plugin. Ultimately, the optimal solution obtained from the optimization results was used to determine the monthly occupancy rates of the guest rooms.

2.4 Model Accuracy Evaluation

This study uses NMBE and CV(RMSE) for model calibration:

$$NMBE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n} \times 100 \quad (2)$$

$$CV(RMSE) = \frac{\sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{n}}}{\bar{y}} \times 100 \quad (3)$$

In equations (2) and (3), y_i represents the actual values, $\hat{y}_i$ represents the predicted values, n is the sample size, and $\bar{y}$ is the average of the actual values [12,13].

After obtaining the simulated and actual energy consumption values for each month, the monthly NMBE and CV(RMSE) can be calculated. According to ASHRAE Guideline 14, the absolute value of NMBE should be within 5%, and CV(RMSE) should not exceed 15%. These thresholds are used to evaluate the accuracy of monthly energy model performance.

3. RESULTS AND DISCUSSION

3.1 Optimization Trends

As shown in Fig. 4, the optimization results across all months exhibit a clear pattern of rapid and stable convergence. Fitness values drop sharply in the first few generations, then level off as the algorithm approaches optimal solutions. The narrowing gap between maximum, mean, and minimum fitness indicates effective convergence and improved solution quality. In summary, the algorithm performs consistently and robustly under varying monthly conditions.

Table 4 shows the optimization results and the corresponding occupancy rates.

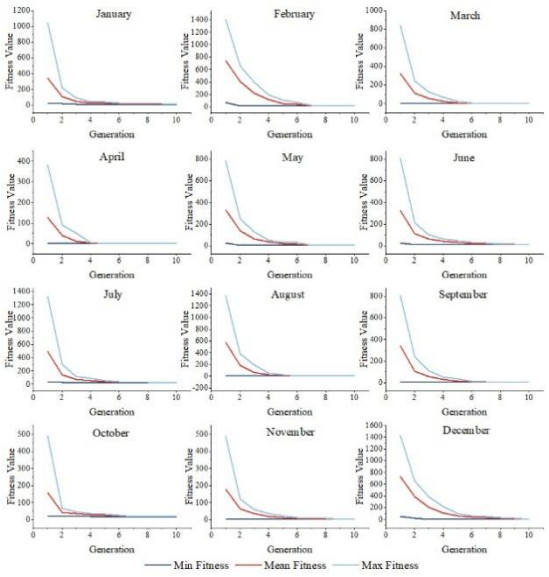

Fig. 4 Monthly Optimization Trends

Table 4
Optimization Results

Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum deviation between actual and simulated energy consumption (kWh)	1.89	16.93	0.16	0.05	3.86	7.8	23.74	2.62	1.49	16.29	1.19	3.27
Occupancy rate	0.6	0.2	0.4	0.6	0.8	0.5	0.8	0.4	0.4	0.6	0.5	0.2

3.2 Analysis of Occupancy Rate Reasonableness

Due to the absence of actual occupancy data, this study assesses the reasonableness of the estimated occupancy rates by examining their correlation with measured energy consumption. As shown in Figure 5, a general positive correlation is observed, indicating that occupancy has a significant impact on energy use in guesthouse-type buildings. Some deviations occur in months such as May and October, when occupancy rates are high due to holiday tourism (Labor Day and National Day), yet energy consumption remains relatively low due to mild weather and minimal HVAC demand. In contrast, January and July—corresponding to winter and summer vacations—exhibit both high occupancy and elevated energy use due to heating and cooling needs. Overall, the occupancy rates estimated by the optimization algorithm align well with operational patterns, supporting their plausibility.

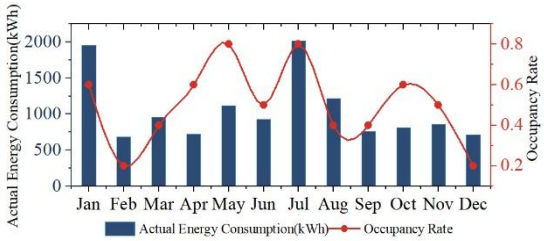

Fig. 5 Correlation of Estimated Occupancy Rates and Energy Consumption

3.3 Monthly NMBE and CV(RMSE) Calculation

Figure. 6 presents a comparison between the simulated and measured monthly energy consumption. The results show an NMBE of 0.067% and a CV(RMSE) of 0.947%, both well within the acceptable thresholds specified by ASHRAE Guideline 14 (NMBE ≤ 5%, CV(RMSE) ≤ 15%), indicating that the simulation model has been effectively calibrated.

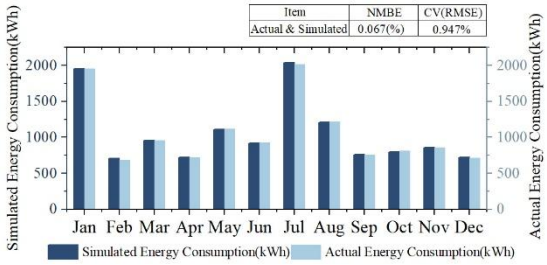

Fig. 6 Comparison of Monthly Simulated and Actual Energy Consumption

4. CONCLUSIONS

This study proposes a rapid calibration method for building energy simulation models tailored to rural-residence-converted guesthouses, addressing the common challenge of unavailable occupancy data. By introducing room occupancy status as an optimization variable and minimizing the deviation between simulated and actual monthly energy consumption, the method enables efficient model calibration under data-scarce conditions. Optimization results demonstrate rapid and stable convergence across all months, indicating strong robustness and adaptability of the algorithm.

In the case study, the monthly energy deviation ranged from 0.05 to 23.74 kWh, and the estimated occupancy rates varied between 20% and 80%. The overall trend of the occupancy estimates exhibited a positive correlation with actual energy consumption, supporting their plausibility. Specifically, January and July showed concurrent increases in both occupancy and energy use due to seasonal HVAC demands, while May and October—despite high occupancy during holiday periods—had relatively low energy consumption, attributed to moderate outdoor temperatures. These patterns further confirm the credibility of the optimization-based occupancy estimates.

The calibrated model achieved an NMBE of 0.067% and a CV(RMSE) of 0.947%, significantly outperforming the ASHRAE Guideline 14 thresholds. These results validate the method's effectiveness and accuracy under limited data conditions.

However, the method's reliability depends on the correctness of the underlying energy model structure and parameter settings. It is most suitable for buildings with detailed architectural and equipment information. Inaccurate model assumptions may lead to "false calibration" effects, where occupancy adjustments mask model deficiencies. Future work will focus on enhancing the robustness and generalizability of the method for more complex and data-deficient scenarios.

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