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Potential uses of renewable energy in construction: Advantages and challenges

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Abstract. The construction industry accounts for a high percentage of the total global energy consumption, placing it among the main sectors contributing to climate change, pollution, and energy-related problems. This fact has placed tremendous pressure on the construction industry to find solutions to this crucial problem and shift to more sustainable, energy-efficient, and cost-effective construction practices. In this study, the importance of using renewable energy in the construction sector, particularly building construction, is highlighted and a review of some emerging practices in using renewable energy in construction is presented. The paper also presents the various sources of renewable energy and their applications in construction along with their advantages and drawbacks. The paper highlights the importance of establishing standards and regulations related to the use of renewable energy in building projects.

Introduction

With the exponential growth of population in the world coupled with the increased needs of humans, the global consumption of energy is growing rapidly at an average annual rate of 2.2% [1, 2] and the construction industry accounts for around 40% of the total global energy consumption and 30% of global carbon dioxide emissions, placing it among the main sectors responsible for air pollution and environmental instability [1]. As a result of the rapid growth of population, more buildings will be needed and, if bult using the old traditional construction methods, the result will be more carbon emissions and environmental instability, such as the greenhouse effect and the extreme weather caused by energy. This has stimulated the importance of using green, low-carbon, sustainable, and other forms of renewable energy in construction. Serving the same purpose, the International Energy Agency has set a goal of net zero emissions by 2050, placing the construction industry under intense pressure to achieve this target [3]. To this end, a number of countries are announcing initiatives to achieve net zero emissions by 2050. However, the world is still behind in terms of the implementation of a clear and well-defined policy to achieve this objective, particularly in the construction industry. Europe and the USA, for example, have redefined regulations and policies related to the development of near-zero-energy buildings for the development of renewable energy [4, 5]. China is also committed to reaching peak carbon by 2030 and carbon neutrality by 2060 [6]. With the construction sector being a main player in this context, the application of renewable energy in construction to produce energy-

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efficient buildings by using natural materials has become a major driver to reduce the contribution of the building sector to climate change and energy use and promote sustainability [7].

It is well established in the literature that natural materials are good sources of renewable energy since they are green, environmentally friendly, and serve as an alternative to traditional energy sources [7, 8]. The use of renewable energy in construction projects becomes eminent as it promotes sustainability and reduces environmental impacts. This is clearly important considering the increasing need to reduce carbon emissions by mitigating the impact of construction activities on the environment. In building construction, renewable energy is an integration of sustainable sources of energy, such as water, wind, solar, plants, biomass, and geothermal in the building life cycle stages, including design, construction, and operation and maintenance to reduce the use of traditional sources of energy and, therefore, mitigate climate change and promote the environmental sustainability of buildings [7, 9, 10]. With the increasing awareness of the use of renewable energy in building construction, its application in modern buildings has also gained momentum. Architects, for example, have designed buildings with proper orientation to facilitate the use of natural sunlight for heating and ventilating [11, 12]. Other engineers involved in the design of buildings are also using sustainable sources in their designs such as solar panels to generate electricity, natural fibers and materials to replace traditional construction materials, and biomass boilers and heating systems to provide sustainable heating and hot water solutions contributing to energy efficiency and reducing carbon emissions. However, the application of renewable energy in buildings depends on the type of the source of energy and the characteristics of energy. As reported by Khan and Al-Ghamdi [9] and Wu and Skye [10], renewable energy sources such as solar, geothermal, wind, and biomass energy have the potential to satisfy the sustainable energy needs of buildings.

Potential Uses of Sustainable Renewable Energy Sources in Construction

The use of renewable energy sources has become a viable solution to the problem of air pollution and environmental instability resulting from construction projects. In this section, the most important renewable energy sources that can be utilized in the construction of buildings to promote sustainability and reduce environmental impact are presented. As shown in Fig. 1, renewable energy sources include solar energy, biomass energy, geothermal energy, wind energy, and hydro energy, in addition to the hybrid renewable energy systems.

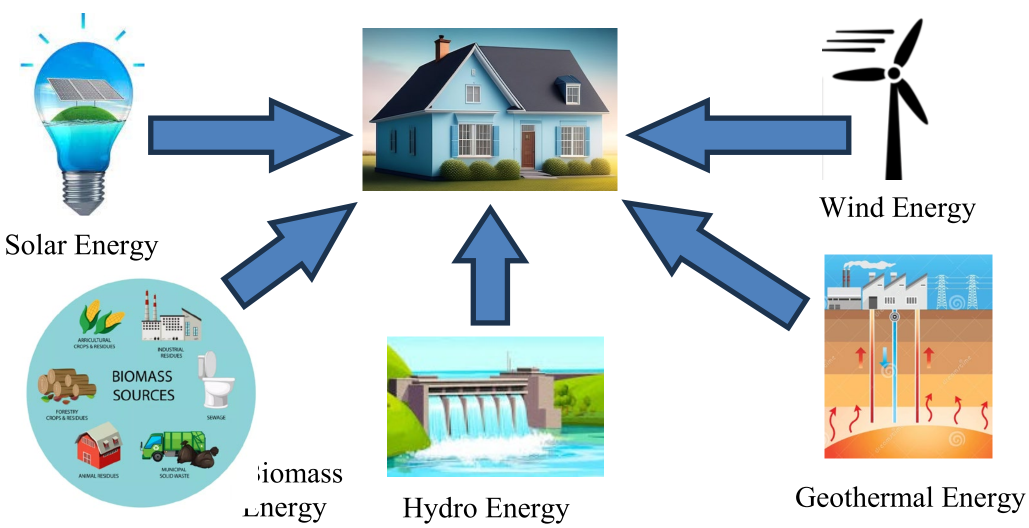

Fig. 1: Major Sources of Renewable Energy Used in Building Construction.

Solar Energy

It is well established that solar energy is the most commonly used source of renewable energy [7]. It is generated for building construction using a range of technologies such as solar power to generate electricity and solar thermal energy, including solar water heating. Solar energy technologies are either passive or active, depending on how they capture and distribute solar energy and convert it into solar power. Active techniques include the use of photovoltaic systems, concentrated solar power, and solar water heating to generate energy while passive techniques include the optimal building orientation towards the sun, selection of materials with favorable thermal mass or light dispersing properties, thermal biomass, and the design of spaces with natural air circulation [8]. Solar energy is known for its environmentally friendly attributes and unlimited supply, placing it among the leading and widely used sources of renewable energy in the world [13]. In the USA, for example, solar energy accounts for 31% of the total energy consumption [10].

Several researchers have addressed the use of solar energy to improve the environmental performance of buildings and facilitate climate circulation. Vassiliades et al. [14], for example, noticed that the use of solar energy in buildings helps reduce the negative impacts of building on the climate and the use of photovoltaic technology improves the energy utilization efficiency and reduces the consumption of energy. Another study by [15] showed that the use of solar systems in buildings can increase the renewable energy factor to 83% and reduce energy demand by 48%. It is, therefore, important to maximize the use of solar energy in buildings during the design phase as this will result in improved efficiency, reduce the operating costs, and enhance the functionality of buildings, in addition to its main benefit of being environmentally friendly as it does not produce greenhouse emissions. Despite all these advantages, the use of solar energy results in high maintenance costs and requires technological advancements.

Biomass Energy

Biomass is an organic material extracted from living organisms such as plants, animals, or microorganisms. Biomass is the oldest renewable energy source used by humans [16]. To lower emissions and reduce dependence on fossil fuels, biomass is usually utilized in the form of biomaterials in structural or non-structural elements of buildings. Biomass energy relies, in general, on natural resources such as wood, plant fibers, and organic waste materials, coming from human, plant, and animal wastes. Biomass includes other materials such as construction waste and animal excreta, which can also be used to generate electricity [9]. Several research efforts investigated the use of biomass energy in buildings. Rahman et al. [17] investigated the possibility of using biomass energy as the main source of power for a residential building. Allouhi et al. [18] and Wu and Skye [10] indicated that biomass can have different uses in buildings including utilizing it as gas, fuel, heat, and power generation. In addition, biomass is carbon–neutral efficient source of energy, and its efficiency can be further enhanced by compressing biomass wood into pellets under high pressure and temperature [19]. However, biomass combustion can lead to corrosion on heating surfaces due to boiler deposits [7]. While woodchip boilers improve local air quality and reduce local ground-level particulate matter concentrations, it may not be as environmentally friendly as compared to natural gas boilers. In addition to its use in buildings as a source of energy, biomass can also be used as a thermal insulation material or as a structural element in building construction, providing a sustainable and green alternative to some traditional building components, and improving energy supply chains by reducing dependence on imported fossil fuels [20].

Despite all the benefits resulting from the use of biomass in buildings, it is important to note that some biomass materials may be less durable and less resistant to some factors such as moisture, fire, and pests as compared to conventional building materials. This is in addition to the

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fact that biomass materials have limited availability and may vary in performance and quality [21]. To address these concerns, additional treatment and protection measures may be required.

Geothermal Energy

The stored internal heat of earth contributes to the generation of geothermal energy, which is a renewable source of energy that is not dependent on climate or time of day and can supply energy all day long, independently of external conditions [6]. Geothermal energy is mainly used for heat production and cooling and can work in combination with other energy systems, such as solar energy. Geothermal energy systems can improve energy efficiency while reducing energy costs and greenhouse gas emissions, as compared to traditional heating and cooling systems. A study by [22] confirmed that the use of geothermal energy significantly reduces energy demand, cost, and CO_2 emissions, as compared to conventional gas boilers, demonstrating its effective contribution to achieve the goal of net-zero-energy buildings. In addition to these advantages, geothermal systems require a relatively small land area, operate quietly without the noise generated by traditional HVAC systems, and provide design flexibility as they can be used with different architectural designs. Despite the mentioned advantages of geothermal energy systems, their installation cost is relatively high and the underground site conditions determine if a geothermal system is feasible or not [7]. It is, therefore, important to conduct a precise study on the subsurface conditions of the site to investigate the costs associated with installing a geothermal energy system for a building. This is in addition to the environmental impact of installing and operating geothermal systems, which are resulting from the noise associated with the installation of the systems and the treatment of geothermal fluids.

Wind Energy

The use of wind energy in buildings is considered one of the most widely used source of renewable energy sources [23]. The wind energy system consists of wind turbines, mechanical energy, heat pumps, and other required energy using wind vortex machines [7]. The most important advantage of using wind energy, as a source of renewable energy, is to reduce carbon emissions and consumption of energy. Statistics indicate that, as of 2017, the use of wind energy has reduced greenhouse gas emissions by at least 600 million tons [7]. According to [24], wind energy can provide around 15% of buildings' energy needs. To best utilize wind energy, architects design buildings in a way that they use natural ventilation for air circulation through natural wind power, which reduces the use of the air conditioning systems and, consequently, reduces energy consumption.

However, equipment needed to generate wind energy require high initial investment and maintenance cost, as compared with traditional energy sources. Another concern is the noise generated by the wind turbines, in addition to the fact that buildings layout limits the use of wind energy since the wind direction and speed between buildings may be affected by turbulence and blocking, which results in a reduced efficiency of generating the wind power [24]. In addition, the uncertain characteristics of wind make the power generated by wind irregular. It is, therefore, important to explore other new technologies to improve the efficiency of wind energy.

Hydro Energy

Hydropower is an energy generated by water. Hydropower is derived from the kinetic energy of falling or flowing water. It can be generated from streams, lakes and rivers or man-made structures such as dams, lagoons and reservoirs. It relies on the water cycle, which is driven by the sun, making it a clean and renewable source of energy. Hydropower is used to generate low-cast electricity, provide flood control, support irrigation, and produce clean drinking water. provides low-cost electricity and durability over time compared to other sources of energy. While the initial construction cost of hydropwoer systems can be costly, the cost can be reduced by using existing structures such as bridges, tunnels, and dams. However, the amount of energy extracted from the water depends on the available water volume and the difference in height between the turbines and the elevated source, known as the hydraulic head.

Hybrid Renewable Energy Systems

Hybrid energy systems combine different energy technologies to reduce costs, reduce greenhouse gas emissions, and improve capability, value, energy efficiency, or environmental performance of buildings as compared with the use of independent renewable energy systems. Hybrid energy systems combine multiple sources of energy with traditional electricity to meet the energy demands of buildings. Examples of hybrid energy systems include combining solar energy with wind energy, solar energy with hydrogen energy, wind energy with hydrogen energy, geothermal energy with hydrogen energy, etc. Hydrogen hybrid energy, for example, can be used for heating houses, supplying hot water, cooking, and meeting electricity needs. The solar-hydrogen hybrid system, for example, is considered the most efficient system of generating renewable energy. As the benefits of hybrid energy systems become more widely recognized, they are becoming increasingly popular in residential commercial and buildings to reduce energy costs and to promote sustainable construction.

Summary and Concluding Remarks

The use of renewable energy in buildings directly addresses the increasing demand of energy worldwide and mitigates the crucial concern of global warming. This paper presents the various types of renewable energy and their application in construction, including energy sources such as solar, biomass, geothermal, wind, and hydro energy, in addition to the hybrid sources of renewable energy. It is quite obvious that each of these sources offer sustainable and environmentally friendly advantages that enhance building energy efficiency and reduce operational costs. However, it is highly recommended to formulate standards and regulations related to renewable energy that can be followed by construction practitioners. The implementation of such standards and regulations will encourage the development of renewable energy in the construction industry and promote sustainability and innovation. It is also important to note that the application of hybrid renewable energy systems in buildings can provide designers and constructors with alternative and cost-effective renewable energy solutions. This study provides construction practitioners with information about the various renewable energy systems that can be used in the design and construction of buildings along with their benefits, challenges, and disadvantages.

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