Energy Proceedings
Vol 59, 2025
ISSN 2004-2965

Bi-Objective Optimization of Buildings Based on the Four Seasons: A Case Study of Traditional Dwellings in Huzhou, Zhejiang Province#

Chen Chen[1], Dewancker Bart Julien[1], HuiFang Wang [1,*]

[1] Graduate School of Environment Engineering, The University of Kitakyushu, Kitakyushu 8080135, Japan

([*]Corresponding Author: whf2504885207@gmail.com)

ABSTRACT

This study proposes a seasonal multi-objective optimization framework for building performance, addressing the balance between carbon emissions and indoor discomfort in traditional dwellings. Using a typical residential building in Huzhou, China, simulations were conducted for spring, summer, autumn, and winter using DesignBuilder and MATLAB. The results reveal significant seasonal differences: winter and summer exhibit the highest emissions and discomfort, while spring and autumn offer better energy-comfort balance. A genetic algorithm was employed to generate Pareto-optimal solutions, and sensitivity analysis identified key design parameters—such as heating/cooling setpoints and window-to-wall ratio—as dominant factors. The findings provide practical guidance for adaptive, season-specific building energy strategies.

Keywords: Genetic algorithm; building energy consumption; comfort; multi-objective optimization;

NONMENCLATURE

Abbreviations	
GA	Genetic algorithm
EA	Evolutionary Algorithm

1. INTRODUCTION

As global energy demand increases and climate concerns intensify, the building sector has become a critical focus for energy efficiency and carbon reduction. According to the International Energy Agency, buildings are responsible for over 30% of global energy use and nearly 28% of CO_2 emissions, much of which stems from operational needs such as heating and cooling. This challenge is especially acute in developing regions, where limited access to efficient building technologies leads to higher energy consumption and environmental impact[1].

Seasonal climate variation plays a key role in building performance. In summer, high cooling demand strains energy systems and increases emissions; in winter, heating requirements—often reliant on fossil fuels—lead to peak carbon output. Yet most existing optimization approaches are based on annual average conditions, overlooking the substantial differences in energy demand and comfort needs between seasons. This can result in design strategies that are inefficient or even counterproductive in practice.

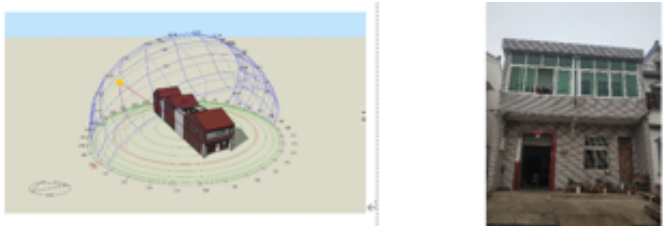

Fig. 1 Measured buildings and models in designbuilder

To address this gap, recent studies have introduced multi-objective optimization methods that consider both energy use and indoor comfort. Tools such as genetic algorithms and simulation platforms like DesignBuilder make it possible to explore trade-offs between conflicting objectives. However, many models still treat buildings uniformly throughout the year, without fully addressing seasonal dynamics.

In this study, we propose a bi-objective optimization framework that evaluates building performance across all four seasons—spring, summer, autumn, and winter—focusing on the dual goals of reducing carbon emissions and minimizing thermal discomfort. The analysis is based on a real-world rural residence in Huzhou, Zhejiang Province, modeled in DesignBuilder with detailed environmental (figure 1), structural, and operational data. By incorporating season-specific meteorological inputs and simulating dynamic thermal behavior, the study aims to provide practical, climate-responsive design guidance for low-carbon and comfortable buildings in similar regions[2, 3].

This is a paper for the 11th Applied Energy Symposium: Low Carbon Cities & Urban Energy Systems (CUE2025), July 18-22, 2024, Kitakyushu, Japan.

2. METHODOLOGY

This study employs a simulation-based bi-objective optimization framework to assess and enhance the energy performance and thermal comfort of a rural residential building across the four seasons—spring, summer, autumn, and winter. A traditional self-built dwelling located in Huzhou, Zhejiang Province, was selected as the research object. The building represents typical rural construction practices in southern China, using brick and concrete materials and featuring basic thermal insulation and ventilation characteristics.

Fig. 2 Instruments for measuring data

The building was modeled in DesignBuilder software, which allowed for precise three-dimensional construction of its architectural form and thermal zones. The physical properties of building materials, HVAC system configurations, window-to-wall ratios, and occupancy schedules were defined based on both on-site measurements and recognized design standards, particularly ASHRAE 90.1. As shown in Figure 2, to ensure the realism and accuracy of the simulation, local meteorological data—including temperature, humidity, solar radiation, and wind speed—were incorporated for each season. Moreover, smart sensors were deployed inside the dwelling to record indoor temperature, humidity, energy consumption, and CO_2 concentration, which were then used to validate the simulation outputs[4-6].

The core of the methodology lies in a bi-objective optimization strategy that aims to minimize both seasonal carbon emissions and occupant thermal discomfort. Carbon emissions were calculated based on the building's total electricity consumption and a standard carbon emission coefficient. Discomfort was defined as the cumulative number of hours when indoor temperatures exceeded the acceptable comfort range (18–26°C). These two objectives are often conflicting, as reducing emissions through tighter temperature control can lead to increased discomfort, and enhancing comfort typically requires more energy[7, 8].

To address this trade-off, a genetic algorithm was implemented in MATLAB to explore the optimal combination of design and operational parameters. The optimization variables included heating and cooling setpoint temperatures, equipment power density, infiltration rates, airtightness, and shading coefficients. These parameters were selected for their strong influence on building thermal performance and were assigned realistic ranges to reflect practical design flexibility.

The optimization process consisted of four key stages. First, a seasonal simulation was conducted in DesignBuilder under varying configurations. Next, the simulation outputs—seasonal energy use, carbon emissions, and discomfort hours—were fed into MATLAB. There, the genetic algorithm iteratively evaluated and evolved potential solutions, identifying non-dominated ones that formed the Pareto frontier. Finally, these frontiers were analyzed to reveal the best trade-offs between emissions and comfort for each season. A sensitivity analysis was also performed to determine the relative influence of each variable on the optimization outcomes[9].

This methodology allows for a seasonally adaptive and data-informed understanding of how building performance can be improved not only in an average annual sense, but with respect to the unique energy and comfort challenges posed by each season.

3. RESULTS AND ANALYSIS

3.1 Seasonal Performance Patterns

The simulation results for House, analyzed under four seasonal conditions using DesignBuilder, show substantial variation in both carbon emissions and discomfort. In winter, carbon emissions reached the highest levels, peaking at 30.0 kg CO_2, with discomfort hours averaging 9.5 hours per day. These outcomes are primarily due to prolonged heating periods, limited insulation, and infiltration losses in the building envelope.

In summer, while total carbon emissions were slightly lower at 22.5 kg CO_2, discomfort remained elevated at 7.8 hours. This is attributed to high solar radiation, elevated cooling demand, and limited shading or envelope reflectivity. These two extreme seasons thus represent the most energy-intensive and comfort-challenged scenarios.

Conversely, spring and autumn performed significantly better in both metrics. In spring, carbon emissions were as low as 10.5 kg CO_2, with discomfort limited to 3.2 hours. Autumn performed slightly better, with 9.5 kg CO_2 in emissions and 2.8 discomfort hours. These transitional seasons benefited from milder outdoor temperatures, greater natural ventilation

potential, and reduced reliance on mechanical systems, suggesting ideal conditions for passive design interventions.

3.2 Pareto Frontier Analysis

Figure 3 illustrates the Pareto-optimal points across all four seasons, mapping the trade-off between carbon emissions and discomfort. Notably, the summer curve (orange) reveals that increasing emissions from 4000 kg to 7000 kg—a 75% rise—can reduce discomfort from 1600 hours to 700 hours, achieving a 56.25% reduction in discomfort. This shows that summer performance can be significantly improved with modest energy input increases.

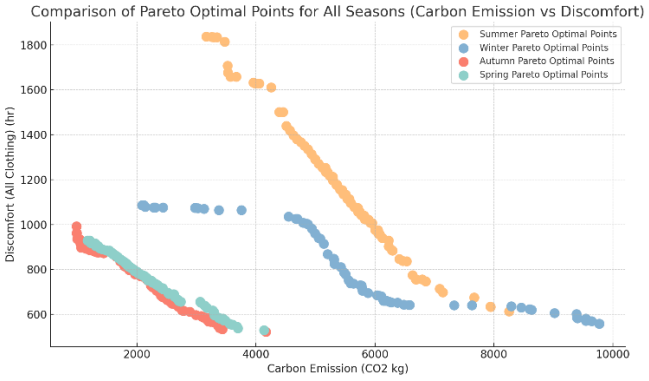

Fig. 3 Pareto front diagram for four seasons

A similar trend is observed in winter (blue). Emissions rise from 4000 kg to 6000 kg (a 50% increase), while discomfort drops from approximately 1100 to 350 hours, amounting to a 68.18% improvement. These data indicate that moderate increases in energy consumption during extreme seasons can produce substantial improvements in occupant comfort.

In contrast, spring and autumn show flatter Pareto fronts, where comfort can be maintained at a high level with relatively low carbon emissions. For example, in both seasons, optimal points stay within 1000–4000 kg CO_2 while keeping discomfort hours under 800. This further supports the idea that spring and autumn are inherently more efficient periods for energy use and thermal regulation.

3.3 Sensitivity Analysis

A radar-based sensitivity analysis (see Figures 4) reveals that the heating setpoint in winter and the cooling setpoint in summer are the most influential parameters on both carbon emissions and discomfort. In spring, the heating setpoint showed an impact coefficient close to 0.9 for emissions, while air conditioning temperature strongly influenced discomfort ($\approx$ 0.6). In summer, the cooling setpoint contributed nearly 0.7 to emission sensitivity and 0.9 to discomfort, underscoring the importance of HVAC control.

Fig. 4 Radar chart of impact factor values in spring and summer

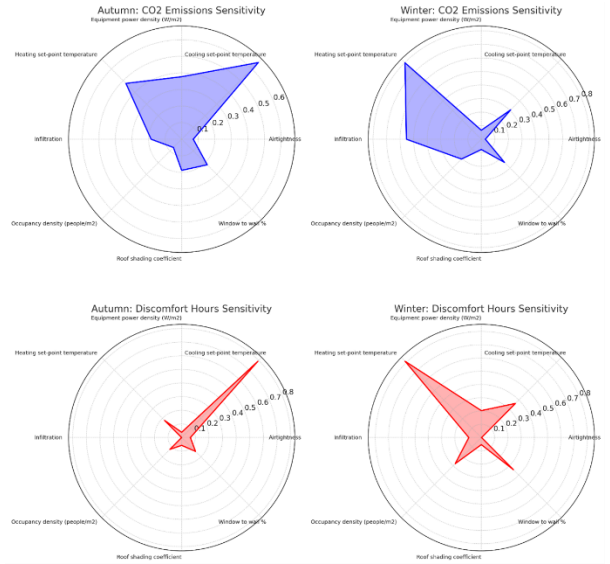

Fig. 5 Radar chart of impact factor values in autumn, winter and summer

In autumn, the air conditioning setpoint remained the dominant factor (impact =0.8), while in winter, both heating setpoint and airtightness exhibited strong influence on discomfort (coefficients around 0.8 and 0.3, respectively).

Interestingly, window-to-wall ratio consistently affected both metrics across all seasons, reflecting its dual role in daylighting and thermal transfer. Meanwhile, equipment power density notably affected emissions but had little influence on discomfort, suggesting that

internal load management is more critical for emissions control than for thermal comfort.

4. CONCLUSIONS

This study proposes a seasonally segmented bi-objective optimization framework to evaluate and improve the energy performance and thermal comfort of rural residential buildings. Using a traditional dwelling in Huzhou, Zhejiang Province as a case study, the research integrates dynamic simulation and genetic algorithm optimization to assess trade-offs between carbon emissions and thermal discomfort across spring, summer, autumn, and winter.

The results reveal significant seasonal differences in energy demand and comfort. Winter and summer are the most energy-intensive, with pronounced trade-offs between emissions and comfort, whereas spring and autumn present more favorable conditions where passive strategies—such as natural ventilation and adaptive setpoints—can effectively achieve low-emission, high-comfort outcomes. Pareto frontier analysis shows that in extreme seasons, small gains in comfort often require disproportionately higher energy consumption.

Sensitivity analysis identifies heating and cooling setpoints, infiltration rate, and window-to-wall ratio as the most influential parameters, although their impacts vary by season. This confirms that a uniform design strategy cannot meet performance requirements year-round. The study therefore proposes season-specific optimization strategies: passive solutions for spring and autumn, solar control and cooling efficiency in summer, and insulation and airtightness for winter. These findings support a shift from static, year-round optimization to dynamic, climate-responsive building operation.

In conclusion, the proposed method offers a practical and flexible framework for sustainable residential design in climates with strong seasonal variation. By recognizing seasonal dynamics and applying adaptive strategies, buildings can achieve improved energy efficiency without compromising occupant comfort. Future research may extend this approach to urban contexts, incorporate real-time control systems, and explore renewable energy integration for year-round optimization.

Although the study innovatively incorporates occupant activity patterns into the optimization process, it has several limitations. The four selected activity modes may not fully reflect the complexity of real residential behavior. The case study's rural context limits broader applicability, and model validation over a short period does not capture long-term or seasonal variation. The discomfort index simplifies the comfort assessment by excluding factors such as humidity and lighting. Additionally, some optimization parameters, like window-to-wall ratio or equipment power density, may not be easily adjustable in practice.

ACKNOWLEDGE

None

REFERENCE

[1] I. Aluclu, A. Dalgic, A Case study on natural ventilation characteristics of the Diyarbakir Surici (Old City) Municipality Building in Turkey, Building and Environment, 40 (11) (2005) 1441-1449.

[2] F. Calise, F. Cappiello, D. D'Agostino, M. Vicidomini, Heat metering for residential buildings: A novel approach through dynamic simulations for the calculation of energy and economic savings, Energy, 234 (2021).

[3] L.K. Campbell, E.S. Svendsen, N.F. Sonti, M.L. Johnson, A social assessment of urban parkland: Analyzing park use and meaning to inform management and resilience planning, Environmental Science & Policy, 62 (2016) 34-44.

[4] Ş. Yılmaz Balaman, J. Scott, A. Matopoulos, D.G. Wright, Incentivising bioenergy production: Economic and environmental insights from a regional optimization methodology, Renewable Energy, 130 (2019) 867-880.

[5] Ş. Yılmaz Balaman, H. Selim, Sustainable design of renewable energy supply chains integrated with district heating systems: A fuzzy optimization approach, Journal of Cleaner Production, 133 (2016) 863-885.

[6] T. Ysebaert, K. Koch, R. Samson, S. Denys, Green walls for mitigating urban particulate matter pollution—A review, Urban Forestry & Urban Greening, 59 (2021).

[7] J. Guo, Y. Huang, C. Wei, North–South debate on district heating: Evidence from a household survey, Energy Policy, 86 (2015) 295-302.

[8] R. Haik, A. Peled, I.A. Meir, The thermal performance of lime hemp concrete (LHC) with alternative binders, Energy and Buildings, 210 (2020).

[9] P.R. Crowe, K. Foley, M.J. Collier, Operationalizing urban resilience through a framework for adaptive co-management and design: Five experiments in urban planning practice and policy, Environmental Science & Policy, 62 (2016) 112-119.