Global Journal of Science & Innovation

Article

Research on Low-Energy Space Organization Methods in the Context of Building System Integration

Qiyuan Liang [1,*]

[1] HGA Architects and Engineer, San Jose, United States
* Correspondence: Qiyuan Liang, HGA Architects and Engineer, San Jose, United States

Abstract: This article mainly elaborates on the comprehensive methods for designing low-energy spaces under the condition of building system integration, as well as the critical supporting roles of system collaboration, advanced simulation analysis, and intelligent control mechanisms in contemporary low-energy space design. Furthermore, it proposes essential key links such as targeted presetting, parametric form generation, and the systematic acquisition of operation and maintenance information throughout the building lifecycle. The research holds that the organization of low-energy spaces must fundamentally break away from the traditional, single functional area design concept. Instead, within modern buildings, the architectural enclosure structure, passive heating and natural ventilation systems, active mechanical heating and cooling systems, alongside renewable energy utilization and dynamic control strategies, should be seamlessly incorporated into a unified, holistic framework. According to varying energy consumption levels, dynamic climate responses, the optimization of the interface between natural daylight and wind patterns, and the continuous monitoring and controlling of the spatial usage status, the complex relationship among the spatial form, equipment systems, and occupant behavior should reach an optimal, balanced state. Ultimately, this integrated approach can effectively reduce the overall heating and cooling loads, significantly lower the lighting and ventilation energy consumption of buildings, and substantially improve both the operational efficiency and the environmental adaptability of the architectural space. By establishing these comprehensive strategies, this study aims to provide highly feasible, innovative methods and practical guidelines for future building energy-saving design and sustainable architectural development.

Keywords: building integration; low-energy space; space organization; operation feedback; energy efficiency

Received: 11 April 2026
Revised: 02 June 2026
Accepted: 15 June 2026
Published: 18 June 2026

Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

The spatial organization has played a pivotal role in advancing low-energy consumption design, emphasizing the collaborative optimization of multiple systems. Traditional architectural design often isolates functional layout, equipment configuration, and operational management, resulting in a lack of coordination between spatial form and energy systems. By integrating building systems, a unified technical framework emerges, enabling the envelope structure, lighting, ventilation, HVAC systems, energy management, and intelligent controls to function cohesively as a single entity [1]. This approach facilitates the creation of energy-efficient spaces by harmonizing various components. The article explores the feasibility, critical aspects, and organizational methods for enhancing energy utilization in building spaces. Key strategies include energy consumption zoning, adaptive responses to climate variations, the integration of solar and wind energy systems, and the incorporation of operation feedback mechanisms. These measures aim to optimize energy efficiency while addressing environmental challenges and promoting sustainable architectural practices.

2. Feasibility of Low-Energy Space Organization in the Context of Building System Integration

2.1. Multi-System Collaboration Provides Technical Support for Low-Energy Space Organization

The integration of building systems has enabled low-energy space organization to evolve from focusing solely on individual spaces to incorporating the coordination of comprehensive technologies [1]. Various subsystems, including the building envelope, lighting systems, ventilation systems, HVAC, energy management, and intelligent control systems, are interconnected within a unified design framework. This integration allows spatial layouts to be determined not only by functional requirements but also by considerations such as thermal environment, light environment, wind environment, and equipment efficiency. By leveraging the combined effects of these systems, designers can predict how factors such as orientation, depth, window opening rates, and functional room divisions influence indoor thermal loads and lighting energy consumption. This predictive capability facilitates informed decisions regarding space arrangement. Furthermore, advancements in Building Information Modeling (BIM) platforms, energy simulation software, and building automation technologies have created opportunities for seamless data exchange, value verification, and system responsiveness. These technological developments provide a robust and stable foundation for achieving low-energy space organization. The integration of these systems ensures that the design process is not only efficient but also adaptable to evolving energy efficiency standards and environmental considerations. Consequently, the feasibility of low-energy space organization is significantly enhanced through the comprehensive integration of building systems, enabling sustainable and energy-efficient architectural solutions.

2.2. Feasibility of the Implementation Plan for Digital Simulation and Intelligent Control Enhancement Measures

The practical implementation of low-energy space organization hinges on the ability to pre-assess its performance outcomes and make continuous adjustments throughout the process. Digital simulation technology provides a feasible pathway to achieve these objectives. Designers can utilize advanced tools such as BIM modeling software, energy consumption simulation software, solar analysis software, and wind environment simulation software to conduct detailed parameter testing. These tests can evaluate critical aspects such as building orientation, depth, window-to-wall area ratio, functional layout, and traffic flow patterns [2]. By analyzing variations in cooling and heating demands, lighting efficiency, air circulation, and equipment energy consumption across different design schemes, designers can minimize errors that might arise from over-reliance on subjective experience. Intelligent control systems further enhance the adaptability of the implementation plan. Through the installation of sensors, meters, and building automation systems, it becomes possible to continuously monitor indoor conditions, including temperature, humidity, light intensity, occupancy levels, and the operational status of various facilities. Based on this real-time data, decisions can be made regarding the optimal operation of lighting systems, ventilation, and air conditioning. This approach ensures that the low-energy space organization is not only quantitatively validated during the design phase but also continuously optimized post-implementation. Such a methodology significantly increases the likelihood of successful execution, as it allows for ongoing refinement and adaptation to changing conditions, ensuring that the system remains efficient and effective over time.

3. Key Steps in Low-Energy Space Organization under the Context of Building System Integration

3.1. Prioritizing Performance Goals and Calibrating Energy Consumption Boundaries

The establishment of performance targets is a critical initial step in the technological implementation of low-energy space organization. This process shifts the focus of energy-saving measures from later-stage equipment adjustments to the early stages of design planning. During the initial design phase, it is essential to define objectives related to controlling heating and cooling loads, optimizing natural lighting, enhancing ventilation efficiency, improving space utilization, and ensuring indoor comfort. These objectives should be tailored to the specific building type, climate zone, usage intensity, and operational schedule. They must then be translated into measurable technical indicators that can guide spatial organization effectively. Furthermore, the calibration of energy consumption boundaries requires a detailed definition of primary energy-consuming elements and their control parameters. This involves categorizing spaces into high-load, low-load, transitional, and buffer zones, while assessing variations in heat and humidity loads, lighting requirements, occupant density, and equipment reliance across different functional areas. By addressing these factors comprehensively, the design process can ensure that energy efficiency is integrated seamlessly into the spatial organization, thereby achieving a balance between functionality and sustainability.

3.2. System Parameter Embedding in Spatial Form Generation

During the spatial form generation phase, the imperative of achieving low energy consumption is translated into a precise alignment between spatial parameters and system parameters. This ensures that the building form transcends being merely an external contour or a combination of planar elements, evolving instead into a technical entity capable of supporting energy consumption control functions. Specifically, considerations such as orientation, body shape coefficient, spatial depth, floor height, opening proportions, shading structures, and traffic organization are integrated with technical parameters like the heat transfer coefficient of the envelope structure, window-wall ratio, air conditioning load, fresh air volume, lighting power density, and equipment zoning control. By embedding these parameters, designers gain the ability to evaluate the influence of various spatial configurations on factors such as solar radiation acquisition, heat exchange through the envelope, natural ventilation pathways, and artificial lighting demands. This enables real-time adjustments to volumetric combinations and spatial interfaces during the design process, ensuring optimal energy efficiency and functional performance of the building form.

4. Low-Energy Space Organization Methods in the Context of Building System Integration

4.1. Reorganize Spatial Functional Zones According to Energy Consumption Levels

Reorganizing spatial functional divisions based on energy consumption levels involves analyzing the intensity of use, heat and humidity load, illumination, and equipment dependence of various spaces [2, 3]. By ranking the energy consumption levels of each functional room within a building, their spatial positions, proximity relationships, and service system scopes can be optimized. The energy consumption intensity per unit area can be calculated using a mathematical expression, which helps identify zones with varying energy demands. High energy consumption zones should ideally be located near the core of equipment services to maximize efficiency. Conversely, low energy consumption zones can be positioned in areas with favorable lighting and ventilation conditions. Spaces related to traffic, storage, or equipment can serve as thermal buffer zones, reducing overall energy demands. This approach ensures that spatial organization aligns with energy efficiency goals, contributing to sustainable building system integration.

$$E_i=\frac{Q_i}{A_i}\#\text{（1）}$$

In this context, E_i represents the energy consumption intensity per unit area of the i type space, measured in kWh/m2. Q_i denotes the total energy consumption of Class i space during the statistical period, expressed in kWh, while □A_i refers to the floor area of the i type space, measured in square meters. Through these calculations, zones can be categorized into high, medium, and low energy consumption areas, along with buffer zones. High energy consumption zones should be strategically connected to equipment service cores to enhance operational efficiency. Low energy consumption zones can be arranged in areas with optimal lighting and ventilation conditions, while traffic, storage, or equipment-related spaces can act as thermal buffer zones. This systematic division ensures that spatial organization is both energy-efficient and functionally coherent, supporting the integration of building systems.

For instance, in the low-energy renovation of a comprehensive office building, designers calculated energy consumption for meeting rooms, open office areas, archives, and transportation spaces. The total energy consumption of the open office area was $Q_1=12000kWh$, with a total area of $A_1=600$ ㎡. The calculated energy consumption intensity was E_1=12000/600=20kWh/㎡. Similarly, the meeting room's total energy consumption was $Q_2=9000kWh$, with an area of $A_2=300$ m2, resulting in $E_2=30kWh/$⍰, indicating it as a relatively high-energy-consuming space. Based on these findings, meeting rooms were concentrated near zones with fresh air or air conditioning control and positioned away from west-facing exterior walls to minimize heat gain. Open office areas were arranged in south-facing positions with favorable lighting conditions. Archives and transportation spaces were placed on the periphery to act as heat buffering zones. This energy-driven functional reorganization clarified spatial layouts and ensured the building system met operational and environmental needs effectively.

4.2. Optimizing Spatial Form Parameters Based on Climate Response

Climate factors have a profound impact on the spatial form of buildings, necessitating careful consideration during the design of low-energy consumption spaces. Key elements such as regional temperature, sunlight exposure angles, prevailing wind directions, and humidity levels must be integrated into the planning process. Adjustments to the building's orientation, shape coefficient, spatial depth, window opening ratios, shading measures, and atrium organization can significantly reduce cooling energy consumption while enhancing environmental performance. The building's shape coefficient serves as a critical reference for evaluating spatial form parameters, calculated using the formula provided. Here, S represents the building form factor, measured in m^{-1}; F denotes the area of the building's outer envelope structure exposed to outdoor air, measured in m^2; and V signifies the enclosed volume of the building, measured in m^3. Generally, a larger form factor correlates with increased heat absorption or dissipation, leading to higher cooling or heating loads. In cold regions, minimizing the form factor is essential to reduce heat loss, while in hot regions, additional measures such as shading installations, ventilation corridors, and elevated floors are necessary to block solar radiation and heat absorption. Utilizing natural wind power effectively can further enhance indoor ventilation, reducing reliance on mechanical cooling systems.

$$S=\frac{F}{V}\#\ (2)$$

Taking the design of a teaching complex building situated in a region with both hot and cold climates as an illustrative example, the original design featured a total external surface area of $F of 6800m^2$ and a building enclosed volume of $V of\ 24000m^3$. Calculations revealed a form factor of $S=6800/24000=0.283m^{-1}$. Energy consumption analysis indicated that the building's west-facing orientation resulted in substantial cooling loads during summer, exacerbated by the deep corridor between indoor and outdoor areas, which hindered effective air circulation. During the optimization process, the layout was transformed from a dispersed arrangement to a more concentrated courtyard-style design. This reorganization reduced the external surface area of the enclosure structure to $F=6100m^2$ while maintaining the enclosed volume at $V=24000m^3$, yielding a revised form factor of $S=6100/24000=0.254m^{-1}$. The main teaching rooms were reoriented to a north-south axis, while stairwells, bathrooms, and equipment rooms were strategically placed on the west side to act as thermal buffer zones. Additionally, the central courtyard was designed to facilitate cross-ventilation, and horizontal shading panels were installed on the south-facing side. These modifications addressed initial heat transfer challenges caused by external environmental fluctuations, significantly reducing the building's reliance on air conditioning systems in later stages [1, 4].

The optimization of spatial form parameters in this example demonstrates the importance of integrating climate-responsive strategies into architectural design. By transitioning to a courtyard-style layout, the building's external surface area was effectively minimized, reducing heat transfer and improving energy efficiency. The incorporation of thermal buffer zones, such as stairwells and equipment rooms, on the west side further mitigated heat gain during summer months. The central courtyard not only enhanced cross-ventilation but also created a more comfortable indoor environment by leveraging natural airflow. Horizontal shading panels on the south-facing side provided additional protection against solar radiation, complementing the overall design strategy. These adjustments underscore the critical role of spatial form optimization in achieving sustainable building performance, particularly in regions with diverse climatic conditions [5]. Through careful planning and the application of climate-responsive measures, the building's energy consumption was significantly reduced, highlighting the potential for similar approaches to be applied in other architectural projects to promote environmental sustainability and energy efficiency.

4.3. Establish a Spatial Interface System That Integrates Light and Wind

To establish a spatial interface system that integrates light and wind effectively, it is essential to organize the interfaces using elements such as opening positions, window-to-wall ratios, profile heights, light wells, atriums, ventilation corridors, and adjustable partitions. These elements help create a connection between the natural lighting path and the natural ventilation path, ensuring their coordination throughout the process. The initial consideration should be determining the lighting distance, openness, and airflow conditions of the primary rooms in use [6, 7]. Subsequently, the shapes of these rooms can be designed based on the building's orientation and the prevailing wind direction. Ventilation organization can be validated using the natural ventilation volume formula, which incorporates factors such as the effective ventilation opening area, average wind speed through the opening, and other relevant parameters. When Q_v is insufficient, adjustments such as increasing the opening area, installing high and low windows, connecting atriums, or reducing internal obstructions can enhance air circulation. Simultaneously, increasing the penetration depth of natural light can further optimize the spatial interface system.

$Q_v=A_e\times v\#$ （3）

In this formula, Q_v represents the natural ventilation volume, measured in appropriate units, while $m^3/s;A_e$ denotes the effective ventilation opening area, measured in m^2. Additionally, v represents the average wind speed through the opening, measured in m/s. When the ventilation volume Q_v is insufficient, it becomes necessary to increase the opening area, incorporate high and low windows, connect atriums, or reduce internal obstructions to improve air circulation. At the same time, the penetration depth of natural light should be increased to ensure a balanced integration of light and wind. These measures collectively contribute to creating a more efficient spatial interface system that minimizes reliance on artificial lighting and mechanical ventilation systems.

Take the renovation of a shared office area in an office building as an example [8, 9]. This area, characterized by its large depth, limited south-facing windows, and numerous interior partitions, faced challenges in achieving adequate natural lighting and ventilation. Rooms closer to the center required prolonged use of artificial lighting and mechanical fresh air systems for ventilation. Before the renovation, the effective ventilation opening area was $A_e was 6m^2$, with an average wind speed of $v of 0.5m/s$. According to calculations, the natural ventilation volume was $Q_v=6\times0.5=3m^3/s$. After the renovation, designers removed several solid partitions and added east-west opening windows, increasing the effective ventilation opening area to $A_e=10m^2$. The shared corridor in the middle facilitated cross-ventilation, and if the average wind speed remained $v=0.5m/s$, the ventilation volume improved to $Q_v=10\times0.5=5m^3/s$. Additionally, glass partitions and high side windows were installed in areas closer to the center, allowing natural light to penetrate deeper into the space. By simultaneously modifying the light and ventilation interfaces, the reliance on artificial lighting and mechanical ventilation systems was significantly reduced, demonstrating the effectiveness of an integrated spatial interface system.

4.4. Adjust the System Linkage Strategy Based on Operation Feedback

After the building is put into use, the low-energy space organization requires continuous adjustments based on operational feedback. This involves not only monitoring energy consumption but also sensing and recording the surrounding environment and the conditions of occupants. Such data helps determine whether the equipment within the space is functioning optimally or encountering issues under specific usage conditions. Based on this information, adjustments can be made to the coordination of air conditioning, fresh air, lighting, and shading systems [10]. This approach emphasizes not only the efficiency of the equipment but also the influence of spatial openness, occupancy levels, and environmental requirements on the overall system. The space operation energy efficiency index serves as a critical metric for evaluation, expressed as R. Here, R represents the energy consumption per unit personnel during operation, measured in kWh per person; E_t denotes the total energy consumed by the space over a specific period, measured in kWh; and N_t indicates the total number of people using the space during the same period, measured in persons. If the R value is excessively high, it suggests a mismatch between the energy consumption of the space and the number of users. In such cases, measures such as reducing the service range of equipment, shortening operational hours, decreasing the lighting area, or lowering the fresh air volume in low-occupancy zones can be implemented to achieve more effective linkage control.

$$R=\frac{E_t}{N_t}\#（4）$$

Take the optimization of the reading area in a library as an illustrative example. Using a management platform, the total energy consumption of air conditioning, lighting, and fresh air systems in the reading area from 18:00 to 21:00 on a specific evening was recorded as $E_t=180kWh$, with the cumulative number of users being $N_t=60$. By calculation, the energy consumption per person was determined to be $R=180/60=3$ kWh. Analysis revealed that even when the three-story reading room had few users, the air conditioning and lighting systems continued to operate as if the entire floor was fully occupied. To address this inefficiency, the system was modified to focus operations on the southern section of the space. Additionally, lights in rarely used rooms were turned off, and the fresh air system was adjusted to operate in a partial supply mode [11]. Following these optimizations, the total energy consumption during the same period decreased to $E_t=105$ kWh, while the cumulative number of users was $N_t=58$. Consequently, the energy consumption per person was recalculated as $R=105/58\approx1.81kWh$. This example demonstrates that adjusting the system's linkage strategy based on real-time conditions can align equipment operation with spatial needs, thereby enhancing the control and efficiency of low-energy consumption space organization.

This case study highlights the importance of dynamic adjustments in system operations to achieve energy efficiency. By leveraging real-time data and operational feedback, it becomes possible to identify inefficiencies and implement targeted modifications. For instance, in the library example, the initial energy consumption per person was disproportionately high due to the uniform operation of systems across the entire space, regardless of actual occupancy. The subsequent adjustments, such as limiting the operational range to high-use areas and reducing energy input in low-use zones, significantly improved efficiency [12]. These changes not only reduced overall energy consumption but also ensured that the systems better matched the actual needs of the space. Such strategies underscore the value of integrating advanced monitoring and control mechanisms into building management systems. By continuously refining these systems based on feedback, it is possible to create spaces that are both energy-efficient and responsive to user requirements, ultimately contributing to sustainable building operations.

5. Conclusion

Based on the integration of building systems, low-energy consumption spatial organization encompasses not only the functional layout on the building plane but also the seamless coordination and unity of spatial form, environmental performance, equipment systems, and associated data. By fostering mutual cooperation among various subsystems, alongside the application of digital simulation and intelligent control, technical support can be effectively harnessed during the design process. This approach enables continuous optimization throughout the operational lifecycle of the building. The methods proposed in this study, such as energy consumption grade classification, climate impact analysis, and the establishment of light and wind collaborative interfaces, significantly contribute to reducing cooling and heating loads, minimizing electricity consumption for lighting and ventilation, and enhancing the adaptability of spatial organization to diverse climatic conditions or operational scenarios. Furthermore, these strategies underscore the importance of integrating spatial design with system-level innovations to achieve sustainable energy goals. Future research and design efforts should prioritize the holistic integration of spatial organization with advanced system configurations, ensuring that low-energy consumption principles are embedded across all phases, including design formulation, technical implementation, and operational management. This comprehensive approach will pave the way for more resilient, energy-efficient, and environmentally adaptive architectural solutions.

References

1. H. Lyu, D. Herring, L. Wang, J. Ninic, J. Andrews, M. Li, ... and S. Wang, "Multi-Objective Optimization for Flexible Building Space Usage," in *2024 IEEE Conference on Artificial Intelligence (CAI)*, June 2024, pp. 932-939.
2. H. Harshalatha, S. Patil, and P. G. Kini, "A review on simulation based multi-objective optimization of space layout design parameters on building energy performance," *Journal of Building Pathology and Rehabilitation*, vol. 9, no. 1, p. 69, 2024.
3. D. Banerjee, "Computational review and assessment of the urban heat island effect and its impact on building space conditioning," *Enquiry The ARCC Journal for Architectural Research*, vol. 20, no. 2, pp. 3-31, 2023.
4. Y. Zeng, R. J. Clark, Y. Galazutdinova, A. Odukomaiya, S. Al-Hallaj, M. Farid, ... and J. Woods, "Open-cycle thermochemical energy storage for building space heating: Practical system configurations and effective energy density," *Applied Energy*, vol. 376, p. 124218, 2024.
5. A. G. Hestnes, "Building integration of solar energy systems," *Solar Energy*, vol. 67, no. 4-6, pp. 181-187, 1999.
6. P. Kivimaa and M. Martiskainen, "Innovation, low energy buildings and intermediaries in Europe: systematic case study review," *Energy Efficiency*, vol. 11, no. 1, pp. 31-51, 2018.
7. E. Heiskanen, H. Nissilä, and R. Lovio, "Demonstration buildings as protected spaces for clean energy solutions–the case of solar building integration in Finland," *Journal of Cleaner Production*, vol. 109, pp. 347-356, 2015.
8. S. Petersen, "Simulation-based support for integrated design of new low-energy office buildings," Ph.D. dissertation, Dept. of Civil Eng., Technical University of Denmark, 2011.
9. F. Garde, E. Ottenwelter, A. Bornarel, and P. M. Tardif, "Integrated building design in tropical climates: Lessons learned from the ENERPOS net zero energy building," *ASHRAE Transactions*, vol. 118, no. 1, 2012.
10. S. C. Hui, "Low energy building design in high density urban cities," *Renewable Energy*, vol. 24, no. 3-4, pp. 627-640, 2001.
11. M. A. Berawi, A. A. Kim, F. Naomi, V. Basten, P. Miraj, L. A. Medal, and M. Sari, "Designing a smart integrated workspace to improve building energy efficiency: an Indonesian case study," *International Journal of Construction Management*, vol. 23, no. 3, pp. 410-422, 2023.
12. A. Hainoun, H. M. Neumann, N. Morishita-Steffen, B. Mougeot, É. Vignali, F. Mandel, ... and B. Rozel, "Smarter together: monitoring and evaluation of integrated building solutions for low-energy districts of lighthouse cities Lyon, Munich, and Vienna," *Energies*, vol. 15, no. 19, p. 6907, 2022.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of Publisher and/or the editor(s). Publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.