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New Energy Applications in Building Energy Efficiency: Progress and Prospects

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Abstract:

With increasing global attention on the utilization of new energy technologies and energy conservation, the application of new energy in building energy efficiency has become a key direction for the future development of the construction industry. This paper consolidates several common new energy technology application scenarios, including solar air conditioning, solar water heating systems, ground-source heat pumps, and radiant floor heating. Focusing on solar and geothermal energy which is the two most widely used energy sources in building energy efficiency, the study analyzes their working principles, compares their advantages and disadvantages, and evaluates their effectiveness in energy conservation. It also examines challenges such as high costs, low adoption rates, and immature technologies in the integration of new energy with buildings. Development strategies and future research directions are proposed to advance the application of new energy in building energy efficiency, offering new methods and ideas for future energy-saving efforts in construction.

Keywords: New energy; Solar energy; Geothermal energy; Building energy efficiency.

1. Introduction

With the continuous growth of the global population and the acceleration of industrialization, energy demand continues to rise, making energy consumption a critical global concern. As the number and scale of buildings increase, building energy consumption continues to account for a significant portion of total societal energy use. Currently, buildings consume one-third of global energy and contribute one-quarter of CO_2 emissions, making them a major factor in energy consumption [1]. Additionally, rising demands for indoor comfort have led to increased use of heating, cooling, ventilation, and lighting systems, positioning building energy efficiency as a key focus area for future green and sustainable development.

Building energy consumption encompasses all stages of construction, including material production, construction, and operational phases. According to the 2024 China Urban and Rural Construction Carbon Emissions Research Report by the China Building Energy Efficiency Association, in 2022, the total energy consumption of buildings in China was 2.42 billion tons of standard coal equivalent (tce), accounting for 44.8% of the national total. Specifically, the material production and construction phases consumed 1.23 billion tce (22.8%), while the operational phase consumed 1.19 billion tce (22.0%) [2]. These figures highlight the significant proportion of building energy consumption, underscoring the need to accelerate the adoption of new energy technologies for energy efficiency.

New energy, as an alternative to traditional fossil fuels, reduces reliance on single energy sources and diversifies the energy mix. It also improves efficiency and lowers consumption, with solar and geothermal energy offering innovative solutions for building energy efficiency. Compared to fossil fuels, new energy is widely distributed, abundant, and environmentally friendly, addressing resource scarcity and ecological challenges. Currently, the utilization efficiency of new energy is approximately 70%–80%, with studies suggesting potential improvements beyond 80% [3]. Additionally, new energy resources are estimated to be 10% more abundant than non-renewable sources, indicating substantial future potential.

In 1975, Owens-Illinois in the U.S. pioneered the development of all-glass vacuum solar collectors for residential hot water systems, marking the beginning of solar energy applications in building energy efficiency [4]. By the late 1990s, projects like the UK's Environmental Building and Integer Eco-Home demonstrated the integration of solar and geothermal technologies with buildings, showcasing the vast potential of new energy in construction [5].

This paper examines current research on new energy applications in buildings, focusing on solar air conditioning, solar water heating systems, ground-source heat pumps, and low-temperature geothermal radiant floor heating. By analyzing their working principles, advantages, disadvantages, and development trends, the study explores pathways for energy efficiency in buildings, offering insights for reducing energy consumption and achieving sustainable development.

2. New Energy Applications in Building Energy Efficiency

Currently, new energy applications in buildings primarily include solar air conditioning, solar water heating systems, ground-source heat pumps, and geothermal radiant floor heating.

2.1 Solar Air Conditioning

Air conditioning accounts for 20% of global building electricity consumption and 10% of total electricity use [6]. The growing demand for air conditioning in residential and commercial buildings has become a major driver of energy consumption in recent decades.

Solar energy is a clean and efficient resource, inexhaustible and capable of supporting continuous energy supply in buildings. Solar air conditioning systems reduce reliance on fossil fuels but face challenges such as high initial installation costs and dependence on ample sunlight and large installation areas. Solar air conditioning includes two main technologies: photovoltaic (PV) solar air conditioning and solar thermal-driven air conditioning.

As shown in Fig. 1, PV solar air conditioning systems consist of solar PV panels, batteries, controllers, inverters, and air conditioning units. The system converts sunlight into electricity via the photovoltaic effect, stores excess energy in batteries for nighttime use, and uses inverters to convert DC to AC power to operate the air conditioning system [7].

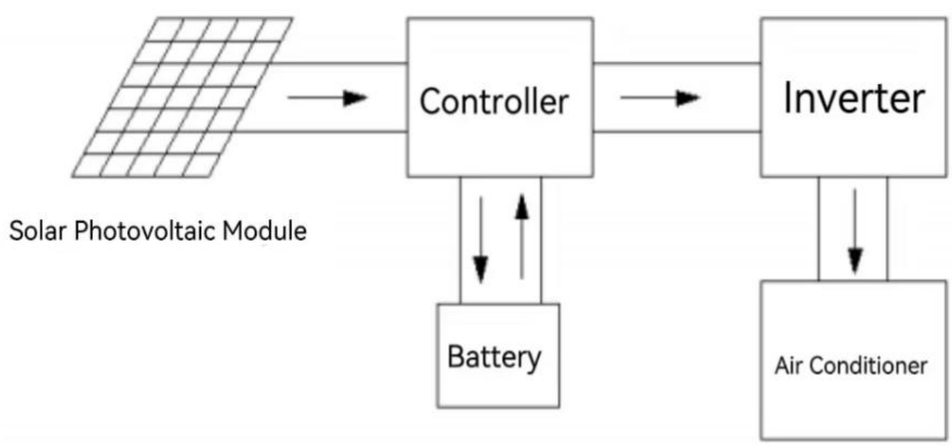

Fig. 1 Workflow of PV Solar Air Conditioning [7]

Solar thermal-driven air conditioning, the more common model, uses rooftop solar collectors (Fig. 2) to generate heat, which drives refrigeration systems to produce chilled water or conditioned air for indoor spaces [8]. These sys-

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tems include adsorption, absorption, desiccant, and ejector refrigeration types.

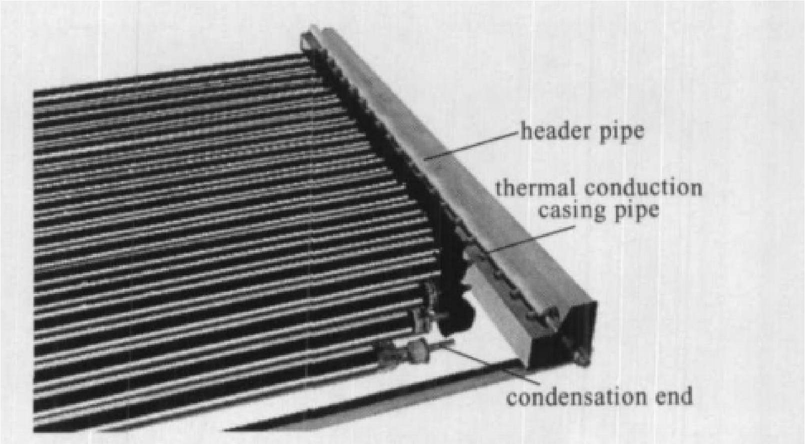

Fig. 2 Solar Collector [8]

2.2 Solar Water Heating Systems

Solar water heating systems use solar energy to heat water and consist mainly of solar collectors and storage tanks. Based on operation modes, they are classified into direct-flow, natural circulation, and forced circulation systems [9].

Direct-flow systems use controllers to circulate heat-transfer fluids under water pressure or external power. They are simple and cost-effective but may suffer from water contamination and scaling.

Natural circulation systems rely on temperature-induced density differences for fluid movement. They are stable and simple but suitable only for small-scale applications like households.

Forced circulation systems use pumps to circulate fluids, offering higher efficiency and faster heat transfer but at higher operational costs. They are ideal for large-scale applications with strict hot water quality and aesthetic requirements.

2.3 Ground-Source Heat Pumps

Geothermal energy, derived from underground heat, is a novel technology in building energy efficiency. It requires conversion into electricity for heating and cooling and is unaffected by time or location, making it a practical solution [10].

Heat pumps transfer heat from low-temperature to high-temperature mediums for building heating, cooling, and hot water supply. Ground-source heat pumps extract geothermal energy, storing summer heat in the ground for winter use and vice versa. They connect to indoor systems like radiators or underfloor heating for heat distribution [11].

Ground-source heat pumps are categorized into surface water, groundwater, and soil-coupled systems, each with distinct advantages and disadvantages (Table 1).

Table 1. Comparison of Ground-Source Heat Pump Systems

Type	Advantages	Disadvantages
Surface Water Systems	Lower investment, energy consumption, and maintenance costs	Vulnerable to damage in shallow lakes; efficiency drops with water temperature fluctuations
Groundwater Systems	Economical, compact, and water-efficient (only heat exchange, no consumption)	Requires compliance with water quality and quantity standards
Soil-Coupled Systems	Stable soil temperatures and excellent heat storage	High drilling costs

2.4 Radiant Floor Heating

As shown in Figure 3, radiant floor heating uses low-temperature heat sources, such as geothermal return water, to warm floors for indoor heating. This method maximizes geothermal resource utilization, enhances energy efficiency, and reduces initial investment costs per unit area [12].

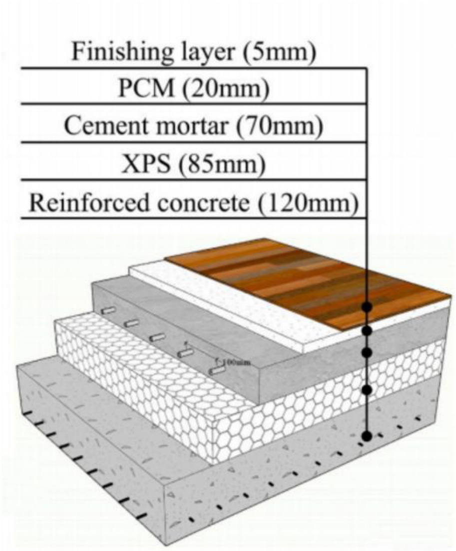

Fig. 3 Cross-Section of Radiant Floor Heating [13]

3. Future Prospects

New energy forms, including solar, wind, hydrogen, tidal, nuclear, and geothermal energy, offer diverse solutions for building integration. Research focuses primarily on solar, geothermal, wind, and hydrogen energy, forming the core of new energy-building integration technologies for sustainable development.

From a technological perspective, new energy applications in building energy efficiency are rapidly evolving. Mature technologies need wider adoption, while emerging technologies require further experimentation. Future innovations may include:

- Advanced building-integrated photovoltaics (BIPV) for higher efficiency and adaptability.
- Smart energy management platforms for intelligent building operations.
- Climate-responsive passive design optimizations to transform buildings from energy consumers to "prosumers."

4. Conclusion

This paper analyzes current new energy applications in building energy efficiency, demonstrating their potential to reduce energy consumption and carbon emissions. Solar and geothermal energy are the most widely used, offering new pathways for green, low-carbon, and sustainable building development. Challenges remain, such as high costs, low market penetration, and immature technologies like biomass energy. Future research should explore interdisciplinary integrations, such as combining solar with nanotechnology for advanced PV materials or using AI to optimize energy management systems for precise demand prediction and distribution.

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