Volume 11, Number 2, 2025

Integrated Approach to Energy Certification and Quality Control of Microclimate Formation in Modern Construction

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Received: September 03, 2025. Revised: October 12, 2025. Accepted: October 20, 2025.

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Abstract

This study presents an integrated approach to energy certification and quality control of ventilation systems in modern construction, emphasizing the role of energy efficiency in building performance. The research investigates current methods for evaluating ventilation effectiveness, compliance with energy standards, and the impact of system design on indoor environmental quality. Comprehensive analysis of regulatory frameworks and practical assessment techniques highlights the interconnection between certification processes and construction quality management. Case studies illustrate how systematic monitoring and optimization of ventilation systems can reduce energy consumption while maintaining comfort for people in the building. The findings provide a foundation for improving energy certification protocols and quality assurance practices, promoting sustainable construction strategies, and supporting the development of high-performance, energy-efficient buildings.

Keywords: energy certification; quality control; ventilation systems; energy efficiency; modern construction; sustainable buildings; performance assessment.

1. Introduction

The construction sector is undergoing a significant transformation driven by the growing need for energy efficiency, environmental sustainability, and enhanced indoor environmental quality. Modern buildings are expected not only to minimize energy consumption but also to maintain optimal air quality, thermal comfort, and operational reliability. Ventilation systems play a crucial role in achieving these objectives, as they directly influence indoor air circulation, pollutant removal, and energy demand. Energy certification has emerged as a critical instrument to evaluate the performance of buildings and ensure compliance with increasingly stringent energy regulations. This process involves the systematic assessment of building energy use, insulation effectiveness, and the operational efficiency of mechanical systems, including ventilation. Despite the recognized importance of energy certification, challenges persist in integrating these assessments with comprehensive quality control mechanisms during construction. Ensuring that ventilation systems meet both design specifications and functional performance requirements is essential for achieving sustainable building objectives. This study adopts an integrated approach, combining energy certification protocols with rigorous quality control measures to enhance the effectiveness of ventilation systems in modern construction. By analyzing regulatory frameworks, practical implementation strategies, and case studies of contemporary projects, the research highlights the interdependence between certification processes

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This paper should be cited as: O. Pryimak, Y. Burda, I. Redko, Y. Pivnenko, O. Gvozdetskii. (2025). Integrated approach to energy certification and quality control of microclimate formation in modern construction. *Energy Engineering and Control Systems*, Vol. 11, No. 2, pp. 79 – 84. https://doi.org/10.23939/jeecs2025.02.079

and quality management practices. The findings provide evidence that a systematic approach to energy evaluation and performance monitoring can lead to substantial reductions in energy consumption while maintaining occupant comfort and safety. This research contributes to the development of strategies for optimizing ventilation systems, improving building energy performance, and supporting the advancement of sustainable construction practices in line with global energy efficiency standards.

2. Analysis of recent research and publications

Recent studies highlight the growing importance of integrating thermodynamic and thermophysical analyses into the design and operation of heat and gas supply systems, as well as ventilation networks, to achieve higher energy efficiency and operational reliability. Comprehensive monographs have established theoretical foundations for understanding the complex interactions within these systems, emphasizing the necessity of systematic engineering solutions for modern buildings [1]. Research on coal-fired power plants has focused on peak-shaving strategies, flexible carbon capture, and wastewater treatment to optimize energy consumption while maintaining environmental compliance [2]. The enhancement of operational flexibility through multi-scale utilization of turbine energy storage further demonstrates the potential for energy-efficient management [3]. Investigations into near-critical fluid behaviors under parameter scaling and chemically reactive flows underline the critical role of accurate thermophysical characterization in modeling and system optimization [4], [5].

In the context of ventilation, intelligent control strategies have been explored using neural networks and non-dimensional modeling to regulate airflow and indoor temperature effectively [6], [7]. Additionally, the economic evaluation of energy efficiency measures and the implementation of renewable technologies has been facilitated by artificial intelligence, providing a data-driven framework for sustainable construction practices [8]. Combined heat and power units have been analyzed to improve operational flexibility while simultaneously supplying electricity and two-pressure steam, emphasizing the significance of integrated system design [9]. Advanced studies on thermophysical properties of material systems provide essential data for improving heat exchange components in building services engineering [10]. Collectively, these studies demonstrate a trend towards holistic approaches that couple theoretical, computational, and practical methodologies to optimize energy performance, ventilation quality, and sustainability in modern construction.

Furthermore, the drive for sustainability is materializing through the assessment of regional renewable resources, such as the prospects for geothermal energy development [11]. These initiatives are complemented by foundational research aimed at enhancing the performance of essential building services, including methods for improving the energy efficiency of heating systems [12].

3. Goal and task setting

The primary goal of this study is to develop an integrated approach to energy certification and quality control of ventilation systems in modern construction, aiming to enhance building energy performance, ensure optimal indoor environmental conditions, and promote sustainability. Achieving this goal requires a holistic understanding of the interconnections between system design, operational efficiency, and regulatory compliance.

The tasks of the research include analyzing current methods of energy certification and quality control, evaluating the performance of ventilation systems through practical and theoretical assessment, and identifying key indicators that influence energy efficiency and occupant comfort. Additionally, the study aims to propose strategies for optimizing system design and management, integrating advanced technologies and monitoring tools to ensure consistent compliance with energy standards. The paper seeks to provide actionable recommendations that support sustainable construction practices and improve the overall effectiveness of energy management within modern buildings.

4. The main part of the study

In modern construction, the concepts of energy certification and quality control are fundamental for ensuring the efficiency, reliability, and sustainability of building systems. Energy certification can be defined as a structured evaluation process that quantifies a building’s energy performance, including the efficiency of its structural components, insulation, and mechanical systems such as heating, cooling, and ventilation. This process establishes benchmarks for energy consumption, identifies areas of inefficiency, and provides guidance for optimizing energy use, thereby supporting compliance with regulatory standards and sustainability objectives.

Quality control in construction refers to the systematic procedures implemented to verify that design specifications, materials, and installation practices meet established performance standards. It ensures that building systems, particularly ventilation and HVAC networks, operate as intended, delivering adequate indoor air quality, thermal comfort, and energy efficiency. This process encompasses continuous monitoring, testing, and validation at multiple stages of construction, from material selection to system commissioning.

The investigation of energy certification and quality control has become increasingly critical in contemporary construction due to rising energy costs, stricter regulatory requirements, and the growing emphasis on sustainable urban development. Effective implementation of these processes enables the reduction of energy consumption, mitigation of environmental impacts, and improvement of occupant comfort and health. Technical analysis and research in these areas allow engineers and designers to develop optimized solutions for energy-efficient buildings, ensuring that ventilation and other building systems function reliably under variable operational conditions.

Energy conservation plays a pivotal role in the design, operation, and management of modern ventilation systems. Ventilation is one of the most energy-intensive components of building operation, as it involves the continuous movement, heating, or cooling of air to maintain indoor air quality and thermal comfort. Implementing energy-saving strategies within these systems directly impacts overall building efficiency, reducing operational costs and environmental footprint.

Modern energy-efficient ventilation systems incorporate advanced technologies such as variable air volume (VAV) control, heat recovery ventilators (HRV), energy recovery systems, and intelligent sensors that regulate airflow according to occupancy and indoor environmental conditions. By optimizing air distribution, minimizing unnecessary airflow, and recovering energy from exhaust air, these systems significantly reduce electricity and heating demands.

Moreover, energy conservation in ventilation systems contributes to sustainable building performance by lowering greenhouse gas emissions and supporting compliance with energy standards and certification requirements. It enhances the reliability of mechanical systems, prolongs equipment lifespan, and improves indoor comfort levels without compromising air quality. Research and practical implementation of energy-saving measures in ventilation are therefore essential for achieving high-performance, cost-effective, and environmentally responsible building operation in contemporary construction.

An integrated approach to energy certification of buildings involves the comprehensive assessment of all factors influencing a building’s energy performance, combining theoretical analysis, practical evaluation, and regulatory compliance into a unified framework. Unlike traditional energy audits, which often focus on isolated components or systems, the integrated approach considers the building as a complex, interdependent system in which structural elements, insulation, heating, cooling, and ventilation collectively determine energy efficiency.

This methodology begins with a detailed evaluation of architectural and structural characteristics, including thermal insulation, glazing, and orientation, which directly affect heat transfer and energy demand. Mechanical systems, particularly ventilation and HVAC networks, are analyzed for their operational efficiency, airflow distribution, and control strategies.

Adopting an integrated energy certification strategy is increasingly essential in contemporary construction, as it aligns with global sustainability objectives, facilitates compliance with stringent energy codes, and provides a scientific basis for improving the energy management and operational reliability of modern buildings. (Table 1).

Table 1. Influence of ventilation system parameters on building energy efficiency.

Parameter	Unit	Value Range	Impact on Energy Efficiency
Heat transfer coefficient of ductwork	$W/m^2{\cdot}K$	0.5 – 2.0	Higher coefficient reduces heat losses
Efficiency of heat recovery unit	%	60 – 90	Higher efficiency decreases heating/cooling demand
Average air flow rate	m^3/h	500 – 2000	Increased flow can raise energy consumption
Supply air temperature	°C	15 – 25	Higher temperature reduces heating requirements
Supply air humidity	%	40 – 60	Optimal humidity enhances indoor comfort
Air changes per hour (ACH)	ACH	1 – 6	Higher ACH may increase energy use

This table illustrates the relationship between different ventilation system parameters and their impact on building energy efficiency. It demonstrates how variations in each parameter influence overall energy consumption and indoor comfort.

Table 2 presents a set of experimental nonlinear data illustrating the interdependent behavior of key ventilation system parameters and their impact on building energy efficiency. The heat transfer coefficient of ductwork reflects thermal losses in the ventilation network, while the heat recovery efficiency indicates the proportion of energy reclaimed from exhaust air to precondition incoming supply air. The average air flow rate represents the volume of ventilated air necessary to maintain indoor air quality and thermal comfort. (Table 2).

Table 2. Experimental data of ventilation system parameters and energy efficiency.

No.	Heat Transfer Coefficient (W/m²·K)	Heat Recovery Efficiency (%)	Average Air Flow Rate (m³/h)
1	0.5	60	520
2	0.7	65	680
3	0.9	70	850
4	1.1	72	1020
5	1.3	75	1180
6	1.5	78	1350
7	1.7	81	1530
8	1.8	84	1700

This table presents experimental nonlinear data for three key ventilation system parameters: heat transfer coefficient of ductwork, heat recovery efficiency, and average air flow rate. The values illustrate how variations in duct insulation and heat recovery performance correlate with changes in airflow, showing a nonlinear trend. These data points can be used to analyze energy efficiency, as improvements in heat recovery efficiency and optimization of duct characteristics affect the required airflow to maintain comfort, thus reducing or increasing energy consumption depending on system tuning.

Below is the 3D graph illustrating the nonlinear relationship between ventilation system parameters and building energy efficiency, showing how the heat transfer coefficient, heat recovery efficiency, and average air flow rate interact to influence energy consumption (Fig. 1).

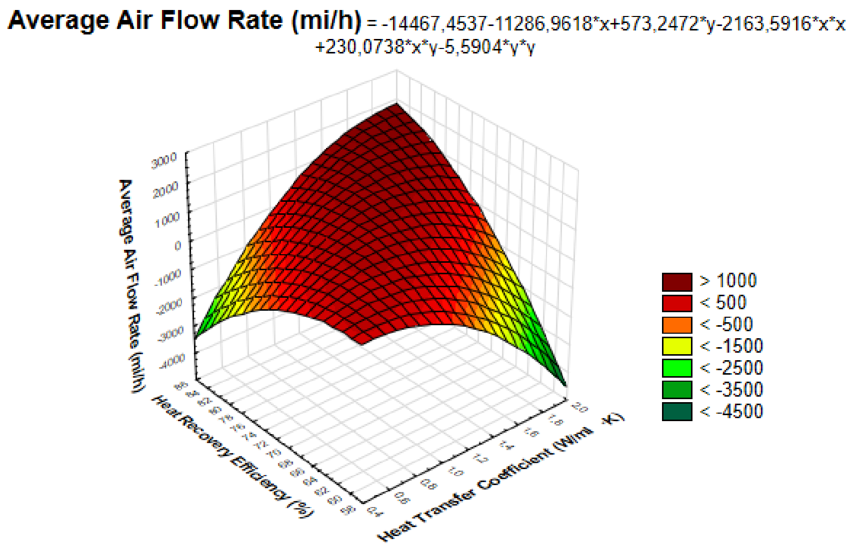

Fig. 1. Nonlinear interaction of ventilation system parameters affecting energy efficiency.

The 3D graph also includes a fitted regression surface that models the nonlinear relationship among the three parameters. This regression equation represents how changes in the heat transfer coefficient and heat recovery efficiency influence the required average air flow rate, providing a predictive tool for estimating energy consumption under varying ventilation system configurations. The surface highlights the complex, nonlinear interactions between duct thermal performance, heat recovery, and airflow, allowing engineers to optimize system design and operational efficiency.

5. Conclusion

The conducted study demonstrates the critical role of energy certification and quality control in modern ventilation systems and building energy efficiency. Analysis of the first table, which presents key ventilation parameters and their general influence on energy consumption, indicates that optimizing the heat transfer coefficient of ductwork, heat recovery efficiency, and airflow characteristics is essential for minimizing energy losses while maintaining indoor comfort. The data highlights that even small improvements in duct insulation or recovery efficiency can lead to significant reductions in energy demand.

The second table, containing experimental nonlinear data, provides a more precise and quantitative understanding of these interactions. The observed nonlinear relationships among the heat transfer coefficient, heat recovery efficiency, and average air flow rate confirm that energy efficiency cannot be addressed through isolated adjustments of individual parameters. Instead, a holistic, integrated approach is necessary to predict and control energy consumption accurately. The regression surface derived from these data serves as a predictive tool for estimating system performance under varying operational conditions.

Overall, the results of this study emphasize that energy-efficient ventilation design requires simultaneous consideration of multiple interdependent parameters. Implementing integrated energy certification practices and continuous quality control allows for optimized airflow, reduced operational costs, and improved environmental performance. These findings provide actionable insights for engineers and designers, supporting sustainable building practices and ensuring compliance with contemporary energy standards.

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Інтегрований підхід до енергетичного сертифікування та контролю якості формування мікроклімату в сучасному будівництві

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Анотація

У статті представлено інтегрований підхід до енергетичного сертифікування та контролю якості вентиляційних систем у сучасному будівництві, що підкреслює роль енергоефективності у забезпеченні експлуатаційних характеристик будівель. Досліджено сучасні методи оцінки ефективності вентиляції, відповідності енергетичним стандартам та вплив конструктивних рішень на внутрішнє середовище приміщень. Комплексний аналіз нормативно-правових вимог та практичних методів контролю демонструє взаємозв'язок між процесами сертифікації та управління якістю будівництва. На прикладі сучасних проектів показано, що систематичний моніторинг і оптимізація вентиляційних систем дозволяють значно зменшити енергоспоживання, водночас забезпечуючи комфорт та безпеку перебування людей у будівлях. Отримані результати створюють наукову основу для вдосконалення процедур енергетичного сертифікування та контролю якості, сприяють впровадженню стійких будівельних стратегій та розвитку високоефективних енергоощадних споруд.

Ключові слова: енергетичне сертифікування; контроль якості; вентиляційні системи; енергоефективність; сучасне будівництво; стійкі будівлі; оцінка ефективності.