DIGITAL ANALYSIS OF DAYLIGHT AND THERMAL PERFORMANCE IN RESIDENTIAL ARCHITECTURE OF DA LAT

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Abstract: *Da Lat has a distinctive highland climate that influences the daylight and thermal conditions of residential buildings. Although the relatively cool climate provides opportunities for passive environmental strategies, residential buildings may still experience uneven daylight distribution and thermal conditions due to differences in orientation, window configuration, building form, and surrounding obstructions. Digital building-performance analysis provides an opportunity to examine these conditions quantitatively and to support more informed architectural decisions. This study aimed to evaluate the daylight and thermal performance of residential architecture in Da Lat and to identify building characteristics that contribute to more comfortable indoor environmental conditions. The research employed a digital simulation approach using a three-dimensional model of a representative residential building. Site and building data, including orientation, room configuration, openings, materials, and climatic conditions, were incorporated into the simulation model. Daylight performance was assessed through spatial daylight distribution, while thermal performance was examined using indoor temperature and thermal comfort indicators. The simulation results were then compared across selected spaces to identify variations in environmental performance. The findings indicated that daylight availability varied considerably between rooms, particularly according to window orientation, opening size, and the presence of adjacent buildings. The thermal analysis also showed differences in indoor conditions between spaces with different levels of solar exposure and ventilation. These findings suggest that digital environmental analysis can provide useful evidence for improving passive design strategies in Da Lat residences. The study contributes a context-specific approach to integrating digital simulation with climate-responsive residential design in a highland tropical environment..*

Keywords: *Da Lat; Daylight Performance; Thermal Performance; Digital Simulation.*

1. Introduction

The quality of the indoor environment is an important consideration in residential architecture because people spend a substantial amount of time inside their homes. Among the environmental factors that influence indoor conditions, daylight and thermal performance are closely related to building orientation, envelope configuration, window design, solar exposure, and surrounding physical conditions. Daylight can reduce dependence on artificial lighting and improve the visual quality of indoor spaces, while excessive solar exposure through windows may increase heat gain and affect thermal comfort. Consequently, residential design requires a balance between providing sufficient daylight and maintaining acceptable thermal conditions rather than treating these two aspects as independent design problems [1], [2].

Daylight performance has increasingly been evaluated through climate-based simulation rather than relying only on conventional daylight factor calculations or qualitative architectural judgment. Reinhart and Fitz [1] demonstrated the growing role of daylight simulation in building design and showed that simulation tools can support design decisions involving building geometry, openings, and daylight availability. More specifically, Dogan and Park [2] argued that residential buildings require particular attention because daylight availability varies over the day and across seasons, while conventional assessment approaches may not adequately capture these variations. The authors proposed a climate-

based framework for evaluating daylight in residential environments, emphasizing the importance of considering the temporal and spatial characteristics of daylight rather than relying on a single static measurement. These developments indicate that digital analysis can provide architects with a more comprehensive understanding of how building form and envelope decisions influence daylight conditions.
At the same time, adequate daylight does not necessarily indicate good environmental performance. Large or poorly oriented openings may increase daylight penetration but can also increase solar heat gains and consequently affect indoor thermal conditions. Previous research on residential buildings has demonstrated that façade and window characteristics can simultaneously influence daylight, energy use, and thermal comfort [3]. Similarly, research examining building profiles in low-rise residential buildings found that building geometry can influence both daylight penetration and indoor temperature, demonstrating the interaction between architectural form and environmental performance [4]. This relationship is particularly important during the early design stage because decisions concerning orientation, window-to-wall ratio, shading, and room configuration can produce different environmental consequences.
Digital building-performance simulation provides an opportunity to investigate these relationships before physical construction or major building modifications are undertaken. EnergyPlus, for example, was developed as a whole-building energy simulation program capable of representing heat balance, building systems, solar processes, and other aspects of building performance [5]. More recent digital workflows combine environmental simulation with three-dimensional modeling, allowing architects to evaluate daylight, solar radiation, thermal comfort, and energy performance within an integrated design environment. Such approaches have become increasingly relevant because building performance can be evaluated through multiple environmental indicators rather than through architectural appearance alone.
The need for an integrated approach is also reflected in current thermal-comfort assessment practices. ASHRAE Standard 55 identifies air temperature, thermal radiation, humidity, and air speed as important environmental factors affecting thermal conditions, together with personal factors such as clothing and activity [6]. Therefore, thermal performance should not simply be interpreted as indoor temperature but should be considered in relation to the conditions experienced by occupants. In parallel, EN 17037 provides recommendations concerning daylight provision, views, sunlight exposure, and glare in buildings [7]. The existence of these assessment frameworks provides a basis for combining daylight and thermal indicators in digital building analysis.
The relevance of this approach becomes particularly interesting in Da Lat, Vietnam. As a highland city with distinctive topographical, climatic, and architectural characteristics, Da Lat provides a different environmental context from many lowland Vietnamese cities. Recent research on the architectural identity of Da Lat identifies climate, topography, slopes, vegetation, and distinctive residential and heritage environments as important components of the city's character [8]. Residential buildings are also exposed to variations in solar access and surrounding obstructions because of the city's sloping terrain and diverse urban morphology. These characteristics suggest that design assumptions developed for other climatic or urban contexts cannot necessarily be transferred directly to residential architecture in Da Lat.
Previous studies have established several important directions in digital building-performance research. First, daylight simulation has developed from static assessment toward annual, climate-based evaluation [1], [2]. Second, residential building geometry and façade configuration have been shown to influence both daylight and thermal conditions [3], [4]. Third, whole-building simulation has provided increasingly sophisticated methods for assessing energy and environmental performance [5]. However, much of the existing research has focused on climatic contexts or building typologies that differ from the highland urban environment of Da Lat. Furthermore, studies that investigate daylight and thermal performance simultaneously in the context of Da Lat residential architecture remain limited. This creates a research gap concerning how the specific characteristics of residential buildings in Da Lat influence the interaction between daylight availability and indoor thermal conditions.
Based on this gap, this study aims to digitally evaluate daylight and thermal performance in selected residential architecture in Da Lat and to identify the architectural characteristics that most strongly influence indoor environmental conditions. The analysis focuses on the relationship between building orientation, window configuration, solar exposure, spatial configuration, daylight availability, and thermal performance. The novelty of the study lies in

integrating daylight and thermal performance within a single digital analysis framework specifically applied to residential architecture in Da Lat. Rather than evaluating daylight or thermal conditions separately, the research considers their interaction to identify potential design trade-offs and opportunities for climate-responsive residential design.

The study is expected to provide both practical and academic benefits. Practically, the findings can provide architects and students with evidence-based guidance for developing residential designs that respond to the environmental characteristics of Da Lat. The results may also support decisions concerning building orientation, opening configuration, shading, and spatial organization. Academically, the study contributes a context-specific case to the growing body of research on digital environmental analysis and demonstrates how digital simulation can be used as a design-support method for climate-responsive residential architecture. The research may also provide a methodological foundation for subsequent studies involving parametric optimization, energy analysis, or comparative studies of residential buildings in other highland cities.

2. Research Methods

This study employed a quantitative digital simulation approach to examine the relationship between daylight availability and thermal performance in residential architecture in Da Lat, Vietnam. The research focused on a representative low-rise residential building selected to reflect common architectural characteristics of houses in the city, including compact spatial organization, externally exposed façades, operable windows, and pitched or sloping roof forms. The building was documented through field observation, measured drawings, photographic documentation, and recording of the orientation, dimensions, room configuration, window position, window-to-wall ratio, construction materials, and surrounding building conditions. The measured data were used to construct a three-dimensional digital model representing the existing residential condition.

The digital model was developed using a consistent geometric and material definition so that the simulation represented the actual building rather than a generalized prototype. The model included the site context within the immediate surrounding area because adjacent buildings and terrain can influence solar exposure and daylight penetration. Each major residential space was modeled as a separate thermal and daylight zone. Windows and doors were represented according to their actual dimensions and orientations, while opaque building elements were assigned material properties corresponding to the observed construction. The geographic location and building orientation were maintained throughout the simulations to ensure consistency between the daylight and thermal analyses.

Daylight performance was evaluated using annual climate-based simulation under the local weather conditions of Da Lat. The analysis examined spatial daylight availability at a horizontal calculation plane positioned 0.75 m above the finished floor level in occupied rooms. A regular calculation grid was established across each room, excluding a narrow boundary zone adjacent to walls. Annual daylight results were evaluated using spatial daylight metrics, with particular attention to the percentage of occupied areas receiving adequate daylight and the occurrence of excessive daylight exposure. The analysis was conducted separately for bedrooms, living spaces, and other regularly occupied rooms to identify differences caused by orientation, room depth, window configuration, and external obstruction.

Thermal performance was simulated using the same geometric model and climatic conditions. The simulation incorporated hourly outdoor temperature, solar radiation, wind-related environmental conditions, building envelope properties, internal heat gains, occupancy schedules, and natural ventilation assumptions. Indoor air temperature and thermal comfort conditions were evaluated at hourly intervals. Particular attention was given to spaces with high solar exposure and spaces located deeper within the building, allowing the influence of façade orientation and opening configuration to be examined.

Finally, the daylight and thermal simulation results were overlaid and compared to identify design conditions that produced favorable performance in both dimensions. The analysis focused on identifying trade-offs between increased daylight penetration and increased solar heat gain. The resulting performance patterns were translated into architectural recommendations concerning building orientation, window proportion, opening placement, shading, and spatial organization. This workflow established a direct connection between measured residential conditions, digital simulation, environmental performance, and climate-responsive design decisions for residential architecture in Da Lat.

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3. Discussion

The analysis of the selected residential building in Da Lat provides an opportunity to understand environmental performance from an architectural perspective rather than viewing daylight and thermal conditions as two separate technical outputs. The simulation indicates that the environmental quality of a dwelling is closely associated with the way the building receives, distributes, and controls solar radiation. In particular, the relationship between the position of openings, room depth, building orientation, and surrounding obstruction determines how much daylight reaches occupied areas and how solar exposure subsequently affects indoor thermal conditions. This relationship is important in the Da Lat context because the relatively distinctive highland environment does not automatically guarantee satisfactory indoor conditions. A building may benefit from the outdoor climate while still producing uneven environmental conditions between rooms because of its architectural configuration.

The most important observation from the digital analysis is therefore not simply whether the residence performs well or poorly, but where and why environmental differences occur within the building. Spaces located near external openings respond differently from spaces positioned deeper within the floor plan, while façades exposed to greater solar radiation create a different thermal response from more protected façades. This spatial differentiation provides a more useful basis for architectural interpretation than a single building-wide performance value. Previous research has similarly shown that residential environmental performance is strongly influenced by the interaction between façade characteristics, room configuration, and solar exposure [9], [10]. The present study extends this understanding to a residential setting in Da Lat by examining daylight and thermal conditions through the same digital building model.

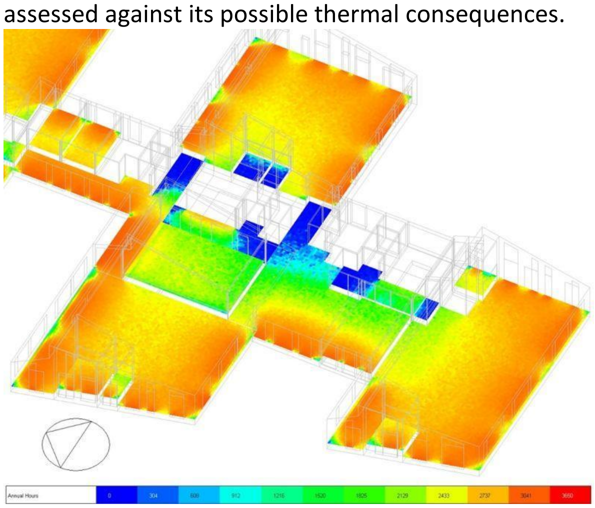
The daylight results show a clear spatial relationship between the external openings and the availability of natural light inside the residence. Areas immediately adjacent to windows receive the strongest daylight contribution, whereas daylight levels tend to decrease as the distance from the opening increases. This pattern is expected from the geometry of daylight penetration, but its architectural significance becomes clearer when the rooms are considered according to their actual proportions and functions. A relatively large opening does not necessarily guarantee an evenly illuminated room. When the room extends substantially behind a single façade opening, the resulting daylight gradient can become pronounced. Li et al. [10] previously demonstrated that room geometry, window configuration, and external obstruction can substantially influence residential daylight performance. The present analysis confirms the importance of considering these factors together rather than evaluating window area as an isolated variable.

The influence of surrounding buildings is particularly relevant to the investigated residence. The three-dimensional model incorporates the immediate physical context so that daylight reaching the building is not evaluated under an unrealistically unobstructed sky. This is important because neighboring buildings can reduce the visible sky component and alter the amount of daylight entering a room. In an urban environment, two identical houses may therefore produce different daylight results simply because their surrounding conditions are different. Li et al. [10] found that heavy obstruction can substantially affect daylight availability in residential buildings. For Da Lat, this finding suggests that residential daylight strategies should consider not only the building envelope but also the spacing and height of neighboring buildings and the physical characteristics of the site.

The spatial pattern of daylight also has implications for room organization. Rooms requiring longer periods of daytime occupation should ideally have stronger access to daylight, whereas less frequently occupied spaces can tolerate lower daylight availability. This consideration provides a direct connection between simulation and architectural programming. Rather than attempting to distribute identical daylight conditions throughout the entire house, the design can respond to the functional requirements of individual spaces. Xue et al. [11] emphasized the value of dynamic daylight assessment for residential environments because daylight availability changes spatially and temporally. The implication for the Da Lat residence is that the success of daylight design should be evaluated according to both the amount of daylight and its distribution within the occupied portion of each room.

The relationship between window area and daylight performance requires further attention. Increasing the window-to-wall ratio generally creates greater potential for daylight penetration, but the improvement is not necessarily proportional to the increase in glazing area. Chi et al. [12] showed that optimum window-to-wall ratios depend on building orientation and that different environmental objectives can produce different optimum configurations. This is particularly relevant to the present case. If an opening already provides adequate daylight to a room, increasing its area may produce limited additional visual benefit while increasing solar exposure. The design implication is therefore to avoid interpreting “more glazing” as synonymous with “better daylight.” The more appropriate question is whether the opening provides sufficient daylight while maintaining acceptable thermal conditions.

This issue becomes clearer when the thermal simulation is considered alongside the daylight results. The thermal response of the residence varies according to solar exposure, envelope characteristics, and the relationship between openings and occupied spaces. Rooms exposed to stronger solar radiation have a greater potential for heat gain, especially where glazing provides a direct path for solar energy to enter the building. Consequently, a façade that performs favorably from a daylight perspective may not necessarily provide the best thermal condition. Vanhoutteghem et al. [13] similarly found that façade window design affects energy consumption, daylight availability, and thermal comfort simultaneously. The present study supports this integrated interpretation by demonstrating that daylight improvement must be assessed against its possible thermal consequences.



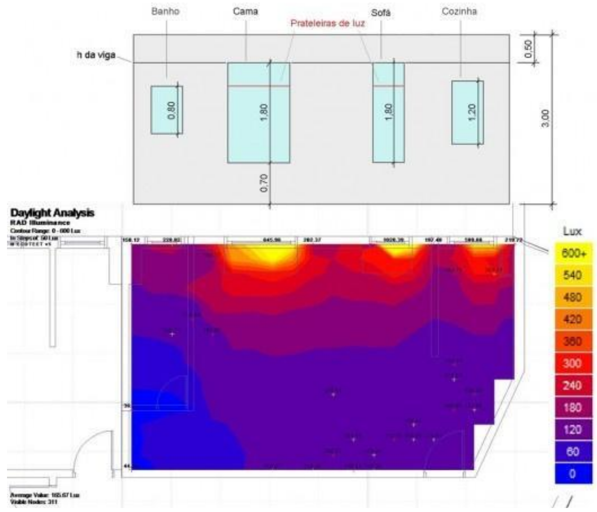


Figure 1. Simulated daylight distribution across the occupied spaces of the investigated Da Lat residence.

The thermal results should consequently be interpreted spatially rather than through a single average indoor temperature. A room with greater exposure to solar radiation may exhibit a different thermal pattern from a room located behind a shaded façade or adjacent to a less exposed part of the building. This distinction is important because thermal comfort depends not only on air temperature but also on the surrounding thermal environment. Kim et al. [14] showed that external shading can influence both daylight and thermal comfort, confirming that façade interventions have simultaneous environmental consequences (see table 1).

Table 1. Relationship between architectural characteristics and environmental performance

Architectural characteristic	Daylight response	Thermal response	Interpretation for Da Lat housing
Large window opening	Greater daylight penetration near façade	Greater potential solar heat gain	Requires controlled solar exposure
Deep room configuration	Strong daylight reduction toward rear	Reduced direct solar exposure in deeper areas	Room depth should correspond to opening access
External obstruction	Reduced daylight availability	Potential reduction	Building spacing must be considered

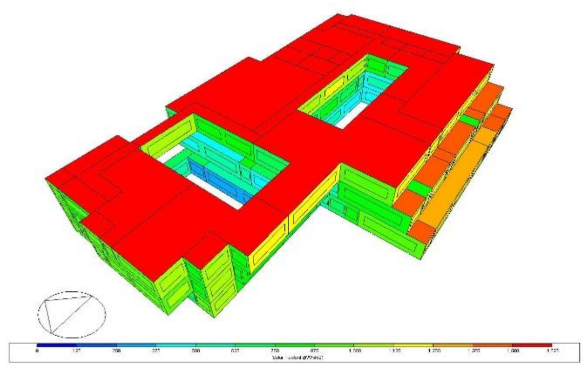
		in direct solar gain	
External shading	Reduces direct solar radiation	Can reduce heat gain	Shading should be optimized to avoid excessive daylight reduction
High solar-exposure façade	Higher daylight potential	Higher thermal load potential	Orientation and shading should be coordinated
Smaller or recessed opening	More limited daylight penetration	Lower direct solar exposure	Suitable only where daylight requirements remain satisfied

The role of external shading deserves particular consideration because it provides a direct architectural mechanism for managing the conflict between daylight and thermal performance. Wong and Istiadji [15] demonstrated that external shading devices influence daylight penetration, while Kim et al. [16] found that exterior shading can improve the thermal performance of residential buildings. However, the present study suggests that shading should not be applied uniformly to all façades. A deeply shaded opening may be appropriate where solar exposure is excessive, but the same strategy may be counterproductive for a room already experiencing insufficient daylight. This supports a façade-specific approach in which shading dimensions respond to orientation and environmental performance.

The geometry of the building envelope also affects this relationship. Balconies, roof overhangs, recessed windows, and projecting walls can modify the solar geometry before radiation reaches the glazing. Such elements should therefore be considered part of the environmental design rather than merely architectural details. Altan et al. [17] demonstrated that building-zone characteristics and geometric configuration influence daylight and thermal performance. In the Da Lat context, this observation is particularly useful because residential architecture frequently incorporates roof projections, terraces, balconies, and articulated façades that can function as passive environmental modifiers.

The combined daylight and thermal results therefore reveal a design trade-off that would be difficult to identify through conventional architectural observation alone. A design modification intended to improve daylight may increase solar heat gain, while a modification intended to reduce heat gain may reduce daylight availability. This trade-off has also been identified in research using multi-objective building optimization. Nasrollahzadeh [18] demonstrated that envelope optimization needs to consider energy, daylight, and thermal comfort simultaneously rather than optimizing a single performance objective. Gamero-Salinas and López-Fidalgo [19] similarly examined the conflict between overheating and useful daylight in residential buildings and showed the value of multi-objective approaches.

This finding provides an important direction for the interpretation of the Da Lat residence. The most successful design should not necessarily be the one with the highest daylight level or the lowest indoor temperature. Instead, the preferred configuration should achieve an appropriate balance between sufficient daylight and acceptable thermal conditions. Wu et al. [20] demonstrated that fenestration and shading optimization can involve simultaneous objectives involving daylight, thermal comfort, energy, and other façade-related criteria. This suggests that the digital workflow developed in the present study can become the first stage of a more advanced parametric optimization process.



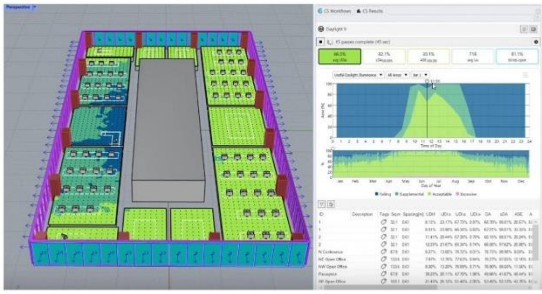


Figure 2. Conceptual relationship between daylight penetration and solar-related thermal response in the investigated residence**.**

In figure 2., the value of the digital approach is consequently found in its ability to connect architectural variables with measurable environmental consequences. Instead of stating that a particular window arrangement is "good" or "bad," the simulation allows the designer to identify which rooms benefit from the configuration, which spaces experience environmental disadvantages, and which architectural parameters may be responsible. This changes the role of digital simulation from a verification tool into a design-support mechanism. Wu et al. [21] demonstrated the potential of combining residential energy consumption, daylighting, and thermal comfort within a multi-objective optimization framework. Such an approach could be applied to the Da Lat residence in subsequent research by systematically varying window size, orientation, shading depth, glazing properties, and room geometry.

The findings also suggest that environmental design recommendations for Da Lat should be locally responsive. A strategy developed for a hot-humid lowland city cannot automatically be transferred to a highland residential environment because the balance between solar exposure, outdoor temperature, daylight, and ventilation differs between locations. Pourel et al. [22] emphasized the importance of considering thermal comfort, daylight, and outdoor microclimate together in residential development. This broader perspective is useful for Da Lat because the environmental behavior of a dwelling is influenced not only by its envelope but also by its immediate outdoor context.

From an architectural perspective, the results point toward four practical principles. First, window area should be optimized rather than maximized. Second, opening orientation should be considered together with solar exposure and room function. Third, external shading should be introduced selectively according to façade performance. Fourth, room depth and surrounding obstruction should be incorporated into daylight decisions. These principles are more useful than prescribing a single window ratio or shading dimension because they allow the design response to adapt to the specific conditions of each residence.

The principal contribution of this study is therefore the integration of daylight and thermal analysis within a context-specific digital workflow for residential architecture in Da Lat. Previous studies have established the importance of fenestration [9], daylight metrics [11], external shading [15], building geometry [17], and multi-objective optimization [18]–[21]. The present research brings these concerns together within a single residential case and interprets their interaction through the spatial characteristics of the building. This approach provides a basis for moving beyond descriptive digital visualization toward evidence-based architectural decision-making.

The findings should nevertheless be interpreted within the scope of the simulation model. Digital simulation represents environmental conditions through defined assumptions concerning weather data, material properties, occupancy, ventilation, and building operation. Therefore, the simulated results are most appropriately used to identify performance patterns and design relationships. Future research can strengthen the analysis through on-site measurements of indoor temperature, illuminance, and other environmental parameters, followed by calibration of the digital model. A calibrated model could then be used for parametric testing and optimization of alternative residential configurations.

Taken together, the discussion demonstrates that the environmental performance of residential architecture in Da Lat is governed by an interaction between daylight access, solar exposure, building geometry, window configuration, shading, and surrounding context. The digital approach makes these relationships visible at the room scale and provides a basis for translating environmental evidence into architectural decisions. Rather than proposing a universal residential solution, the study supports a more contextual approach in which digital analysis is used to determine the appropriate balance between daylight and thermal performance for the specific characteristics of Da Lat.

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4. Conclusion

This study evaluated the daylight and thermal performance of residential architecture in Da Lat through a digital simulation approach and examined how architectural characteristics influenced indoor environmental conditions. The results showed that environmental performance varied considerably between spaces within the same residence. Daylight availability was strongly influenced by the position and size of openings, room depth, building orientation, and surrounding obstruction. Spaces located closer to external openings generally received greater daylight, while deeper areas experienced a reduction in daylight availability. The analysis also demonstrated that surrounding buildings could modify daylight access by reducing exposure to the sky, indicating that residential daylight performance could not be assessed independently from its immediate urban context.

The thermal analysis showed that solar exposure and façade configuration played important roles in determining differences in indoor thermal conditions. Openings that increased daylight penetration could also increase solar heat gain, particularly on façades with greater solar exposure. Therefore, the results indicated that maximizing window area was not necessarily the most appropriate strategy for improving indoor environmental quality. Instead, window configuration, orientation, room depth, and external shading needed to be considered together.

The study answered the research problem by demonstrating that satisfactory residential environmental performance in Da Lat depended on achieving an appropriate balance between daylight availability and thermal conditions rather than optimizing either parameter independently. The main contribution was the integration of daylight and thermal analysis within a context-specific digital workflow that connected architectural characteristics with environmental performance. The findings provided a basis for more climate-responsive residential design in Da Lat, while further research involving on-site measurements and model calibration was needed to validate and strengthen the simulation results.

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