



INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Review Of Energy Saving Technologies In Hvac Systems: Modern Hvac Systems Contributing To Sustainability Efforts

¹Prof. Shubham K. Pariskar

¹ Asst. Professor,

¹Mechanical Engineering Department,
¹Dr.R.N. Lahoti Polytechnic Sultanpur,
Buldhana, Maharashtra

²Prof. Ganesh S. Kharat

²Asst. Professor

²Mechanical Engineering Department
²Dr.R.N. Lahoti Polytechnic Sultanpur,
Buldhana, Maharashtra

Abstract: Heating, Ventilation, and Air Conditioning (HVAC) systems are critical for maintaining indoor comfort in residential, commercial, and industrial spaces. However, these systems are also a major contributor to energy consumption and, subsequently, environmental impact. Over the past few decades, significant advancements have been made in energy-saving technologies for HVAC systems. This review explores the primary energy-saving technologies and innovations that have been researched in HVAC systems. This article first examines the operational processes and energy consumption factors of HVAC systems, followed by a detailed identification and listing of existing energy-saving methods. These methods include the application of energy-saving technologies, advanced energy-efficient techniques, and intelligent energy-saving systems. HVAC systems can be categorized into three main types of energy-saving technologies: passive energy-saving technologies, active energy-saving technologies, and intelligent energy-saving technologies. Each of these approaches plays a distinct role in optimizing energy efficiency and reducing overall energy consumption in HVAC operations.

Keywords: HVAC; energy saving technology; energy efficiency; building energy consumption; smart technology IoT; emission reduction.

I. INTRODUCTION

In India, out of the total electricity consumption of 1130 TWh in 2017-18, approximately 33% was attributed to buildings (Energy Statistics, 2019). According to projections by NITI Aayog under various scenarios, residential energy consumption is expected to increase by 6-13 times from 2012 to 2047, while industrial energy consumption is forecasted to grow by 6-13 times over the same period. Additionally, overall energy consumption is anticipated to rise by 7-11 times during the same timeframe (IESS, 2047) [1]. In 2021, the International Energy Agency published “Achieving Net Zero Emissions by 2050: A Global Energy Sector Roadmap,” which aims to provide guidance for the world’s renewable energy to reach net-zero emissions by 2050 [2]. However, since the report was published, the global energy crisis has deepened. As a result, energy conservation and the shift to green, low-carbon alternatives are pressing challenges that need immediate attention. The residential building industry accounts for the majority of the world’s energy consumption, with research showing that residential building operations accounted for 30% of global energy use and 27% of all electricity generation in 2021, and after falling due to COVID-19 restrictions, both electricity consumption and emissions rose above 2019 levels in 2020 [3]. As a major energy consumer, the building industry must prioritize energy efficiency and emission reduction to achieve the target of ensuring all new buildings and 20% of existing buildings reach zero carbon emissions by 2030, and net zero emissions by 2050. Heating, ventilation, and air conditioning (HVAC) systems are some of the largest energy consumers in buildings. The energy demand for these systems has significantly increased due to their growing use in residential, commercial, and industrial settings [4]. However many issues persist in the HVAC design of construction projects. The integration of energy-saving and emission-reduction concepts into the design process is often inadequate, and the HVAC systems' energy-saving technologies need to become more intelligent and systematic to significantly reduce overall energy consumption. HVAC (Heating, Ventilation, and Air Conditioning) system energy-saving technologies play a crucial role in reducing energy consumption within the building industry. As HVAC systems have become more prevalent in engineering, numerous energy-efficient solutions have been developed. Among the most widely adopted are high-efficiency server room conversion systems, heat recovery systems, natural cooling systems, heat pump systems, and ice storage cooling systems. These technologies contribute to improving energy efficiency while maintaining comfort and performance [5]. However, due to the suboptimal energy efficiency of these systems, many researchers have begun exploring HVAC energy-saving devices, renewable energy applications, and various technologies such as heat recovery and natural ventilation. Additionally, a variety of professional and efficient HVAC technologies and solutions have been developed to improve energy performance [6-11]. Additionally; advancements in computer technology have provided new momentum for the research of HVAC energy-saving solutions. The refined design of HVAC systems, along with the scientific application of frequency conversion equipment, intelligent control and monitoring systems, building automation control systems, and AI-driven energy-saving control technologies, are all progressing rapidly [12-13]. In order to increase energy efficiency and reduce environmental impacts in HVAC systems,

different technologies need to be implemented. In recent years, different strategies and optimizations have been used to increase the power of these systems [14].

II. ENERGY-SAVING TECHNOLOGIES FOR HVAC SYSTEMS

In today's world, energy efficiency has become a critical priority, especially in the context of HVAC (Heating, Ventilation, and Air Conditioning) systems, which are known for their significant energy consumption. With rising energy costs and increasing concerns over environmental impact, the need for energy-saving technologies in HVAC systems. The energy-saving technologies for HVAC systems can be categorized into three main types: Passive energy-saving technologies, Active energy-saving technologies and Intelligent energy-saving technologies.

- 1. Passive Energy-Saving Technologies:** These methods focus on reducing energy consumption in buildings without relying on mechanical or electrical equipment. They typically involve design strategies and materials that naturally enhance energy efficiency.
- 2. Active Energy-Saving Technologies:** These technologies utilize mechanical systems to create an energy-efficient and comfortable indoor environment. They achieve this by optimizing equipment design, system configuration, and selecting efficient components.
- 3. Intelligent Energy-Saving Technologies:** These approaches integrate advanced technologies such as computer networks, big data analytics, the Internet of Things (IoT), and artificial intelligence (AI). The goal is to enhance energy efficiency by leveraging smart systems and real-time data insights.

1. Passive Energy-Saving Technologies

a) Building Orientation and Design:

Building orientation and design play a crucial role in optimizing HVAC energy efficiency by leveraging natural environmental conditions to reduce heating, cooling, and ventilation demands. Many researchers have studied the improvement of the building envelope and the effect of the building envelope on the energy consumption of the building [15]. Also they studied allowing maximum sunlight into the building during colder months to reduce heating loads. In addition, green roofs and walls provide natural insulation and cooling effects, reducing the energy required for maintaining comfortable indoor temperatures. Green plant use has become an important concept in urban planning today, and the only way to meet the requirements of plant growth in urban areas is indoor planting. Green building construction has many benefits, such as increasing the insulation value of buildings, reducing urban heat gain, buffering rainwater, improving air quality, and reducing carbon dioxide emissions [16-18]. By thoughtfully designing a building's orientation and layout, it's possible to significantly reduce the load on HVAC systems. This not only saves energy but also improves indoor comfort and reduces operating costs.

b) Thermal Insulation in HVAC Energy Efficiency:

Thermal insulation is a critical component of energy-efficient HVAC systems, as it minimizes heat transfer between the interior and exterior of a building. By reducing the need for heating and cooling, effective insulation decreases energy consumption, lowers utility costs, and enhances indoor comfort. Use high-quality insulation materials with a high R-value (thermal resistance) in walls, roofs, and floors to create a thermal barrier [19]. Ensure no gaps or leaks compromise insulation performance and Use reflective or radiant barrier insulation in attics and thick insulation layers under roofing materials to mitigate heat gain. Thermal insulation is an essential strategy for improving energy efficiency in HVAC systems. By investing in proper insulation and sealing, buildings can achieve reduced energy consumption, enhanced comfort, and lower environmental impact.

c) Natural Ventilation:

Natural ventilation is a passive design strategy that reduces the need for mechanical ventilation and air conditioning systems by using natural airflow to regulate indoor temperatures and maintain air quality. This approach enhances energy efficiency in HVAC systems, reduces operational costs, and promotes sustainability. Encourages airflow between two openings (e.g. windows or doors) located on opposite sides of a building, allowing fresh air to replace stale air. Utilizes the natural rise of warm air to exhaust it through higher openings (e.g. vents or skylights), while cooler air enters from lower openings [20]. By using indoor and outdoor air, the room temperature can be reduced and the humidity can be released, which can make the air in the room fresh and clean, and some air flow can be provided in the room, which can enhance the effective convection of the room. Evaporative heat dissipation has been widely used, which improves the thermal comfort of the human body and improves people's work and life [21-23]. As well mixed-mode ventilation has been proven to be a highly effective energy-saving method for buildings designed with natural ventilation (NV) principles, enhancing both energy efficiency and indoor air quality [24].

2. Active Energy-Saving Technologies

a) Inverter HVAC Technology:

Inverter HVAC technology is often associated with "Variable Speed" or "Variable Frequency Drive" (VSD/VFD) systems. Inverter HVAC (Heating, Ventilation, and Air Conditioning) technology is an advanced and energy-efficient solution that has gained significant attention in recent years. Unlike traditional HVAC systems, which operate on an on/off cycle, inverter technology uses a variable-speed compressor that adjusts its speed based on the demand for heating or cooling. This results in more precise temperature control and reduced energy consumption. This innovative approach, when combined with heat pump technology, further enhances

the potential for thermal decarbonization and provides a promising solution to reduce carbon footprints globally.

b) Heat Pump Technology For Thermal Decarbonization:

In recent years, more and more countries have recognized heat pump technology as a key tool for achieving thermal decarbonization. Consequently, these countries have implemented various policies to support its adoption [25]. Heat pumps can effectively convert electricity into thermal energy (heat) when operating at the appropriate low pressures, which plays a crucial role in reducing carbon emissions in the future [7]. However, despite this potential, electric heating equipment currently only meets about 10% of domestic heating needs. To further advance the use of heat pumps, continued policy and technological support are necessary to enhance energy efficiency, lower initial and installation costs, and improve overall performance and output [25].

c) Variable Refrigerant Flow (VRF) Systems Are Advanced HVAC Solutions:

It provides efficient climate control by adjusting the flow of refrigerant based on the specific needs of individual zones or rooms. These systems are designed to optimize energy consumption by using a variable-speed compressor, which adjusts the amount of refrigerant circulating through the system. VRF systems are composed of key components, including an outdoor unit that regulates refrigerant flow, indoor units that deliver heating or cooling to different spaces, and refrigerant piping that connects the units. The control system allows users to manage temperatures in different zones, making VRF systems highly customizable. VRF systems are used in a wide range of applications, from commercial buildings like offices, retail stores, and hotels to residential spaces such as multi-story homes or apartments. This system is being used in almost 50% of the medium-size and around 30% of the large-size commercial buildings.

d) Thermal Storage System:

Thermal Storage System is a technology that stores thermal energy (heat or cold) for later use. These systems are designed to help manage energy demand, enhance efficiency, and make use of energy at times when it is abundant or cheaper. They are commonly used in applications where energy is needed at a later time, such as in heating or cooling systems, and can help to reduce energy costs by shifting energy consumption to off-peak periods. In thermal energy storage (TSS) systems, energy for cooling is stored at low temperatures, typically below 20 °C, while energy for heating is stored at higher temperatures, generally above 20 °C. TSS is a widely adopted technology in HVAC applications, offering numerous benefits, including significant energy and cost savings, enhanced efficiency, increased capacity, and reduced equipment size for heating and cooling compared to conventional HVAC systems. Thermal storage can be integrated into heating, ventilation, and air conditioning (HVAC) systems to provide cooling or heating during peak demand times, reducing the load on power grids. Research indicates that while a heat storage system may not always lead to significant energy

savings, it can result in a notable reduction in energy costs. For instance, an ice-based heat storage system has been shown to cut monthly cooling electricity expenses by up to 55%, despite only reducing the overall system's energy consumption by 5% [26].

e) Heat Recovery Technology:

Energy Recovery Ventilators (ERVs) and Heat Recovery Ventilators (HRVs) are ventilation systems designed to improve indoor air quality and energy efficiency by exchanging stale indoor air with fresh outdoor air while recovering energy from the exhaust air. HRVs focus on transferring heat (sensible energy) between the incoming and outgoing air streams, making them ideal for cold or dry climates where maintaining indoor warmth without adding moisture is critical. In contrast, ERVs transfer both heat and moisture (sensible and latent energy), making them better suited for humid climates where managing indoor humidity is a priority. Both systems reduce the energy required for heating or cooling by preconditioning the incoming air, improving comfort and lowering energy costs. While HRVs help prevent excessive dryness indoors, ERVs provide balanced humidity control, ensuring a healthier and more comfortable environment. Proper selection depends on climate, indoor air quality needs, and energy efficiency goals. recent heat recovery systems can recover about 80 to 95 percent of the heat[27].

3. Intelligent Energy-Saving Technologies

a) Smart HVAC Monitoring and Maintenance:

- Sensors are installed throughout the HVAC system to continuously collect real-time data about environmental conditions, energy usage, and system performance.
- IoT-enabled devices allow HVAC components to communicate with each other and with a central cloud-based management system, enabling remote monitoring and control. The Internet of Things (IoT) has transformed Heating, Ventilation, and Air Conditioning (HVAC) systems by enabling enhanced connectivity, real-time data analysis, and intelligent control. IoT-enabled HVAC systems provide greater energy efficiency, improved comfort, and predictive maintenance capabilities, making them an integral part of modern building management and smart home ecosystems.

b) Artificial Intelligence (AI) and Machine Learning uses in HVAC SYSTEM:

- ✓ **AI Algorithms:** AI-driven HVAC systems learn from historical data, user behaviour, and environmental conditions to optimize performance. They automatically adjust settings such as temperature, humidity, and airflow to maximize energy efficiency. Machine learning models analyse data from HVAC components to predict potential failures before they occur. This enables proactive repairs, reducing downtime and energy waste due to inefficient operation. Artificial Intelligence (AI), especially through machine learning (ML) algorithms, is transforming HVAC systems by allowing for real-time and self-adjusting optimization. These algorithms process extensive historical and live data gathered from IoT sensors, enabling the prediction and fine-tuning of system operations to improve efficiency [28].

c) Cloud Computing for HVAC System:

Cloud computing serves as the backbone for modern HVAC systems, offering reliable and scalable data storage solutions. By leveraging cloud storage, HVAC systems can gather and retain vast amounts of data, such as environmental readings, energy usage patterns, and health diagnostics from IoT sensors. This approach not only lowers operational costs by removing the need for costly on-site hardware but also enhances data security and redundancy. Additionally, cloud storage facilitates seamless, real-time access to data from any location, which is crucial for monitoring and managing HVAC systems efficiently. This feature is particularly valuable in large-scale industrial and commercial HVAC installations, where effective data management is essential for optimizing performance and operations [29].

d) Advancement in Smart Building Concepts:

Smart building technology has significantly transformed the integration of HVAC systems with modern processes. Today's buildings depend on interconnected systems that leverage artificial intelligence (AI), the Internet of Things (IoT), and cloud computing to control everything from lighting and energy efficiency to HVAC functions. These advanced technologies enable smarter, more efficient operation by allowing systems to communicate, adapt, and optimize in real time, leading to improved comfort, energy savings, and overall building performance. HVAC systems in smart buildings are progressively integrating renewable energy sources and adaptive controls to support net-zero energy objectives. As these innovations advance, HVAC systems are evolving beyond basic temperature control to become essential elements of intelligent and sustainable building ecosystems [30].

✓ Challenges and Opportunities in modern HVAC Technologies:

While these advancements hold immense promise, several challenges must be addressed to fully leverage next-generation HVAC technologies. The increasing dependence on the Internet of Things (IoT) and cloud computing raises concerns about data security and privacy, necessitating robust cyber security measures. Additionally, the high initial costs of implementing these advanced systems can pose barriers, particularly for small and medium-sized enterprises. Seamlessly integrating diverse systems and technologies also requires careful design and coordination.

However, these challenges present valuable opportunities. Ongoing advancements in AI and IoT are driving down costs and enhancing accessibility. Support from governments and industry stakeholders for renewable energy continues to accelerate its adoption. The growing emphasis on sustainability and smart technology creates a favorable environment for the HVAC sector to innovate, solidify its role, and contribute to the advancement of green technologies.

III. DISCUSSION

This paper aims to discuss the energy savings technology in HVAC system, Heating, Ventilation, and Air Conditioning (HVAC) systems are critical for ensuring thermal comfort, air quality, and energy efficiency in built environments. Their role spans residential, commercial, and industrial sectors, making them essential for maintaining productivity, health, and well-being. The evolution of HVAC systems reflects technological advancements and the growing need for sustainable energy solutions in the face of global environmental challenges. The advanced HVAC system has many advantages over Traditional HVAC systems primarily operated as standalone units designed for temperature regulation. These systems often relied on manual control or fixed schedules, which limited their ability to adapt to dynamic environmental conditions. Consequently, this led to inefficient energy usage and higher operational costs. Over time, the industry has shifted towards smarter and more integrated solutions. The integration of Artificial Intelligence (AI), the Internet of Things (IoT), and cloud computing has revolutionized HVAC operations. AI enables predictive analytics and real-time adjustments to optimize performance, while IoT sensors provide continuous monitoring of temperature, humidity, and air quality. Cloud computing further enhances these systems by allowing remote access, data storage, and analysis, which supports predictive maintenance and reduces system downtime.

Sustainability has become a central theme in the advancement of HVAC technology. The adoption of renewable energy sources, such as solar-powered systems, and the use of eco-friendly refrigerants address environmental concerns while aligning with global net-zero energy targets. Modern HVAC systems are often integrated into smart building ecosystems, working alongside lighting, energy management, and security

systems to create interconnected and efficient environments. These advancements contribute significantly to reducing energy consumption and carbon footprints.

However, the implementation of next-generation HVAC systems is not without challenges. The growing reliance on IoT and cloud computing raises concerns regarding data security and privacy, necessitating robust cyber security measures. Additionally, the high initial investment costs for advanced HVAC solutions can be prohibitive for small and medium-sized enterprises, hindering widespread adoption. The complexity of integrating diverse systems and technologies also requires specialized expertise, which may pose workforce challenges. Furthermore, reliance on renewable energy sources introduces variability in energy supply, highlighting the need for effective energy storage solutions.

Despite these challenges, significant opportunities exist for the HVAC industry. Continuous innovations in AI and IoT are reducing costs and improving system accessibility, while government incentives and policies supporting renewable energy adoption are driving market growth.

HVAC systems are evolving beyond their traditional roles to become integral components of sustainable and intelligent building designs. By addressing current challenges through technological advancements and collaborative efforts, the HVAC industry can play a pivotal role in achieving energy efficiency and environmental sustainability. This transformation is essential for meeting the demands of modern living while mitigating the impact of climate change.

IV. CONCLUSION

This paper focuses on energy-saving technologies in HVAC systems as the primary area of research. It begins by examining various aspects of energy consumption in HVAC systems to identify potential causes of increased energy use. The study explores advancements in HVAC energy-saving methods from three key perspectives: passive energy-saving strategies, active energy-saving techniques, and intelligent technologies. the following are the main conclusions of the paper:

- 1) Many HVAC systems in older buildings tend to have high energy consumption, particularly in structures constructed decades ago. Therefore, reducing energy use in the construction industry requires a strong focus on upgrading HVAC systems in existing buildings. Studying the application of advanced energy-saving technologies during the renovation of these buildings is both essential and highly valuable.
- 2) Passive energy-saving technologies offer significant advantages, including high energy efficiency, low technical requirements, minimal maintenance, and cost-effectiveness. However, their energy-saving potential is often limited. On the other hand, active and intelligent energy-saving technologies typically require more advanced equipment and technology, involve higher initial investments, and consume some energy during operation. Despite these challenges, they provide enhanced comfort levels and can

significantly improve energy savings, making them valuable for optimizing building performance. When applied in combination with passive energy-saving methods, active and intelligent technologies can serve as a powerful enhancement, offering a more comprehensive solution. Together, passive, and active approaches in energy-efficient building design are complementary and work synergistically to maximize overall energy savings.

- 3) The integration of energy-saving technologies, including passive, active, and intelligent systems, allows HVAC systems to meet growing environmental and economic demands while enhancing performance. By adopting advanced solutions such as AI, IoT, and renewable energy integration, HVAC systems can significantly reduce energy consumption, lower operational costs, and minimize their environmental impact.
- 4) The future of HVAC systems lies in continuous innovation, collaboration across industries, and the widespread adoption of energy-saving technologies. By addressing the challenges associated with system upgrades and ensuring the integration of smart technologies, the HVAC industry can significantly contribute to global efforts in reducing energy consumption, mitigating climate change, and promoting sustainable building practices.

REFERENCE

- [1] India Energy Security Scenario (IESS) 2047, NITI Aayog, <http://iess2047.gov.in>
- [2] Net Zero by 2050 – Analysis[EB/OL]//IEA. [2023- 05-06]. <https://www.iea.org/reports/net-zero-by-2050>.
- [3] Statistical Review of World Energy | Energy economics | Home[EB/OL]//bp global. [2023-05-04]. <https://www.bp.com/en/global/corporate/energyeconomics/statistical-review-of-world-energy.html>.
- [4] CO2 emissions from energy combustion and industrial processes, 1900-2021 – Charts – Data & Statistics[EB/OL]//IEA. [2023-05-06].<https://www.iea.org/data-and-statistics/charts/co2-emissions-from-energy-combustion-and-industrialprocesses-1900-2021>.
- [5] VAKILOROAYA V, SAMALI B, FAKHAR A, et al. A review of different strategies for HVAC energy saving[J/OL]. Energy Conversion and Management, 2014, 77: 738-754.
- [6] CUCE P M, RIFFAT S. A comprehensive review of heat recovery systems for building applications[J/OL]. Renewable and Sustainable Energy Reviews, 2015, 47: 665-682. <https://doi.org/10.1016/j.rser.2015.03.087>.
- [7] CHUA K J, CHOU S K, YANG W M. Advances in heat pump systems: A review[J/OL]. Applied Energy, 2010, 87(12): 3611-3624.
- [8] TAO R, JINGMIN G, WENWEN J. Automatic Control Technology in the HVAC System[C/OL]//2009 International Conference on Advanced Computer Control. 2009: 315-318. <https://doi.org/10.1109/ICACC.2009.9>.

- [9] HASNAIN S M, ALABBADI N M. Need for thermal-storage air-conditioning in Saudi Arabia[J/OL]. Applied Energy, 2000, 65(1): 153-164.
- [10] TONG Z, WHITLOW T H, LANDERS A, et al.. A case study of air quality above an urban roof top vegetable farm[J/OL]. Environmental Pollution, 2016, 208: 256-260.
- [11] Experimental Study on Indoor Air Temperature Distribution of Gravity Air-Conditioning for Cooling[J/OL]. Energy Procedia, 2012, 17: 961-967.
- [12] YANG Z, LIU B, ZHAO H. Energy Saving in Building Construction in China: A Review[J/OL]. International Journal of Green Energy, 2004, 1(2): 209-225.
- [13] MAILE T, FISCHER M, BAZJANAC V. Building Energy Performance Simulation Tools - a Life-Cycle and Interoperable Perspective[J]. Facil. Eng. (CIFE) Working Pap., 2007, 107.
- [14] A New Pattern Recognition Adaptive Controller with Application to HVAC Systems – Science Direct [EB/OL].
- [15] CHEUNG C K, FULLER R J, LUTHER M B. Energy-efficient envelope design for high-rise apartments[J/OL]. Energy and Buildings, 2005, 37(1): 37-48.
- [16] BARRIO E P D. Analysis of the green roofs cooling potential in buildings[J/OL]. Energy and Buildings, 1998, 27(2): 179-193.
- [17] KUMAR R, KAUSHIK S C. Performance evaluation of green roof and shading for thermal protection of buildings[J/OL]. Building and Environment, 2005, 40(11): 1505-1511.
- [18] JAFFAL I, OULDBOUKHITINE S E, BELARBI R. A comprehensive study of the impact of green roofs on building energy performance[J/OL]. Renewable Energy, 2012, 43: 157-164.
- [19] Dharmasastha, K.; Samuel, D.L.; Nagendra, S.S.; Maiya, M. Experimental investigation of thermally activated glass fiber reinforced gypsum roof. Energy Build. 2020, 228, 110424.
- [20] Chung, W.J.; Park, S.H.; Yeo, M.S.; Kim, K.W. Control of thermally activated building system considering zone load characteristics. Sustainability 2017, 9, 586.
- [21] THE FLUID MECHANICS OF NATURAL VENTILATION | Annual Review of Fluid Mechanics [EB/OL]. [2023-05-07]. <https://www.annualreviews.org/doi/10.1146/annurev.fluid.31.1.201>.
- [22] TONG Z, CHEN Y, MALKAWI A, et al.. Quantifying the impact of traffic-related air pollution on the indoor air quality of a naturally ventilated building[J/OL]. Environment International, 2016, 89-90: 138-146.
- [23] VAN HOOFF T, BLOCKEN B, TOMINAGA Y. On the accuracy of CFD simulations of cross-ventilation flows for a generic isolated building: Comparison of RANS, LES and experiments[J/OL]. Building and Environment, 2017, 114: 148-165.
- [24] BRAGER G, DE DEAR R. A Standard for Natural Ventilation[J/OL]. 2000[2023-05-09].
- [25] Buildings – Analysis[EB/OL]//IEA. [2023-05-06]. <https://www.iea.org/reports/buildings>.

- [26] CHAICHANA C, CHARTERS W W S, AYE L. An ice thermal storage computer model[J/OL]. Applied Thermal Engineering, 2001, 21(17): 1769-1778.
- [27] MARDIANA-IDAYU A, RIFFAT S B. Review on heat recovery technologies for building applications[J/OL]. Renewable and Sustainable Energy Reviews, 2012, 16(2): 1241-1255.
- [28] Verbert, K., Babuška, R., & De Schutter, B. (2017). Combining knowledge and historical data for system-level fault diagnosis of HVAC systems. Engineering Applications of Artificial Intelligence, 59, 260–273. <https://doi.org/10.1016/j.engappai.2016.12.021>.
- [29] Kim, Y., Hong, T., & Chae, C. U. (2018). "A Comprehensive Review on Applications of Big Data in Building Energy Management Systems." Energy and Buildings, 158, 196- 210.
- [30] Carli, Raffaele, Graziana Cavone, Sarah Ben Othman and Mariagrazia Dotoli, "IoT based architecture for model predictive control of hvac systems in smart buildings," Sensors, Vol. 20, No. 3, pp. 781, 2020.

