

Article

A Geometry Simplification Strategy for Early-Stage Energy-Oriented Design of Office Buildings in Hot–Humid Regions: Application to Orientation Optimization

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Abstract

During the conceptual design phase, detailed geometric models are often unavailable, hindering energy-driven decisions for five-story office buildings. This paper proposes a geometry simplification strategy for office buildings in hot–humid regions using only length and width. Based on 130,976 geometric parameter combinations, stratified into an 80% selection set and a 20% validation set using four-dimensional parameter stratification, a standardized rectangular energy model is built, and EnergyPlus simulates orientations from 0° to 179° (1° step), totaling 23.6 million runs. Three simplification methods are compared: aspect ratio, floor area, and the proposed length–width combination. The length–width combination simplification strategy achieves an average relative energy deviation of 6.89% (6.87% on the held-out validation set), with a reduced maximum deviation on the held-out validation set (27.70% for the length–width method vs. 32.07% for the floor area method), thus meeting conceptual design accuracy requirements. Using this simplified model, the optimal orientation is identified as 0° (true south–north), accounting for 83.14% of cases. For the three representative geometric configurations examined, a near-optimal orientation band of $\pm 15^\circ$ around their respective optimal orientations is identified, within which the energy penalty remains below 1% of the minimum, providing designers with potentially flexible guidance that accommodates site-specific constraints without compromising energy performance. The orientation range 39–86° is not recommended when energy performance is prioritized, as it contains over 99% of worst-case orientations. The proposed strategy enables rapid energy estimation and orientation guidance from basic parameters, shifting energy-efficient design from late verification to early-stage driving, and providing quantifiable support for early-stage energy-efficient design as the foundation for subsequent nearly zero-energy building development in hot–humid regions.



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Keywords: geometry simplification; conceptual design; orientation optimization; nearly zero-energy building; hot–humid region; EnergyPlus

1. Introduction

Global climate warming has become a severe challenge for human society, and the resulting pressure to reduce greenhouse gas emissions is increasingly urgent. In China's building sector, carbon emissions from building operations account for 22% of total societal carbon emissions [1], while the whole-life-cycle carbon emissions of buildings account

for as much as 50.6% of the national total [2]. This means that the building sector is a key contributor to achieving the “dual carbon” goals. Achieving carbon neutrality in the building sector primarily relies on the synergistic effect of three technical pathways: “demand reduction—efficiency enhancement—energy generation”. “Demand reduction” refers to the use of passive energy-saving technologies [3], which constitute the “first move” in emission reduction. “Efficiency enhancement” refers to the use of high-efficiency equipment [4–6] to improve energy utilization efficiency, representing the “second move”. “Energy generation” means using buildings as carriers to harness renewable energy for energy supply [7–10]. The combination logic of these three pathways determines the ultimate form of carbon neutrality—nearly zero-energy buildings. This study focuses specifically on the ‘demand reduction’ pathway. While comprehensive NZEB design requires all three pathways, this paper addresses the foundational step of reducing cooling demand through optimal orientation and geometric simplification during conceptual design. The proposed method provides architects with immediate feedback on passive design decisions, which can later be complemented by efficiency measures and renewable generation to achieve NZEB status.

In China’s Hot Summer and Warm Winter (HSWW) zone, hot–humid conditions pose special challenges for building energy efficiency [11]. Office buildings, in particular, due to their high energy-saving potential, dense occupancy, and long operating hours (typically exceeding 10 h/day), become typical and urgent candidates for zero-energy technology applications. In terms of orientation optimization, a previous study [12] highlighted in their review that orientation is one of the most important passive design parameters affecting building energy demand, as it is a low-cost measure applicable at the initial design stage. Their review particularly emphasized that the conceptual design phase is the optimal timing for integrating such sustainable strategies, as passive measures implemented at this stage substantially reduce subsequent construction costs [12].

At the start of the conceptual design phase, detailed geometric models are usually not yet determined. However, decisions made at this phase have a decisive impact on the final performance of the building [13]. Traditional design methods often treat energy-saving design as a “late add-on”, lacking an integrated, performance-driven design approach that runs through the project from its inception [14,15].

Existing solutions to this problem mainly fall into two categories. The first involves conducting energy efficiency design or performance verification after the conceptual design is finalized (i.e., with detailed geometric models available), for example by using energy simulation software such as EnergyPlus to perform detailed simulations on established building schemes [16]. The second is to optimize building form and functional layout by establishing fast energy consumption prediction algorithms [13]. Specifically, in the field of fast building energy prediction, existing approaches can be categorized as follows. The first category comprises geometric reduced-order models, such as the “Shoebboxer” algorithm proposed by Dogan and Reinhart [17], which abstracts arbitrarily shaped building volumes into simplified shoebox models (i.e., simplified perimeter and core zone combinations). This method achieves root mean square errors of 5–10% in annual energy use intensity (EUI) while accelerating simulation speed by a factor of up to 296 compared to conventional multi-zone models, and is primarily applied to urban-scale building energy modeling and early-stage schematic design [17]. The second category involves archetype-based urban building energy models (UBEM). As reviewed by Reinhart and Cerezo Davila [18], such approaches classify building stocks into representative archetypes with standardized thermal properties to automatically generate multi-zone models; however, at the individual building level, simulation errors can range from 5% to as high as 99% when aggregated, reflecting significant information loss in capturing specific geometric forms and occupant

behavior patterns [18]. The third category comprises machine learning-based surrogate models. Shirzadi et al. [19] trained three surrogate models—Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Multilayer Perceptron (MLP)—on a synthetic dataset of 2000 EnergyPlus-simulated building design scenarios for midrise apartment buildings in the Toronto area, to predict both energy use intensity (EUI) and construction costs. All three models achieved R^2 values exceeding 0.9; MLP performed best in EUI prediction with a testing RMSE of 0.002 GJ/m², while XGBoost achieved the lowest RMSE of 5.13 CAD/m² for cost prediction. More importantly, these surrogate models achieved 200- to 340-fold speedups over the physics-based simulation model, demonstrating their significant potential for rapid decision-making during early-stage building design [19]. However, that study focused on a specific climate zone (Toronto) and building typology (midrise apartments), with limited coverage of the wider geometric parameter space that is essential for comprehensive early-stage design exploration [19].

Regardless of the method, relatively detailed model information is required. However, in the conceptual design phase, detailed geometric models are not yet available. If energy performance verification is postponed until the design scheme is finalized, designers will lack energy-performance-based guidance during the design of nearly zero-energy buildings. Moreover, if verification fails, it leads to design rework, causing losses in both efficiency and cost. And, existing simplified modeling and orientation optimization studies are typically case-specific [12] or rely on backward simplification from detailed models [17–19], lacking a forward-prediction framework that covers a wide geometric parameter space and provides immediate orientation guidance at the very early design stage.

To address the above problem, this paper proposes a geometry simplification strategy suitable for the conceptual design of office buildings in hot–humid regions. The strategy requires only basic parameters such as building length, width, and number of stories to quickly estimate energy consumption and guide orientation decisions, thus transforming energy-efficient design from “late-stage verification” to “early-stage driving”, and providing a quantifiable methodological support for the conceptual design of nearly zero-energy buildings. Specific research objectives include:

1. Based on a parametric survey of 22 typical office building projects in hot–humid regions, construct a large-scale parametric sample library covering a reasonable geometric space (130,976 cases), and split it into an 80% selection set and a 20% validation set via stratified sampling to enable prospective validation;
2. Compare the energy estimation accuracy of three geometry simplification strategies (aspect ratio, floor area, and length–width combination) to select the optimal method;
3. Based on the optimal simplified model, conduct full-orientation simulations to determine the optimal orientation and the orientation range not to be recommended for office buildings in hot–humid regions (for detailed definitions and simulation settings, see Section 2.5), and define a near-optimal orientation band.

It should be noted that the findings of this study are specifically applicable to five-story office buildings, as the number of stories is fixed at five in the current simulation campaign. Generalization to other building stories is not claimed and is reserved for future work (see Section 4.4).

2. Materials and Methods

2.1. Survey of Typical Office Building Parameters and Database Construction

To establish a representative geometry simplification model, this study first conducted a statistical survey of core geometric parameters from 22 built typical office building projects in the hot–humid region (China’s HSWW climate zone). All surveyed buildings are situated in Guangdong Province, with the majority located in Zhuhai (a city between Guangzhou

and Macao), and the remainder in the surrounding Pearl River Delta metropolitan area. These cities share a typical hot-summer and warm-winter climate and represent the primary office development zone in South China.

The surveyed buildings were completed between 2015 and 2024, covering a recent construction period that reflects current design practice and building code requirements. All buildings are regular rectangular office buildings with a central core configuration, consistent with the baseline model illustrated in Figure 1. Buildings with irregular floor plans (e.g., L-shaped, U-shaped, curved, or with significant setbacks) were deliberately excluded from this survey to maintain a consistent geometry typology for the simplification library. This selection criterion ensures that the parameter space is representative of the most common office building form in the region, while acknowledging that complex geometries require separate treatment (see Section 4.4).

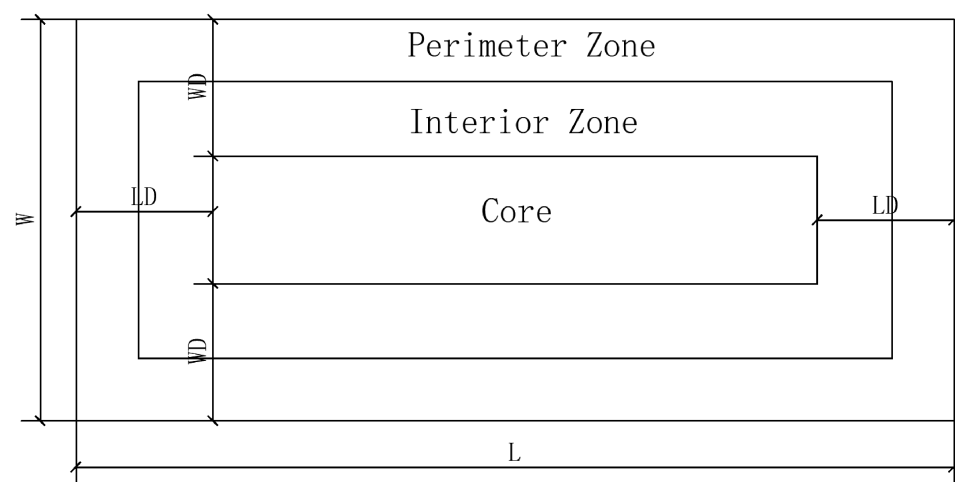


Figure 1. Baseline model with dimension definitions: L = building length, W = building width, LD = depth along long side, WD = depth along short side.

Survey indicators included: building total length, building total width, depth along the long side of the standard floor, and depth along the short side of the standard floor. The complete survey data for all 22 buildings—including individual geometric parameters—are provided as Supplementary Material (Table S1) to ensure transparency and reproducibility. Summary statistics are shown in Table 1.

Table 1. Core parameter ranges of typical office buildings.

Value Type	Building Length (m)	Building Width (m)	Depth Along Long Side (m)	Depth Along Short Side (m)
Maximum	95.7	41.6	16	14
Minimum	32.6	20.6	6.9	6.4
Average	49.83	31.75	9.78	9.42

Based on the survey results, a parameter generation tool was developed to generate geometric parameter combinations covering different scales with a step size of 1 m. To avoid parameter redundancy and irrationality, the constraints shown in Table 2 were set, resulting in a valid parameter sample library of 130,976 cases.

Table 2. Parameter constraints.

No.	Constraint Condition	Purpose
1	Building length > Building width	Avoid parameter duplication
2	Depth along long side > 5; Depth along short side > 5	Meet conventional office space size requirements
3	Building length > Depth along long side + 4; Building width > Depth along short side + 4	Reserve space for core (stairwells, elevator shafts) to ensure model practicality
4	When building length = building width, then Depth along long side $\geq$ Depth along short side	Avoid duplication for square floor plans, ensure sample uniqueness

2.2. Baseline Energy Model Setup

1. Geometric model

Referring to typical office building layouts in hot–humid regions, a baseline model containing perimeter zones, interior zones, and a core was constructed (as shown in Figure 1). The core, located in the middle of the building, contains stairwells and elevator shafts to meet egress and transportation functions. The perimeter zone is the office space along the building envelope, and the interior zone is the office space around the core (influenced only by internal loads). This zoning approach follows common practice in energy simulation.

As annotated in Figure 1, the four key geometric parameters surveyed in Table 1 correspond to: building length (L), building width (W), depth along the long side (LD), and depth along the short side (WD).

Based on the design principles of minimizing facade complexity and heat dissipation area and maximizing space for renewable energy deployment in nearly zero-energy buildings—with all floors identical—this study assumes identical floor plans for all stories, ignoring inter-story variations. The floor-to-floor height is fixed at 4.2 m (a common value for office buildings in hot–humid regions). Furthermore, to reduce uncertainty in the conceptual design phase, the window-to-wall ratio is uniformly set to a middle value of 0.5, and external shading is not considered for now. The frame-to-window area ratio is 0.15. To clarify the terminology used throughout this study: the window-to-wall ratio (WWR) is defined as the total window area (including both glazing and frame) divided by the gross wall area. The frame-to-window ratio is defined as the frame area divided by the total window area (frame area + glazing area). Thus, the relationships among these quantities are window area = frame area + glazing area, WWR = 0.5, and frame-to-window ratio = 0.15. The WWR value of 0.5 therefore includes the frame contribution, consistent with the frame-to-window ratio specified above.

A WWR of 0.5 and a fixed SHGC are adopted as mid-range values consistent with the Technical standard for nearly zero energy buildings (GB/T 51350-2019) [20], which recommends moderate glazing WWR and SHGC to balance daylighting and thermal performance. While these values may not represent all design possibilities, they serve as a reasonable baseline for comparative orientation analysis, where the focus is on the relative ranking of orientations rather than absolute energy predictions.

The total number of stories is set to 5 in this study. This choice is motivated by the survey of 22 existing office buildings (Section 2.1), which indicates that 5 stories is the most frequently occurring height among mid-rise office buildings in the study region, making it a representative baseline for the conceptual design phase.

Importantly, the findings of this study are specifically applicable to five-story mid-rise office buildings. Extension to other building heights is not claimed and is explicitly acknowledged as a limitation (see Section 4.4).

2. Thermal and operational parameters

The thermal performance of the building envelope complies with the limit requirements of the Technical standard for nearly zero energy buildings (GB/T 51350-2019) [20], avoiding interference from variations in thermal parameters on energy consumption comparison results. Parameters such as indoor occupant density, equipment power density, lighting power density, and hourly schedules are set according to national and industry standards (see Tables 3–6 for details), ensuring consistency in the energy simulation baseline.

Table 3. Overall model parameters.

Parameter Type	Parameter Name	Value	Basis
Simulation input parameters	Location	Guangzhou, Guangdong Province, China (23.13°N, 113.27°E)	CSWD weather file
	Weather file	CHN_Guangdong.Guangzhou.592870_CSWD.epw	EnergyPlus built-in database
	Simulation period	January 1–December 31 (non-leap year)	Full calendar year
	Infiltration	0.5 ACH (air changes per hour)	Typical office building assumption
Geometric parameters	Floor-to-floor height	4.2 m	Typical public building dimension
	Number of stories	5	Assumed for conceptual design (see Section 2.2 for rationale)
	Frame-to-window area ratio	0.15	Conventional dimension
Material parameters	Glass SHGC	0.3	Typical for double-silver Low-E glass; 0.255 if considering frame
	Window heat transfer coefficient	2.8 W/(m ² ·K)	GB/T 51350-2019 [20]
	Roof average heat transfer coefficient	0.45 W/(m ² ·K)	
	Wall average heat transfer coefficient	0.55 W/(m ² ·K)	
	Interior surface coefficient of heat transfer (wall/roof)	8.7 W/(m ² ·K)	GB 50176-2016 [21]
	Exterior surface coefficient of heat transfer (wall/roof)	19 W/(m ² ·K)	GB 50176-2016 [21], summer value for Guangzhou; office buildings in this area do not need heating
	Indoor surface reflectance	Ceiling: 0.75 Wall: 0.6 Floor: 0.3	GB 50378-2019 (2024 edition) [22] and JGJ/T 449-2018 [23]

Table 4. Room parameters.

No.	Parameter	Unit	Office	Stairwell	Basis
1	Occupant density	person/m ²	0.125	-	JGJ/T 449-2018 [23]
2	Occupant heat gain	W/person	134	-	
3	Lighting power density	W/m ²	6.5	1.5	GB/T 50034-2024 (target values for general office [24])
4	Illuminance	lx	300	50	Same as above
5	Equipment power density	W/m ²	15	15	JGJ/T 449-2018 [23]
6	Summer cooling setpoint	°C	26	-	
7	Winter heating setpoint	°C	20	-	
8	Fresh air supply rate	L/(s·person)	8.333	-	
9	Holidays	-	-	-	Based on 2025 calendar

Table 5. Hourly operational schedules (hours 1–12).

		Hour											
Category	Condition	1	2	3	4	5	6	7	8	9	10	11	12
Lighting schedule (%)	Weekday (interior)	10	10	10	10	10	10	10	50	100	100	100	80
	Weekday (perimeter)	10	10	10	10	10	10	10	36	62	56	54	43
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Equipment usage rate (%)	Weekday	0	0	0	0	0	0	10	50	100	100	100	100
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Occupancy rate (%)	Weekday	0	0	0	0	0	0	10	50	100	100	100	30
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Fresh air operation (0 = off, 1 = on)	Weekday	0	0	0	0	0	0	1	1	1	1	1	1
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Summer hourly temperature for air-conditioned rooms (°C)	Weekday	37	37	37	37	37	37	29	26	26	26	26	26
	Holiday	37	37	37	37	37	37	37	37	37	37	37	37
Winter hourly temperature for air-conditioned rooms (°C)	Weekday	10	10	10	10	10	12	16	20	20	20	20	20
	Holiday	10	10	10	10	10	10	10	10	10	10	10	10

Table 6. Hourly operational schedules (hours 13–24).

		Hour											
Category	Condition	13	14	15	16	17	18	19	20	21	22	23	24
Lighting schedule (%)	Weekday (interior)	100	100	100	100	50	20	10	10	10	10	10	10
	Weekday (perimeter)	53	55	58	67	40	18	10	10	10	10	10	10
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Equipment usage rate (%)	Weekday	100	100	100	100	50	20	10	0	0	0	0	0
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Occupancy rate (%)	Weekday	100	100	100	100	50	20	10	0	0	0	0	0
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Fresh air operation (0 = off, 1 = on)	Weekday	1	1	1	1	1	1	1	0	0	0	0	0
	Holiday	0	0	0	0	0	0	0	0	0	0	0	0
Summer hourly temperature for air-conditioned rooms (°C)	Weekday	26	26	26	26	26	26	37	37	37	37	37	37
	Holiday	37	37	37	37	37	37	37	37	37	37	37	37
Winter hourly temperature for air-conditioned rooms (°C)	Weekday	20	20	20	20	20	20	18	10	10	10	10	10
	Holiday	10	10	10	10	10	10	10	10	10	10	10	10

3. Ideal air conditioning system

To avoid the influence of air conditioner capacity selection on the simulation results, this study employs an ideal air conditioning system within EnergyPlus. The reported energy performance is based on calculated cooling and heating loads (rather than actual compressor or chiller energy use) to maintain the indoor setpoint temperatures. This approach ensures that the comparison reflects only the passive thermal response of the building envelope.

The *annual energy consumption per unit floor area* ($\text{kWh}/(\text{m}^2 \cdot \text{a})$) is defined as the sum of the annual cumulative cooling load (including both sensible and latent components, calculated through hour-by-hour integration over the entire simulation period), the annual cumulative heating load, the annual lighting electricity consumption, and the annual equipment electricity consumption, divided by the total gross floor area. The latent cooling load associated with dehumidification is inherently captured through the fresh air supply schedule and the site-specific weather data (TMY file), ensuring that the moisture removal penalty in the hot-humid climate is properly reflected in the reported metric. Although office buildings in the hot-summer and warm-winter climate zone do not require active space heating under normal conditions, the heating load is retained in this definition because it serves as an indicator of building discomfort during occasional cold spells and reflects the passive thermal response of the envelope. This indicator thus provides a comprehensive basis for comparing energy and passive thermal performance across different design options. This definition is consistent with the EnergyPlus Input Output Reference documentation, which states that for the ZoneHVAC:IdealLoadsAirSystem, any change in the moisture content of the supply air stream results in a latent cooling (dehumidification) or latent heating (humidification) load [25]. Regardless of the Dehumidification Control Type or Humidification Control Type settings in IDF file, this passive latent load accounting remains effective; however, it does not constitute active humidity control and does not maintain a fixed indoor relative humidity setpoint.

4. Simulation tool and batch computation

EnergyPlus 24.02 is used as the energy simulation engine. For each set of geometric parameters, simulations are performed for orientations from 0° to 179° (1° increments), resulting in a total of $130,976 \times 180 = 23,575,680$ simulation runs. Distributed parallel computing technology is employed to allocate simulation tasks to multi-core processors across multiple computers, significantly reducing total computation time. The core output indicator is annual energy consumption per unit floor area [$\text{kWh}/(\text{m}^2 \cdot \text{a})$].

2.3. Definition of Geometry Simplification Strategies

To select the most suitable simplification method for the conceptual design phase, three strategies are defined and compared. Each strategy aims to select a representative subset from the 130,976 samples for rapid energy estimation and then compare the deviation against the actual energy consumption of all samples.

1. Strategy 1: Grouping by aspect ratio

The aspect ratio ($\text{AR} = \text{length}/\text{width}$) is calculated for each sample. Samples with the same AR value are grouped together. Within each group, the sample whose energy consumption is closest to the group average is selected as the representative model for that AR value.

2. Strategy 2: Grouping by floor area

The standard floor area ($\text{SA} = \text{length} \times \text{width}$) is calculated for each sample. Samples with the same SA value (rounded to the nearest integer) are grouped together. Within each group, the sample with energy consumption closest to the group average is selected as the representative model.

3. Strategy 3: Grouping by length–width combination (proposed in this paper)

A two-dimensional grid is constructed with length and width as the two dimensions, with a grid step of 1 m. Each grid node (length i , width j) contains the set of all depth values for that specific length–width combination. For each grid node, the sample with energy consumption closest to the average is selected as the representative model for that combination. This strategy preserves the independent information of length and width, offering finer granularity than single-parameter grouping.

2.4. Orientation Optimization Analysis Method

1. Dataset splitting for prospective validation

To evaluate the predictive performance of the simplification strategies on unseen building geometries, the full dataset of 130,976 samples was split into a selection set (80%) for library building and method evaluation, and a validation set (20%) for independent prospective validation. A stratified sampling approach was adopted rather than simple random sampling for the following reasons. First, the dataset was generated by exhaustive grid search over the parameter space (with constraints), resulting in a highly structured dataset rather than a randomly collected sample. Simple random sampling could, due to random fluctuation, cause disproportionate representation of critical geometric combinations (e.g., boundary parameters, extreme depths) in the validation set. Second, stratified sampling ensures that the validation set preserves the representativeness of the parameter space, reducing the risk of erroneously rejecting a method due to uneven splitting. The stratified sampling protocol described above is designed to validate the representativeness of the selected models (Section 2.3), not the bilinear interpolation procedure introduced in Section 2.6. The interpolation step remains unvalidated and is explicitly acknowledged as such.

2. Strata definition

The four geometric parameters were divided into sub-intervals in Table 7:

Table 7. Strata definition.

Parameter	Range	Intervals
Building length	30–100	[30, 45), [45, 60), [60, 75), [75, 90), [90, 100]
Building width	20–45	[20, 26), [26, 33), [33, 39), [39, 45]
Depth along long side	6–16	[6, 9), [9, 12), [12, 16]
Depth along short side	6–14	[6, 9), [9, 12), [12, 14]

The combination of these intervals yields $5 \times 4 \times 3 \times 3 = 180$ theoretical strata, of which 165 were non-empty. Within each non-empty stratum, 20% of the samples were randomly selected to form the validation set, and the remaining 80% formed the selection set. A global random seed of 25 was set to ensure reproducibility of all random operations.

3. Evaluation protocol

All three simplification strategies (aspect ratio, floor area, and length–width combination) were first evaluated on the selection set to determine their representativeness (Section 3.4). The same evaluation metrics—including mean absolute deviation, mean relative deviation, and percentile values (25th, 50th, 75th, and maximum)—were then computed independently on the validation set. If the validation set results closely match the selection set results in terms of ranking, magnitude, and distribution characteristics, the conclusions are considered robust and generalizable.

2.5. Orientation Definition and Simulation Range

In this study, the building orientation angle is defined as follows (Figure 2): 0° represents true north. A positive angle indicates rotation towards the east, and a negative angle indicates rotation towards the west. Consequently, a building facing true east has an orientation of $+90^\circ$, and true west corresponds to -90° (or $+270^\circ$). In the same way, a building with an orientation angle at 0° is described as having a south–north orientation in this paper.

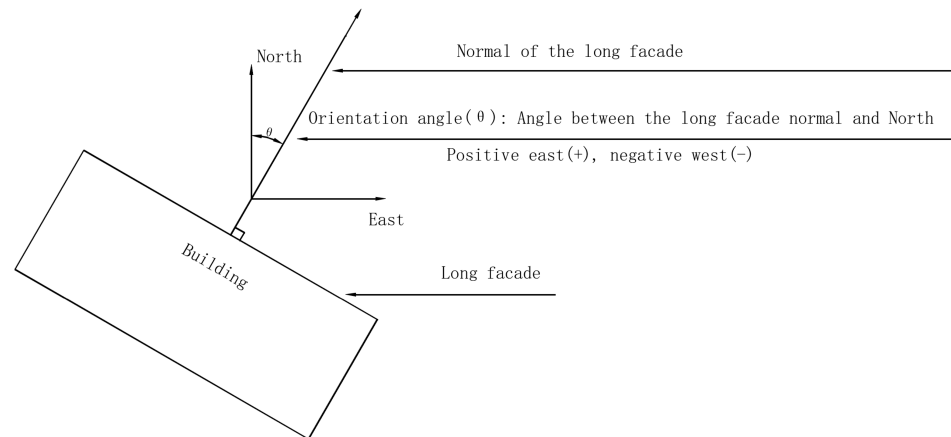


Figure 2. Definition of orientation angle.

Because all geometric models used in this paper are symmetric rectangles (i.e., rotating a rectangle by 180° results in an identical geometry), the simulation range is limited to 0° to 179° . This range covers all unique orientations without redundant simulations.

2.6. Application Workflow for Conceptual Design

The simplified geometry library is intended for use during the conceptual design phase when only three parameters—building length (L), width (W), and number of stories (N)—are known. The application workflow comprises the following steps:

1. Parameter specification: The designer specifies L, W, and N for the proposed building.
2. Lookup or interpolation: For each (L, W) combination, a representative model has been precomputed in the library (see Section 2.3) using the full simulation results. If the exact (L, W) combination exists in the library, the representative model for that combination is retrieved directly. For combinations not in the library (e.g., when L or W falls between grid nodes), energy consumption is estimated using bilinear interpolation between the four nearest grid nodes in the two-dimensional length–width space. The representative model for each grid node was precomputed during the library-building phase. It should be noted that the bilinear interpolation procedure described here is proposed as a practical mechanism for obtaining energy estimates for length–width combinations not present in the precomputed library. This interpolation method has not been prospectively validated. Therefore, the interpolation step should be considered a procedural convenience rather than a statistically validated prediction method.
3. Energy estimation: The retrieved or interpolated annual energy consumption per unit floor area [$\text{kWh}/(\text{m}^2 \cdot \text{a})$] provides an estimate of the building's energy consumption.
4. Orientation guidance: Unlike energy estimation, which depends on the specific (L, W) values, the orientation recommendations are derived directly from the statistical findings of this study (Sections 3.1–3.3), which are based on the full dataset of 130,976 samples and are therefore geometry-independent.

This workflow enables designers to obtain energy estimates through lookup or interpolation, and to receive immediate orientation guidance based on the validated statistical conclusions of this study, without requiring new simulations. The precomputed library—comprising representative models for all 130,976 parameter combinations—is provided as Supplementary Material (Table S2), which contains 1726 unique (L, W) nodes, each linked to its representative model and its energy value at the optimal orientation.

3. Results

3.1. Optimal Orientation Distribution

The results presented in this section and Section 3.2 are based on the full dataset (all 130,976 samples), as the orientation optimization analysis aims to identify global statistical patterns—specifically, the most frequent optimal and worst orientations—that are independent of specific geometric parameter combinations and are not subject to the selection/validation split used for the simplification strategy evaluation in Section 3.4.

Based on the energy simulation results for 130,976 geometric samples over the orientation range of 0–179°, the optimal orientation (the angle minimizing energy consumption) for each sample was determined. The frequency distribution is shown in Figure 3 and Table 8.

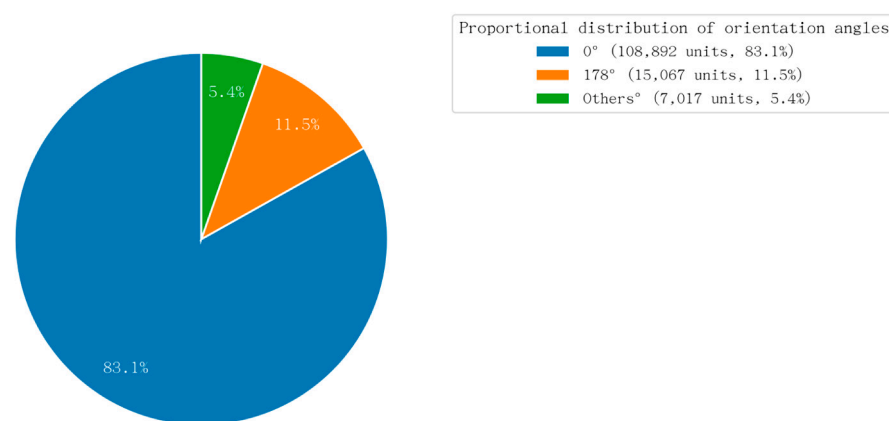


Figure 3. Frequency distribution of optimal orientation angles.

Table 8. Proportional distribution of optimal orientation angles.

Optimal Angle	Frequency	Proportion
0	108,892	83.14%
1	8	0.01%
89	27	0.02%
90	1	0.00%
177	3,138	2.40%
178	15,067	11.50%
179	3,843	2.93%
Total	130,976	100%

The results show that true south–north (0°) is the dominant optimal orientation. A total of 108,892 samples (83.14% of all samples) have their optimal orientation at 0°. In addition, angles close to 0°, such as 1°, 177°, 178°, and 179°, also account for a certain proportion (approximately 16.3% in total). Only in the case of square floor plans (aspect ratio = 1) do a very few samples (less than 0.01% of total) show optimal orientations at 89–90°. If 0° and its adjacent angles (177–179°, 0–1°) are combined, the coverage exceeds 99%. This indicates

that for office buildings in hot–humid regions, the true south–north orientation achieves the lowest energy consumption for the vast majority of geometric forms.

3.2. Worst Orientation Distribution

Similarly, the worst orientation (the angle maximizing energy consumption) for each sample was determined. The results are shown in Figure 4 and Table 9.

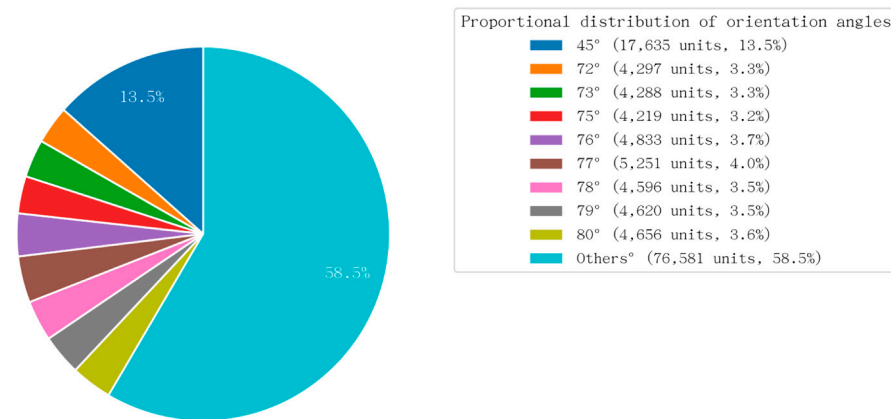


Figure 4. Frequency distribution of worst orientation angles.

Table 9. Proportional distribution of worst orientation angles.

Worst Angle	Frequency	Proportion
39	3	0.00%
40	27	0.02%
41	61	0.05%
42	117	0.09%
43	152	0.12%
44	147	0.11%
45	17,635	13.46%
46	152	0.12%
47	156	0.12%
48	145	0.11%
49	105	0.08%
50	215	0.16%
51	1206	0.92%
52	2322	1.77%
53	2771	2.12%
54	2808	2.14%
55	2682	2.05%
56	2443	1.87%
57	2294	1.75%
58	3293	2.51%
59	3142	2.40%
60	3136	2.39%
61	3246	2.48%
62	3311	2.53%
63	3006	2.30%
64	3336	2.55%
65	3317	2.53%
66	3576	2.73%
67	3338	2.55%
68	3783	2.89%
69	3866	2.95%

Table 9. *Cont.*

Worst Angle	Frequency	Proportion
70	3657	2.79%
71	3413	2.61%
72	4297	3.28%
73	4288	3.27%
74	3662	2.80%
75	4219	3.22%
76	4833	3.69%
77	5251	4.01%
78	4596	3.51%
79	4620	3.53%
80	4656	3.55%
81	3597	2.75%
82	2394	1.83%
83	1340	1.02%
84	277	0.21%
85	82	0.06%
86	2	0.00%
135	1	0.00%
Total	130,976	100%

The worst orientations are concentrated in the range of 39–86°, which covers more than 99% of worst-case scenarios. Among these, 45° has the highest frequency, with 17,635 samples (13.46% of total). Other high-frequency angles range from 52° to 85°, each accounting for 1.5–4.0%. In the single case where aspect ratio = 1 (square plan), a worst orientation of 135° appears once, but its proportion is negligible. Overall, building orientations where the long side faces southeast to northeast (39–86°) are not recommended when energy performance is a primary design objective, as this range experiences intense direct solar radiation during morning to noon hours in summer.

3.3. Energy Penalty of Off-Optimal Orientations

1. Orientation-dependent energy curves

To illustrate how energy consumption varies with orientation for different building geometries, three representative cases were selected from the 130,976 samples: Model 1 (L = 100.0 m, W = 20.0 m, LD = 6.0 m, WD = 6.0 m), which exhibits the maximum relative energy difference between the optimal and worst orientations (3.13%); Model 2 (L = 45.0 m, W = 45.0 m, LD = 14.0 m, WD = 13.0 m), which exhibits the minimum relative difference (0.29%); and Model 3 (L = 30.0 m, W = 20.0 m, LD = 9.0 m, WD = 7.0 m), which represents the average relative difference (1.15%). Figures 5–7 present the normalized energy consumption curves for these three models across the full orientation range of 0° to 179°.

Three key patterns emerge from these curves. First, all curves are symmetric about 90°, with nearly identical energy variation trends on both sides. This symmetry is consistent with the geometric symmetry of rectangular floor plans, where rotating a rectangle by 180° yields an identical geometry. Second, for buildings with a large aspect ratio (Model 1, AR = 5.0), the energy curve exhibits a single-peak pattern: energy consumption is highest near 90° and lowest near the two ends (0° and 180°). Third, as the aspect ratio decreases (from Model 1 to Model 3 to Model 2), the energy curve gradually transitions to a double-peak pattern, with local maxima near 45° and 135°, local minima near 0° and 180°, and a secondary local minimum near 90°. As the aspect ratio approaches unity (Model 2, AR = 1.0), the magnitudes of the minima at the two ends and at 90° become nearly equal, reflecting the near-isotropic thermal behavior of square plans.

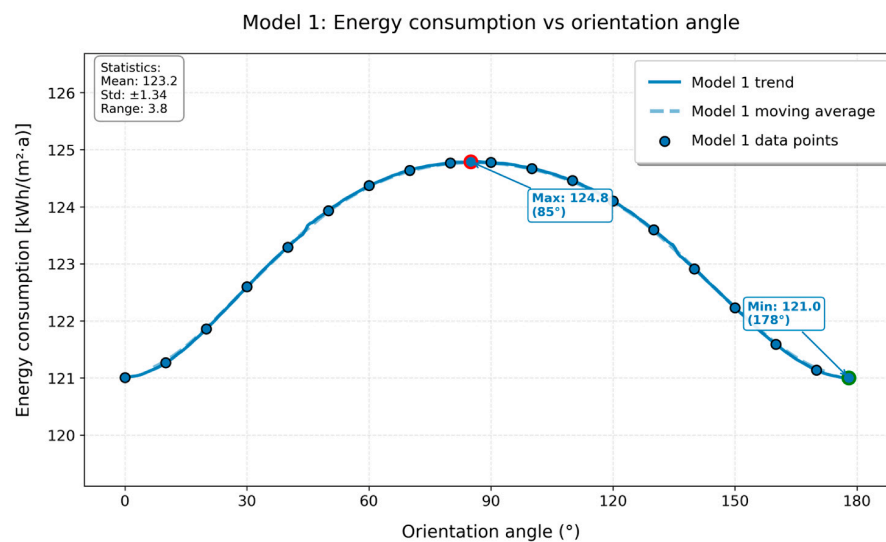


Figure 5. Orientation-dependent energy curves of model1.

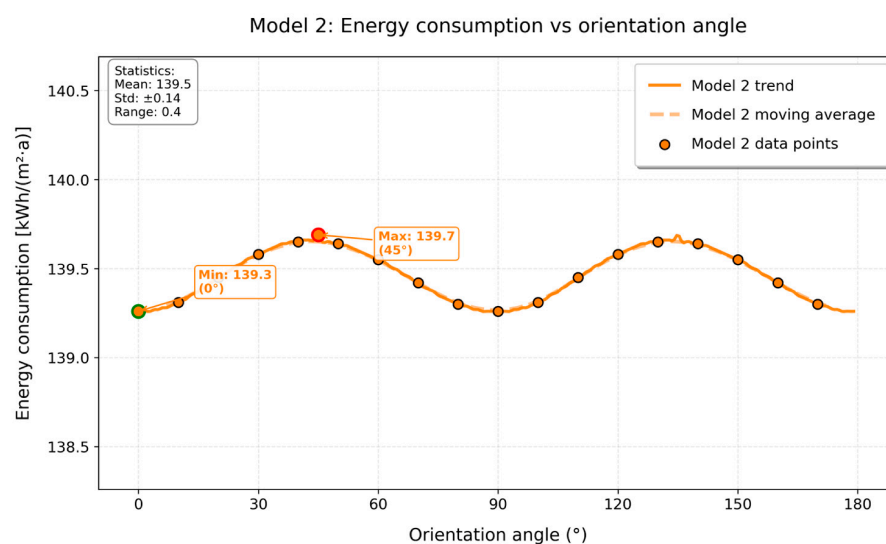


Figure 6. Orientation-dependent energy curves of model2.

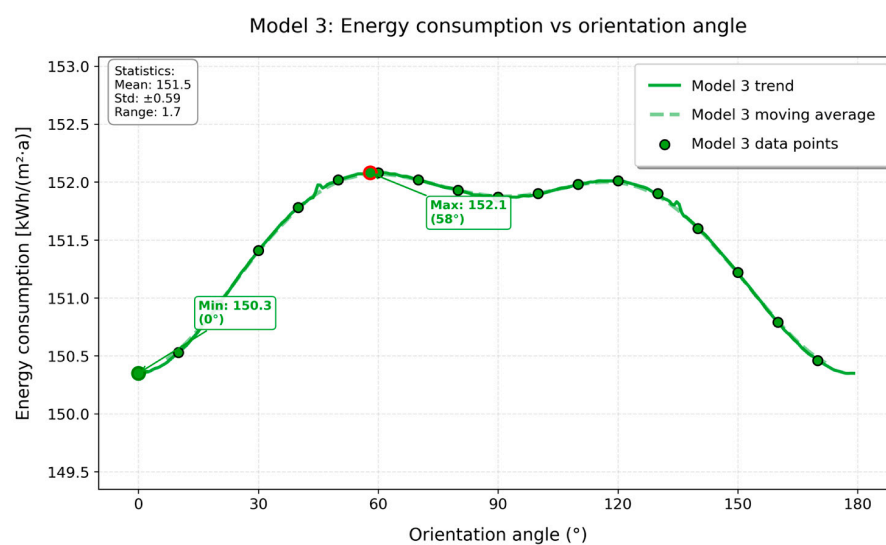


Figure 7. Orientation-dependent energy curves of model3.

2. Distribution of energy penalties across all samples

While the three representative curves illustrate the general patterns, the full distribution of energy penalties across all 130,976 samples is presented in Figure 8 using a hexbin plot. The horizontal axis represents the absolute energy difference between the optimal and worst orientations for each sample [$\text{kWh}/(\text{m}^2 \cdot \text{a})$], and the vertical axis represents the relative difference (%). Marginal histograms are provided on the top and right sides of the plot to show the distributions of the absolute and relative differences, respectively.

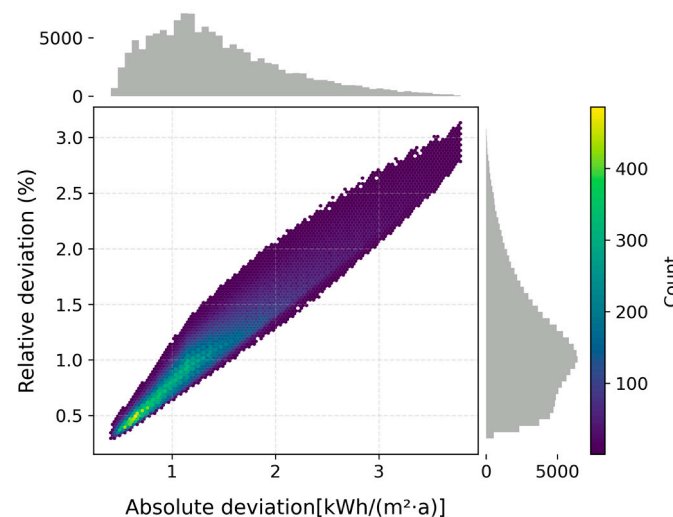


Figure 8. Distribution of energy penalties across all samples.

3. Definition of the near-optimal orientation band

Based on the penalty distribution shown in Figure 8, a near-optimal orientation band is defined to provide practical design guidance. Due to the limitations of the available data—the analysis of the near-optimal band is conducted on the three representative models (Models 1, 2, and 3). For each model, the penalty as a function of angular deviation from its respective optimal orientation was calculated. The analysis shows that for all three models, the energy penalty remains below 1% for orientations within $\pm 15^\circ$ of their respective optima (with the maximum value being 0.43% for Model 1). These findings suggest that a $\pm 15^\circ$ near-optimal band may offer practical flexibility in conceptual design. However, this conclusion is explicitly limited to the three representative configurations; generalization to the full parameter space would require access to the complete angle-resolved simulation results for all samples, which were not retained.

The rationale for defining $\pm 15^\circ$ as the near-optimal band extends beyond energy considerations alone. First, allowing a $\pm 15^\circ$ tolerance provides flexibility to accommodate other design constraints—such as site conditions, views, natural ventilation potential, and solar access for occupant comfort—without sacrificing energy performance. Second, this band helps designers avoid over-constraining the building orientation solely for energy optimization, which might conflict with urban planning requirements or functional layouts. Third, the 1% energy penalty threshold ensures that the energy impact of orientation adjustments within this band is practically negligible.

It is worth noting that the near-optimal band defined here is based purely on energy performance. When other factors—such as natural ventilation (which may extend the period during which mechanical cooling can be reduced or avoided), daylighting quality, and solar radiation control for occupant comfort—are considered, the optimal orientation may shift slightly. However, the finding that south–north orientation minimizes cooling loads is consistent with previous studies [26] that have considered these additional factors,

reinforcing the importance of south–north orientation for nearly zero-energy buildings in hot–humid regions from an energy perspective.

3.4. Prospective Validation of Simplification Strategies

To assess the generalizability of the three simplification strategies (aspect ratio, floor area, and length–width combination) to unseen building geometries, the stratified split protocol described in Section 2.4 was applied. The selection set (80% of samples) was used to build the representative model library and evaluate the strategies, while the validation set (20%) was used exclusively for independent testing.

1. Deviation distribution on the data set

For each strategy, the absolute deviation and relative deviation between the representative model's estimated energy consumption and the actual simulated energy consumption of all samples within the same group were calculated. Figure 9 presents hexbin plots showing the joint distribution of absolute deviation and relative deviation for the three strategies on both the selection set and the validation set. Figure 10 presents boxplots comparing the distributions of absolute deviation and relative deviation across the three strategies for both datasets.

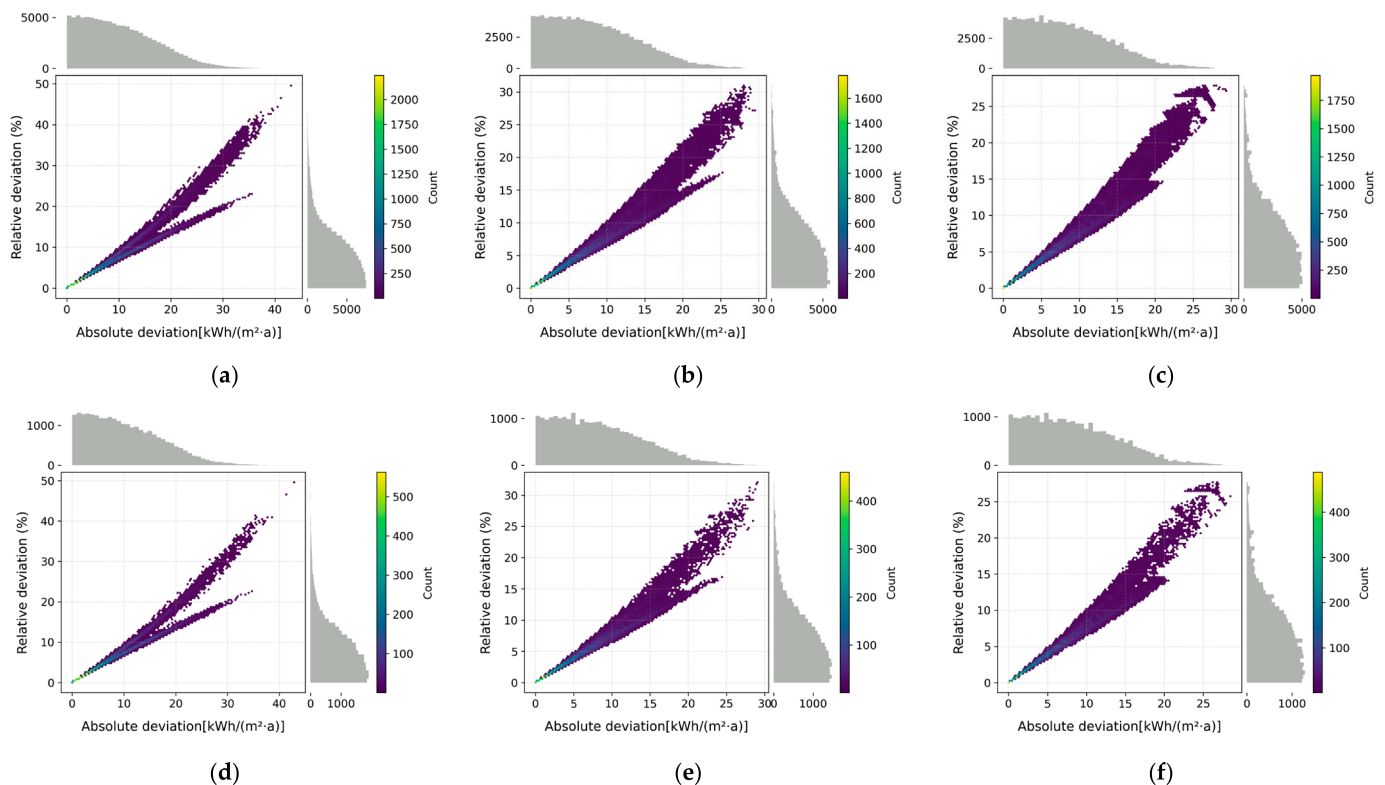


Figure 9. Joint Deviation distribution of 3 strategies. (a) Aspect ratio strategy deviation distribution of selection set. (b) Floor area strategy deviation distribution of selection set. (c) Length–width combination strategy deviation distribution of selection set. (d) Aspect ratio strategy deviation distribution of validation set. (e) Floor area strategy deviation distribution of validation set. (f) Length–width combination strategy deviation distribution of validation set.

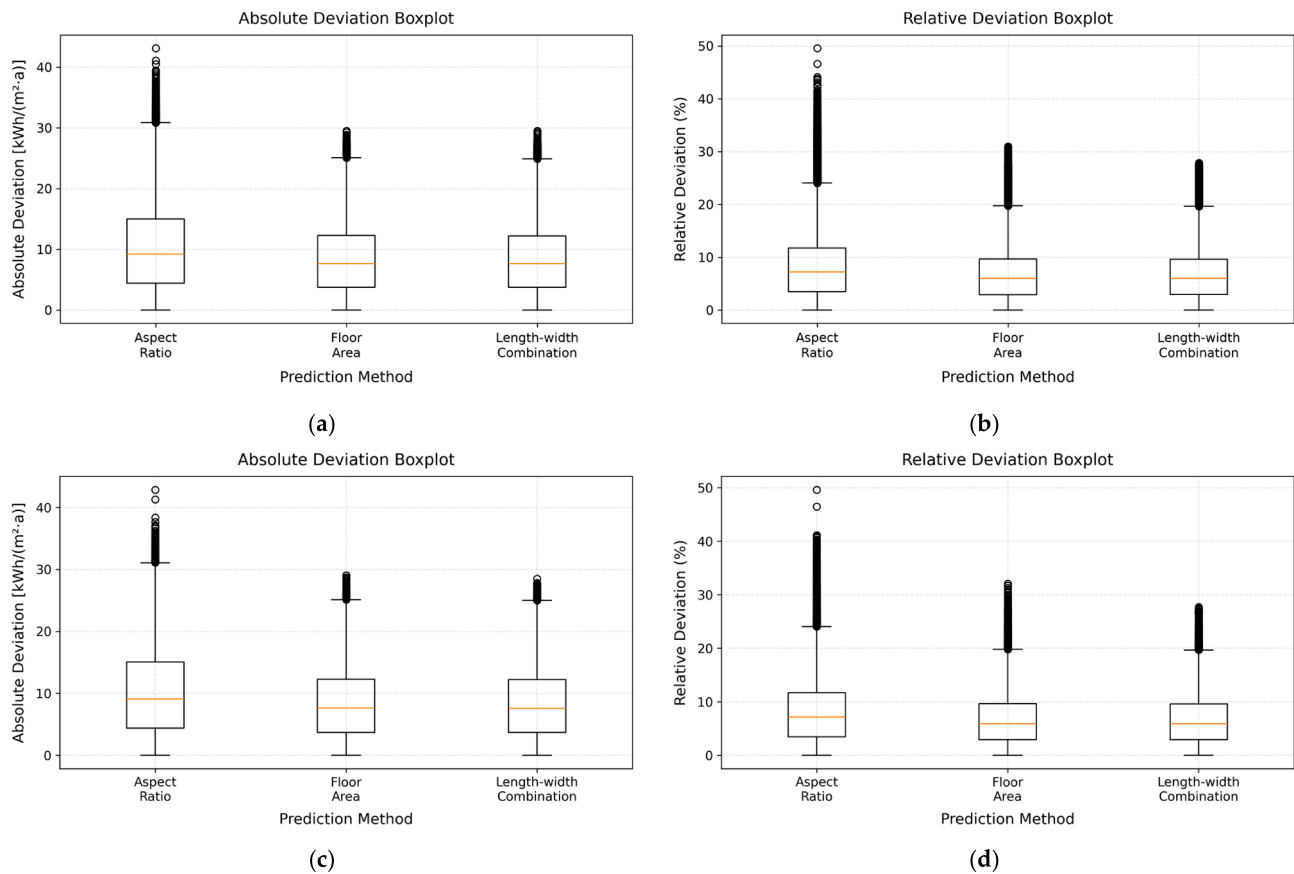


Figure 10. Deviation distribution of 3 strategies. (a) Absolute deviation distribution of selection set. (b) Relative deviation distribution of selection set. (c) Absolute deviation distribution of validation set. (d) Relative deviation distribution of validation set.

The hexbin plots reveal that the selection set and validation set distributions are highly similar for all three strategies, confirming that the stratified sampling successfully preserved the parameter space structure.

2. Deviation statistics and comparison

Table 10 summarizes the deviation statistics for all three strategies on both the selection set and the validation set.

Table 10. Deviations of energy consumption estimates using different parameter simplifications.

Dataset	Grouping Parameter	Deviation Type	Mean	25th %ile	Median	75th %ile	90th %ile	Max
Selection set (80%)	Aspect ratio	Absolute	10.29	4.45	9.24	15.02	20.3	43.11
		Relative	8.42%	3.51%	7.24%	11.73%	16.56%	49.56%
	Floor area	Absolute	8.44	3.75	7.65	12.28	16.46	29.51
		Relative	6.92%	2.95%	5.98%	9.67%	13.56%	30.97%
	Length-width	Absolute	8.40	3.75	7.65	12.22	16.25	29.51
		Relative	6.89%	2.95%	5.98%	9.62%	13.40%	27.86%
Validation set (20%)	Aspect ratio	Absolute	10.24	4.38	9.1	15.06	20.22	42.86
		Relative	8.38%	3.45%	7.14%	11.69%	16.55%	49.62%
	Floor area	Absolute	8.41	3.69	7.63	12.26	16.46	29.07
		Relative	6.90%	2.91%	5.92%	9.67%	13.60%	32.07%
	Length-width	Absolute	8.37	3.7	7.59	12.22	16.26	28.49
		Relative	6.87%	2.91%	5.93%	9.62%	13.45%	27.70%

Several key findings emerge from these statistics.

First, the validation set results closely match the selection set results across all strategies and metrics. For the length–width combination strategy, the mean relative deviation differs by only 0.02 percentage points between the two datasets (6.89% on the selection set vs. 6.87% on the validation set); similar agreement is observed for the floor area strategy (6.92% vs. 6.90%) and the aspect ratio strategy (8.42% vs. 8.38%). This close alignment demonstrates that the conclusions drawn from the selection set generalize reliably to unseen geometric combinations.

Second, across both datasets, the aspect ratio strategy consistently exhibits the largest errors, with mean relative deviations of 8.42% (selection) and 8.38% (validation), and maximum relative deviations of 49.56% and 49.62%, respectively. This substantial error renders the aspect ratio strategy unsuitable for reliable energy estimation at the conceptual design stage.

Third, the floor area and length–width strategies show very similar performance in terms of mean and median errors. On the validation set, the floor area method achieves a mean relative deviation of 6.90% and a median of 5.92%, while the length–width method achieves 6.87% and 5.93%, respectively—a difference of only 0.03 percentage points in the mean. The 25th and 75th percentiles are also nearly identical between the two methods (2.91% vs. 2.91% at the 25th percentile; 9.67% vs. 9.62% at the 75th percentile on the validation set). These results confirm that the two methods are essentially equivalent in terms of average accuracy and central tendency.

Fourth, and most importantly, the length–width combination strategy consistently outperforms the floor area strategy in reducing extreme errors. On the validation set, the maximum relative deviation drops from 32.07% (floor area) to 27.70% (length–width), a reduction of 4.37 percentage points—more than an order of magnitude larger than the 0.03-point difference in mean accuracy. The 75th percentile values are also slightly but consistently lower for the length–width method (9.62% vs. 9.67% on the validation set), indicating a modest improvement in the upper tail of the error distribution. This confirms that the length–width strategy offers superior robustness against worst-case estimation errors, a property that is particularly valuable when dealing with a wide range of building geometries at the conceptual design stage.

In summary, the prospective validation confirms that the conclusions drawn from the selection set generalize reliably to unseen geometric combinations. While the length–width combination strategy provides only marginal improvement in average accuracy over the simpler floor area method, its consistent and meaningful reduction in extreme errors (maximum deviation reduced by 4.37 percentage points) makes it the preferred choice for conceptual design applications where worst-case performance matters.

4. Discussion

4.1. Accuracy and Applicability of the Simplification Strategies

Among the three strategies, the “length–width combination” strategy achieves an average relative deviation of 6.89% on the selection set (6.87% on the validation set), compared with 8.42% (selection)/8.38% (validation) for the aspect ratio strategy and 6.92% (selection)/6.90% (validation) for the floor area strategy. The length–width method offers a modest improvement in average accuracy over the floor area method (approximately 0.03 percentage points) and a more meaningful reduction in extreme errors (maximum deviation reduced by 4.37 percentage points on the validation set). This result can be attributed to the fact that the length–width combination preserves the two-dimensional information of the building floor plan shape, whereas single-parameter compression (aspect ratio or area) loses information dimensions. For example, two buildings with the same aspect ratio of 2 could be “100 m × 50 m” or “40 m × 20 m”, and their energy

characteristics (e.g., perimeter zone volume fraction, heat loss paths) differ significantly. Although the area strategy accounts for scale, it cannot distinguish between an elongated rectangle and a near-square plan. Therefore, the length–width combination strategy is the optimal choice for the conceptual design phase, with accuracy (deviation <7%) sufficient for preliminary energy estimation and orientation comparison. If higher accuracy is required at later stages, detailed models should be used. The prospective validation on the held-out 20% test set (Section 3.4) confirms that the accuracy statistics reported for the selection set are generalizable to unseen geometric combinations. For the length–width combination strategy, the mean relative deviation on the validation set (6.87%) differs from the selection set value (6.89%) by only 0.02 percentage points, and the rank ordering of the three strategies remains unchanged. This close agreement demonstrates that the stratified splitting protocol successfully preserved the representativeness of the parameter space, and that the conclusions—including the superiority of the length–width method in reducing extreme errors—are not artifacts of the specific sample used for evaluation.

4.2. Physical Mechanisms Behind the Orientation Optimization Results

The optimal orientation is 0° (true south–north) for as many as 83.14% of samples. This result aligns well with the solar movement patterns in hot–humid regions: a true south–north layout minimizes the area of east and west facades. Low-angle direct sunlight in the morning and afternoon strikes east and west walls, causing significant heat gain—a phenomenon consistent with the finding that east- and west-facing walls receive the highest solar radiation among all orientations during summer months in low-latitude regions [27]. The north–south orientation avoids this problem while allowing low-angle winter solar radiation to enter the interior. Hence, true south–north is the best choice.

The orientation range of 39–86°, which covers southeast to northeast directions, is not recommended when energy performance is a primary design objective. Within this range, the building’s long facade faces the direction of direct solar radiation during morning to noon hours. This conclusion provides architects with a clear orientation range that is not recommended, advising against sacrificing energy performance for architectural form or views.

4.3. Implications for Conceptual Design Practice

The simplification strategy proposed in this study requires only three basic parameters (length, width, and number of stories) to rapidly generate a standard energy model and provide orientation recommendations. This enables architects to obtain quantitative decision support even before the conceptual design scheme is finalized (i.e., during the site analysis phase), truly achieving “performance-driven design”.

4.4. Limitations

This study has the following limitations:

1. Geometric limitations: The simplified model only considers rectangular floor plans; actual buildings may include setbacks, curved shapes, L-shapes, and other complex forms. Future research should develop equivalent simplification methods for non-rectangular plans.
2. Climatic limitations: The simulation results presented in this study are based on the Typical Meteorological Year (TMY) weather file for Guangzhou, China. While Guangzhou is representative of the broader HSWW climate zone in southern China, extension to cold or mild regions requires revalidation.
3. Building type limitations: The study focuses only on office buildings. Internal load patterns (e.g., occupant density, equipment usage) differ for other building types, so the parameters of the simplification strategy would need corresponding adjustments.

4. Building stories: The number of stories is fixed at five in this study. The findings may not generalize to high-rise (≥ 12 stories) or low-rise (≤ 3 stories) office buildings, as the relative importance of roof heat gain, vertical heat loss, facade-to-volume ratio, and core-to-perimeter zone ratio varies substantially with building height. For example, high-rise buildings have increased facade exposure and wind-driven infiltration, while low-rise buildings exhibit greater relative roof exposure and potentially different cooling-load profiles. Future work should include the number of stories as a variable parameter to quantify the interaction between building height and optimal orientation, and to extend the proposed simplification strategy to a wider range of building typologies.
5. Window-to-wall ratio and glazing properties: This study adopts a fixed window-to-wall ratio of 0.5 and a fixed solar heat gain coefficient (SHGC) of 0.3 for all orientations, following the requirements of GB/T 51350-2019 for nearly zero-energy buildings. Future work should integrate a wider range of WWR values and glazing types, as well as dynamic shading strategies, to develop a more comprehensive orientation guidance framework.
6. Data limitations: The angle-resolved simulation results for all 130,976 geometric configurations were not fully retained. The near-optimal orientation band analysis is therefore based on the three representative models. Future work should validate the near-optimal band across the full parameter space.
7. Humidity control passively implemented: The ZoneHVAC:IdealLoadsAirSystem objects in the EnergyPlus models were configured with Dehumidification Control Type and Humidification Control Type set to 'None'. However, latent cooling loads associated with moisture changes in the supply air stream are still passively captured by EnergyPlus and are included in the reported cumulative cooling load (see Section 2.2).

5. Conclusions

This study addresses the core problem of missing geometric models and delayed energy performance evaluation during the conceptual design phase of office buildings in hot-humid regions. It proposes a geometry simplification method based on “length–width combination” and applies it to orientation optimization decisions. The main conclusions are as follows:

1. For five-story office buildings in hot-humid regions (Guangzhou weather file, WWR = 0.5, SHGC = 0.3), the length–width combination simplification strategy achieves an average relative energy deviation of 6.89% (6.87% on the held-out validation set), with a reduced maximum deviation of 27.70% compared to 32.07% for the floor area method—a reduction of 4.37 percentage points. Prospective validation on a 20% test set confirms that these accuracy statistics generalize reliably to unseen geometric combinations. The method meets the accuracy requirements of the conceptual design phase (error < 10%). The method requires only three basic parameters—building length, width, and number of stories—making it highly practical.
2. Based on batch simulations of 23,575,680 cases for five-story office buildings in Guangzhou, with the specific facade assumptions (WWR = 0.5, SHGC = 0.3), the optimal orientation for office buildings in hot-humid regions is determined to be true south–north (0°), with approximately 83.14% of geometric samples achieving their lowest energy consumption at this orientation. The orientation range that is not recommended for designs prioritizing energy performance is 39° – 86° , within which more than 99% of the worst-case orientations are concentrated. Furthermore, for the three representative geometric configurations examined, a near-optimal orientation band of $\pm 15^\circ$ around their respective optimal orientations is established, within which the

energy penalty is less than 1%. This band offers potential flexibility for designers to balance energy performance with other design considerations such as site conditions, views, and natural ventilation potential. These findings are specifically applicable to mid-rise (approximately five-story) buildings; extension to other heights is not claimed in this study.

3. The proposed simplification strategy and orientation findings can provide immediate, quantitative performance feedback to architects during the conceptual design phase, transforming energy-efficient design from “late-stage verification” to “early-stage driving”. This provides foundational methodological support for the passive design component of nearly zero-energy office buildings in hot-humid regions, with system efficiency and renewable generation to be addressed in subsequent design.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/buildings16153097/s1>, Table S1: Complete geometric parameters of the 22 surveyed office buildings (building length, building width, depth along long side and depth along short side). Table S2: Representative model lookup table for length–width combinations (representative models for each unique length–width grid node; 1726 unique nodes, where 1726 is the number of distinct (L, W) combinations satisfying the constraints in Table 2, with duplicate entries removed). Table S3: Aggregated simulation results. S4: Model-generation scripts for IDF creation and batch simulation (.zip archive), including IDFGenerator.py for parameterized IDF generation and orientation_research-na.py for running EnergyPlus simulations across all 180 orientations and extracting angle-resolved results.

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Data Availability Statement: The full raw simulation output (23.6 million runs) is not publicly available due to its large volume. However, the following supporting data and materials have been provided as Supplementary Material to ensure transparency and reproducibility: Table S1 (complete geometric parameters of the 22 surveyed office buildings), Table S2 (representative model lookup table for length–width combinations), Table S3 (aggregated simulation results), and S4 (model-generation scripts for IDF creation and batch simulation, provided as a .zip archive). Additional data can be made available upon reasonable request from the corresponding author.

Conflicts of Interest: Author Zhang Liu was employed by the company Runa Smart Equipment Co., Ltd. Author Duo Luo was employed by the company Trinasolar Evergreen (Shanghai) PV Tech. Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Xu, W.; Zhang, S.; Wang, K.; Wang, Q. Comparative Research of Carbon Peak and Carbon Neutral Implementation Paths in the Building Sector. *Jiangsu Constr.* **2022**, 1–6. [[CrossRef](#)]
2. China Association of Building Energy Efficiency. *Research Report on Building Energy Consumption and Carbon Emissions in China (2021)*; China Association of Building Energy Efficiency: Beijing, China, 2021.
3. Yu, J.; Yang, C.; Tian, L. Low-Energy Envelope Design of Residential Building in Hot Summer and Cold Winter Zone in China. *Energy Build.* **2008**, *40*, 1536–1546. [[CrossRef](#)]
4. Huo, M. Analysis and Optimization on the Central Air Conditioning Energy Consumption of Building in Moist Heat Areas of China. Ph.D. Thesis, Guangdong University of Technology, Guangzhou, China, 2014.
5. Wang, J. Analysis on Technical Route of “Chongqing design for energy efficiency 75% of public building” and Energy Saving Index of the Cold Source System. Master’s Thesis, Chongqing University, Chongqing, China, 2013.

6. Zhao, D.; Zhang, X.; Xu, Q. Overtime operating energy consumption analysis of VRF system in office buildings based on measured data. *HV&C* **2019**, *49*, 43–48. [[CrossRef](#)]
7. Deng, X. Research of Optimization and Design Method for PV Building. Master's Thesis, Hunan University, Changsha, China, 2012.
8. Deng, X.; Liu, Z.; Zhang, L.; Li, Y.; Zhao, L. Advancements and Applications of Building-Integrated Photovoltaics (BIPV) in China. In Proceedings of the 3rd International Joint Conference on Energy, Electrical and Power Engineering, CoEEPE 2023, Melbourne, Australia, 22–24 November 2023; Springer Science and Business Media Deutschland GmbH: Melbourne, Australia, 2024; Volume 1208 LNEE, pp. 579–590.
9. Deng, X.; Li, Z.; Ling, R. Analysis of Solar Irradiation for Building-Integrated Photovoltaic (BIPV) Systems. *China Constr. Met. Struct.* **2012**, *32*, 32–36. [[CrossRef](#)]
10. Yang, R.; Zang, Y.; Yang, J.; Wakefield, R.; Nguyen, K.; Shi, L.; Trigunarysyah, B.; Parolini, F.; Bonomo, P.; Frontini, F.; et al. Fire Safety Requirements for Building Integrated Photovoltaics (BIPV): A Cross-Country Comparison. *Renew. Sustain. Energy Rev.* **2023**, *173*, 113112. [[CrossRef](#)]
11. Feng, W.; Zhang, Q.; Ji, H.; Wang, R.; Zhou, N.; Ye, Q.; Hao, B.; Li, Y.; Luo, D.; Lau, S.S.Y. A Review of Net Zero Energy Buildings in Hot and Humid Climates: Experience Learned from 34 Case Study Buildings. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109303. [[CrossRef](#)]
12. Pacheco, R.; Ordóñez, J.; Martínez, G. Energy Efficient Design of Building: A Review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3559–3573. [[CrossRef](#)]
13. Lin, B.; Li, Z. Building energy-saving approach in early design stage. *Chin. Sci. Bull.* **2016**, *61*, 113–121. [[CrossRef](#)]
14. Yao, G.; Chen, Y.; Han, C.; Duan, Z. Research on the Decision-Making Method for the Passive Design Parameters of Zero Energy Houses in Severe Cold Regions Based on Decision Trees. *Energies* **2024**, *17*, 506. [[CrossRef](#)]
15. Torcellini, P.; Pless, S.; Deru, M.; Griffith, B.; Long, N.; Judkoff, R. *Lessons Learned from Case Studies of Six High-Performance Buildings*; NREL/TP-550-37542; National Renewable Energy Laboratory: Golden, CO, USA, 2006. [[CrossRef](#)]
16. Crawley, D.B.; Lawrie, L.K.; Winkelmann, F.C.; Buhl, W.F.; Huang, Y.J.; Pedersen, C.O.; Strand, R.K.; Liesen, R.J.; Fisher, D.E.; Witte, M.J.; et al. EnergyPlus: Creating a New-Generation Building Energy Simulation Program. *Energy Build.* **2001**, *33*, 319–331. [[CrossRef](#)]
17. Dogan, T.; Reinhart, C. Shoeboxer: An Algorithm for Abstracted Rapid Multi-Zone Urban Building Energy Model Generation and Simulation. *Energy Build.* **2017**, *140*, 140–153. [[CrossRef](#)]
18. Reinhart, C.F.; Cerezo Davila, C. Urban Building Energy Modeling—A Review of a Nascent Field. *Build. Environ.* **2016**, *97*, 196–202. [[CrossRef](#)]
19. Shirzadi, N.; Lau, D.; Stylianou, M. Surrogate Modeling for Building Design: Energy and Cost Prediction Compared to Simulation-Based Methods. *Buildings* **2025**, *15*, 2361. [[CrossRef](#)]
20. GB/T 51350-2019; Technical Standard for Nearly Zero Energy Buildings. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2019.
21. GB 50176-2016; Code for Thermal Design of Civil Building. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2016.
22. GB/T 50378-2019; Assessment Standard for Green Building: GB 50378-2019 (2024 Edition). Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2024.
23. JGJ/T 449-2018; Standard for Green Performance Calculation of Civil Buildings. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2018.
24. GB/T 50034-2024; Standard for Lighting Design of Buildings. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2024.
25. Group Zone Forced Air Units: Input Output Reference—EnergyPlus 24.2. Available online: <https://bigladdersoftware.com/epx/docs/24-2/input-output-reference/group-zone-forced-air-units.html#zonehvacidealloadsairsystem> (accessed on 20 July 2026).
26. GB/T 50378-2014; Assessment standard for green building: GB 50378-2014. Ministry of Housing and Urban-Rural Development of the People's Republic of China: Beijing, China; China Architecture Publishing & Media Co., Ltd.: Beijing, China, 2014.
27. Cheng, C.; Wu, X. Distribution and Calculation of Possible Sunny Day Hourly Solar Radiation Amount Received by Wall Surfaces. *J. Nanjing Inst. Meteorol.* **2008**, *31*, 83–91. [[CrossRef](#)]

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