Advances in Sustainable Architecture and Energy Efficiency

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Abstract

The importance of energy-efficient buildings seems to be essential due to the rapid depletion of energy resources, energy shortages, and increasing environmental pollution. Innovative methods are essential to reduce energy consumption. The construction industry is one of the largest energy-consuming sectors. In modern buildings, significant energy is used to maintain the tranquility of the building environment. In developing countries such as India, population growth, increasing standards Rapid living and urbanization lead to an increase in building construction activities. To achieve the collective goals of energy security and environmental protection, environmentally sensitive buildings that use their resources wisely, minimize their greenhouse gas emissions, and have efficient waste management systems must be considered and designed. The options available in architectural intervention, building materials, and design methods should be carefully evaluated to minimize energy consumption. Overall, the studies reviewed show the importance of sustainable architecture and building materials in creating climate-resilient infrastructure. They highlight the potential to reduce greenhouse gas emissions, improve energy efficiency, and increase the comfort and well-being of residents through the adoption of sustainable building practices. The findings of the survey provide insights into sustainable building practices that can determine policy decisions and guide the development of climate-resilient infrastructure in the future.

Keywords: sustainable architecture, green building materials, energy efficient buildings, weather and weather resistant substructure, super concrete with high performance

1. Introduction

Sustainable building has become a key issue for many developing and developed countries in the 21st century. The world's population is expected to increase from 7.7 billion in 2019 to 9.7 billion in 2050 and reach more than 10.9 billion by the end of this century [1]. This increase in the world's inhabitants will increase the demand for water, energy, and natural resources, respectively, which will overwhelm biological systems and gradually degrade nature as energy use expands, resulting in an overall impact on the built environment. Previous studies have shown that buildings are the main key to energy consumers. It consumes the most energy, with the building sector accounting for about 30 to 40 percent [2]. In addition, more than one-third of all greenhouse gas emissions, which are a critical contributor to global warming and climate change, produce waste and potentially harmful atmospheric emissions. Therefore, achieving sustainability in buildings is a way to objectively reduce these negative effects.

Sustainability in buildings is a concept that has multidimensional pillars, including environmental, economic, social, ecological, technical, and technological aspects. Green and sustainable buildings can help reduce the effects of buildings on the environment, economy, and society. In addition, achieving sustainability in buildings by reducing greenhouse gas emissions with embodied energy through the use of natural resources, emissions of pollutants, recycling of materials, ensuring building safety, and meeting indoor environmental quality requirements. Some researchers and academics defined sustainable buildings as green buildings that are better able to reduce greenhouse gas emissions than conventional buildings and can achieve the commitment of net-zero carbon buildings. However, energy efficiency should be considered as a fundamental concept to achieve sustainable buildings, green buildings, energy-efficient buildings, ultra-low energy buildings. andzero-energy buildings[3]

To achieve sustainability in buildings, high energy efficiency must be achieved by reducing environmental impacts through energy performance benchmarking methods, energy-saving measures, integrating wind turbines into high-rise buildings, an integrated approach using multi-objective search, energy modeling and overall heat transfer value calculations, integrated building photovoltaic facades , lighting fixtures, high-performance building coverings., building materials with efficient resources, and innovative energy concepts[4].
The economic effects can be achieved by achieving cost savings and operational cost reduction (hard and soft costs) by using life cycle assessment, developing cost-benefit analysis, applying green price premiums, applying an optimal design method for multi-energy systems in buildings such as photovoltaic (PV) power generation system, solar water heating system and seasonal cold storage by minimizing the total cost. Life cycle reduced [5 and 6].

vernacular architecture, all parts of the world, which arose due to the nature around it and in harmony with the climate, were forgotten. Modern architecture, which was born of these developments, completely ignored the context of the formation of architecture.Modern man with the slogan of "domination over nature" fueled the crises of development more than ever.Our cities, our technology, and our architecture create the illusion in our can be 1970s minds that we are controlling nature while we are in control of nature and a part of it. The considered the decade of becoming aware of the crisis. Sustainable architecture is the result of a deep knowledge of the surrounding environment.In this architecture, quality is in line with one goal, which is comfort.The important point that is considered in this type of architecture is that all the factors involved in comfort are related to each other and are considered as a single system. Through architecture, society can be made aware of the desirability and abundant economic and environmental value of energies that are called harmless, green, calm, etc. It has become famous to inform that the energies that can be called beautiful from the point of view of artists and architects, the future of the world lies in beautiful energies. Therefore, we must Overall, this review article aims to provide a energies. discover the beauty hidden in the pure and vibrant comprehensive understanding of recent advances in sustainable architecture and building materials for climate-resilient infrastructure. By shedding light on the latest developments, challenges, and opportunities, this article aims to inspire further research and promote the adoption of sustainable practices that can help create a more resilient and environmentally friendly environment

2. Literature Review:

This review checks and searches for relevant articles based on relevant keywords. Research papers published in reputable scientific journals based on the Google scholar database and ScienceDirect have been mainly reviewed since 2000 with topics focused on the research title and keywords including sustainable architecture, green building materials, energy efficient buildings, weather-resistant infrastructure, and ultra-high-performance concrete. In the article, we have focused on sustainability in architecture, sustainable design principles, and energy efficiency.

- Sustainability in architecture

The World Commission on Environment and Sustainable Development has defined sustainability as meeting the needs of the present without compromising the ability of future generations to meet their own needs. The optimal use of non-renewable energy sources is important not only from an economic point of view, but also from an environmental point of view. Although maintaining and strengthening economic institutions is vital in achieving sustainable development, it is our duty to preserve the environment for the present and future generations.

Architecture is one of the most prominent forms of economic activity. It has been suggested that the intensity (consumption) of architectural resources (the ratio of per capita consumption of architectural resources to per capita income) generally follows a pattern. The economic development of a country requires the construction of more companies, formal and residential buildings.

- Sustainable development and architecture in the construction industry

Sustainable development and architecture in the construction industry is a new phenomenon. According tothe predictions، about 75% of the world's population tends to live in cities. Therefore، natural resources should be used in a way to maintain their sustainability to provide the required facilities. On the other hand، architecture is clearly one of the largest manifestations of economic activities in a country. Economic development of a country into a factorywill require more office buildings and residential buildings. For a family, the growth of financial income leads to a kind of attraction and desire to own and owna larger house with more expensive building materials, furniture, and household appliances, creating more comfortable temperature conditions in the interior spaces of the house, garden, or larger yard.

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-Sustainable Design Principles:

In general, the goals of sustainable design in the framework of sustainable development emphasize the simultaneous protection of the natural environment and the man-made environment. Based on the views of theorists, the following three principles can be briefly introduced as the three principles of sustainable design from a technical point of view:

In short, the principles of sustainable development in relation to environmental sustainability include paying attention to the use of renewable resources, less use ofnon-renewable and polluting energies, meeting the basic needs of humans and society and creating a healthy environment for future generations, paying attention to the environment and reducing pollution, as well as paying attention toenvironmental cycles. The manifestation of sustainable development in the field of the built environment is called sustainable architecture. What is considered in this article is the approach of sustainable architecture to environmental issues, although it is difficult to separate this
issue from other economic, cultural, and social aspects. From the perspective of Richard Rogers, sustainable design aims to meet the needs of the future, without destroying the natural resources that remain for future generations.

Tawil mentions. According to Jong-jin Kim, the three principles of resource conservation, life-cycle design, and humane design are the topics of sustainable architecture.

It takes time to minimize energy consumption by all possible means. From another perspective, the available energy must be used wisely. No serious thought is given to using energy at an optimal level. Although it is very difficult to shorten the requirements, a new culture of energy conservation must be created. Energy efficient buildings are essential to reduce the energy burden and improve development, and also help support the economy of our country. It is useful. In this regard, the construction industry has played a vital role. Engineering has ushered buildings into a new era of this modern world. Today, buildings are designed with energy efficiency and sustainability in mind.

-Sustainable buildings

Sustainable buildings are buildings that are operated with the least consumption of natural resources without harming operations, services, and products. These buildings do not need to supply energy from external sources. Energy is produced and consumed on-site, which is the best option for the environment. Energy-efficient buildings are also sometimes called sustainable buildings or green buildings. Eco-friendly process for design, construction , maintenance, operation and renovation of energy-efficient buildings[11].

-Energy efficient buildings

Energy-efficient buildings are buildings whose design has been changed through architectural tools and a modified construction methodology is adopted, due to which the building is self-sufficient in terms of energy. However, there are always energy losses, but energy is retained inside the building, and less energy is required to operate the building, which provides the same level of comfort and living performance It does. High-quality building materials are used[12].

- Passive and low-energy buildings

Passive and low-energy buildings are where there are specific design criteria to reduce the operational energy consumption in a building. They are designed to significantly reduce the energy requirement for the ecological footprint of the building, improve the heating, ventilation and air conditioning of lighting, building cladding elements, etc., which depends on the passive solar design, high levels of insulation. The standards of good ventilation, controlled ventilation, high-performance glazing and efficient heating systems are designed. Building Cover A It is the main component in the structure of the building, separating the indoor and outdoor environment, and reducing heat transfer. Light cement with lower material density, lower thermal conductivity, and autoclave aerated concrete with the intrinsic nature of high porosity AAC result in superior thermal properties that reduce the heating and cooling load in the building cladding[13]. The roof is susceptible to solar radiation, thus affecting the comfort of indoor occupants as well as the temperature of the outside air in urban areas, accounting for 20 to 25 percent of all urban surfaces. In recent days, some passive techniques have been used to reduce the solar absorption of the roof, which include reflective/cooling solar roofs, partially or fully green roofs with vegetation, roof insulation, Evaporative roofs and photovoltaic (PV) roofs[14].Recently, gypsum wall boards with embedded PCM have been used to reduce the maximum internal temperature.Ground-to-air converters are used directly for heating and cooling the space in buildings. The temperature of the air at the outlet, the geological characteristics of the soil, the characteristics of the pipe related to heat exchange, and the climatic conditions of the site are some of the factors affecting the effectiveness of ground cooling systems. It reduces the electricity consumption of a typical building by between 25 and 30 percent. Cold night air is also used to cool the heat. absorbed by the building[15]..

The performance of these passive methods is highly dependent on climatic conditions, so an appropriate design strategy with a proper understanding of climatic factors should be used.

-General principles of energy management in building systems

Energy management in buildings can be studied according to several factors, including the location of the building, the building covering, and the building systems:

The choice of building location determines the weather conditions to which the building will be exposed. Building cladding determines the impact of local conditions on the occupants of a building. Building systems complement the heating and cooling power and accessible lighting of the surrounding environment. As far as the use of these complementary systems is related to the building's cladding and its local features, energy consumption can be minimized. Kills. [16]..

Buildings are closely related to air conditioning. This connection involves factors over temperature. Human comfort depends on humidity, the speed of air flow, as well as temperature. The absorption and waste of energy in buildings depends on these factors, as well as the speed of solar energy, the shade of trees or hills, the speed of the wind, and the length of the hot and cold seasons. In order to achieve stable buildings, insulation, the use of materials optical, selective layers, and radiation barriers [16]..

Climatic divisions and typology of architecture

The diverse characteristics of each climate have a great impact on the formation of cities and the architectural structure of that region. Therefore, determining the accuracy of the climatic zones of different regions is very important in providing appropriate plans suitable for the climate of each region.

One of the critical issues in construction, residential and climatic architecture is heating them in the cold seasons of the year and cooling them in the warm seasons of the year to reach the limits of human heating comfort. As a result, considering special arrangements related to the shape, size of windows, the nature of building materials, and weather conditions can lead to the greatest savings in heating and heating.

Cooling residential areas is a vital problem in understanding the architectural value of each period and each region knows how to adapt a building to the specific climate of that area. How the building uses the sun, breeze, and greenery, and how the architect creates a small climate. Another factor that reduces the impact of climatic factors on buildings is the size of the building. If we quadruple a shape, the ratio of its volume to its surface decreases from 1.6 to 1.15, and as a result of reducing the outer area to the covered volume, the impact of climatic factors is reduced. However, we can propose principles for buildings, which are as follows:

1) In cold regions, closed and compact forms and cubic buildings or adjacent buildings at the back are preferred along the north-south axis. In such areas, high-rise buildings are more suitable.
2) In temperate climates, it is easier and more free to choose forms, but by the way, forms are preferred along the east-west axis.
3) In hot and dry regions, solid and compact forms are recommended. Cubic forms or forms with a larger north-south side are better than their east-west side. High-rise buildings are also preferable to short buildings.

4) In humid areas, buildings that extend freely along the east-west axis are more suitable, but buildings that extend along the north-south axis are not suitable because they are exposed to intense solar radiation.

Simultaneous analysis of thermal comfort and energy consumption in the building

In order to predict the thermal comfort conditions in a building, as well as to analyze the performance of heating and cooling systems in terms of energy consumption and thermal comfort, so that a suitable ventilation system can be selected or the performance of these systems can be optimized according to the climatic conditions. Local conditions, traditions, and customs and existing limitations, the interior of a building must be modeled from a thermal point of view.18]..

In general, heating and cooling systems of buildings can be divided into two main categories: radiation systems and convection systems. Underfloor heating systems, as well as cooling and ceiling heating systems, are among the most important and practical radiant ventilation systems.

Due to the widespread use of central heating systems in Iran, it seems that optimization of these systems to achieve high efficiency and ultimately reduce costs and energy consumption is inevitable.

In general, in a central heating system, the energy-saving potentials can be summarized as follows:

- Prevent energy waste of central heating services and transportation machinery
- Reducing excess energy consumption by boilers and ancillary equipment
- Preventing unnecessary work of energy-consuming machines that lack an independent control system
- Using appropriate controllers to control heating[16].

- Methods of optimizing energy consumption in ventilation systems of buildings

1) Minimizing the uptime of ventilation equipment by installing educational placards
2) Minimizing ventilation equipment uptime by entrusting the task of turning ventilation equipment on and off to reliable staff
3) Minimizing the uptime of ventilation equipment by installing adjustable thermostats or space controllers
4) Minimizing the operation time of ventilation equipment by installing timed disconnects.

-Electrical energy saving techniques

The lighting system is one of the most important consumers of electrical energy. Of the total electrical energy consumed in the lighting system, 63% is allocated to formal buildings, 22% to residential buildings, and 12% to streets and roads.

The lighting system is used to illuminate different places. This system converts electrical energy into light. A lighting system consists of an electrical part and a non-electrical part and has different parts such as power supply, launch equipment, ballast control, lamps, and light (Sharif 2006). Lighting system design means determining the number and type of lamp for a specific place. In such a way that the intensity of lighting in that place is sufficient for the intended purpose.

The steps of an energy consumption management plan for lighting systems are as follows:

1) Measuring the size of current brightness levels
2) Proper Daylight Use
3) Improvement Suggestions with Existing Equipment
4) Evaluation of alternatives and installation of new equipment.

-Technical Tips for Sustainable Building Design

From an environmental perspective, paying attention to climate and lifestyle is a good way to meet architectural needs and achieve a holistic vision for design. To achieve successive successes, designers need to increase their knowledge of new design philosophies and the relationship between interior and exterior spaces. The relationship between form, structure, and comfort depends on the characteristics of the building's orientation, location, and education. The application of sustainable design in architecture has been proposed.

-Methods for applying sustainable design in architecture

- **Energy Saving**

Energy conservation is one of the methods of reducing inlet discharge. The main goal of this technique is to reduce the consumption of fossil fuels. Buildings not only consume energy when they are used for heating, cooling, and lighting purposes, but they also consume energy during construction. Consumables in architecture are first extracted and harvested from raw materials, then they go through the production process, and finally they are transported to the building site. In the construction phase, a lot of energy is used for various activities from excavation to welding.

- **Energy-Based Planning for a Site**

Such planning enables the designers to make the most of the natural resources available on the site. In temperate weather, the creation of pores on the south side of the building increases passive solar heating. Deciduous trees shade in the summers and make it possible to receive the sun's heat in the winters. By planting evergreen plants on the north side of the building, it can be protected from winter winds and Improve its energy efficiency. To provide natural cooling conditions in summer, buildings can be placed near water sources on site .

This important prerequisite is often overlooked in the design of modern buildings. The passive architecture of the solar system provides us with solutions and arrangements so that we can use the sun's radiation at more useful times of the day. By creating shade with the help of canopies or plants, it is possible to avoid receiving heat in the summer and subsequently the costs imposed for ventilation services. Wind or airflow has been an important advantage among the major issues of urban planning[16].

- **Insulation:**

The windows are highly efficient and the walls are insulated and prevent heat from being received and wasted. Reducing such heat transfer reduces the amount of heating and cooling charge of the building, thereby reducing energy consumption. Lower heating and cooling costs require smaller ventilation systems. These tangible and objective advantages, highly efficient windows and insulated walls provide more suitable heating conditions in practice. Due to the characteristics of insulating materials, the degree of heating of windows and walls is higher in winters and less in summers. The use of smaller ventilation equipment reduces the noise of mechanical machines and increases the sound quality of interior spaces..

-Progress in energy-efficient buildings for new and old buildings

Population growth and increasing energy demand have both led to major increases in energy consumption. Currently, buildings account for more than 40% of the world's energy consumption and 33% of global greenhouse gas emissions. Numerous studies have shown that EEBs provide a prospect for financial savings while also reducing greenhouse gas emissions. Building ion automation, which has recently been added to the construction industry, can improve the comfort of occupants, the efficiency of building systems, and reduce energy consumption and operating costs. Automation has been achieved with a variety of tools, including mechanical, hydraulic, pneumatic, electrical, electronic, and computers, commonly known in combination as smart building automation system. Unlike ion automation, it is not easy to install energy-saving and environmentally friendly materials in older or built buildings. Implementation These materials are wiser in the design and manufacturing stage. Energy-efficient materials are more cost-effective and efficient

-Silica aerogel blanket as an ultra-insulating material for the development of energy-efficient buildings

However , the cost of making them remains high, so the latest research efforts have focused on reducing the time and cost in the manufacturing process of super-insulating materials such as silica aerogel .Due to these drawbacks, more studies are underway on how to create an effective alternative to silica aerogel[20].

Since aerogel blankets are highly porous materials and water vapor can pass through the pores, so the factor of "μ water vapor diffusion resistance" was selected as the main parameter for this study. This shows the relative value of the water vapor resistance of the product and an equally thick layer of still air at the same temperature. Here is the μ value for the aerogel blanket remaining 5.5 -2.8. for insulation materials. Thermal is acceptable. Conventional mineral wool has μ = 1-3 and organic insulators have μ = 60-150. [20]..

Table 1 - Basic properties of aerogel blankets.

Needle Glass Fiber Aerogel Blanket	Wool Needle Glass Fibers	Silica Aerogel	Properties
150	150	Granular	Length (mm)
8	6%	x	Thickness
4%	4%	x	Fraction Volume Iliaf

15-17	31	14-15	Thermal Conductivity (Mw.m-1. K-1)
150	100	100-110	(g. cm-3) Density
6/206	x	20>	Stability Khumsi (kPa)

Although residential structures still have the majority of potential. With a lower thickness, it can provide the same insulation as traditional insulation materials. In the future, aerogel blankets could be a viable alternative to traditional insulation. Although the concept is currently uncommon in underdeveloped countries such as Bangladesh, interest in GB (green building) is growing. Bangladeshi buildings, which are both commercial and residential, use nearly 32% of primary energy.

-Ultra High Performance Concrete (UHPC)

Ultra-high-performance concrete (UHPC) is a material that has gained traction in recent years for its exceptional mechanical properties, durability, and potential for sustainable construction. However, UHPC's high production costs and environmental impact have limited its widespread use in construction applications. The use of secondary aggregates in UHPC can improve the overall performance of UHPC, especially in terms of durability and sustainability, by reducing waste entering landfills and reducing carbon emissions associated with cement production, which is responsible for about 8% of global carbon emissions. Recycled materials can improve the microstructure of UHPC by reducing porosity and improving particle packaging density[21]. In addition, the use of recycled materials can improve the long-term sustainability of UHPC by reducing the need for virgin materials and conserving natural resources. One of the main challenges is the diversity of recycled materials. Therefore, it is important to carefully select and test recycled materials to ensure that they are suitable for UHPC production. UHPC with EGA has been found to have better mechanical properties than conventional UHPC and other secondary aggregates with compressive strength greater than 127 MPa and flexural strength greater than 21 MPa**.** In addition, the water absorption of UHPC with EGA was lower than that of conventional UHPC, indicating better durability and moisture resistance. Life cycle valuation of ultra-high-performance concrete with EGA also shows recognizable results from other secondary materials, showing a significant reduction in environmental impact compared to conventional UHPC[21].

The embodied carbon footprint of UHPC with EGA was approximately 16% lower than that of conventional UHPC. In addition, UHPC designed with 15% coral coral sand and 30% coral sand together showed comparable properties. Application of secondary aggregate in UHPC It has the potential to address the environmental and economic challenges associated with UHPC production while improving the yield and durability of the material. However, a careful examination of the quality and availability of recycled materials is essential to ensure that UHPC is suitable for specific applications. Figure 1 shows a comprehensive analysis of UHPC according to the embedded CO2, compressive strength, and substitution level of various waste materials. [22].

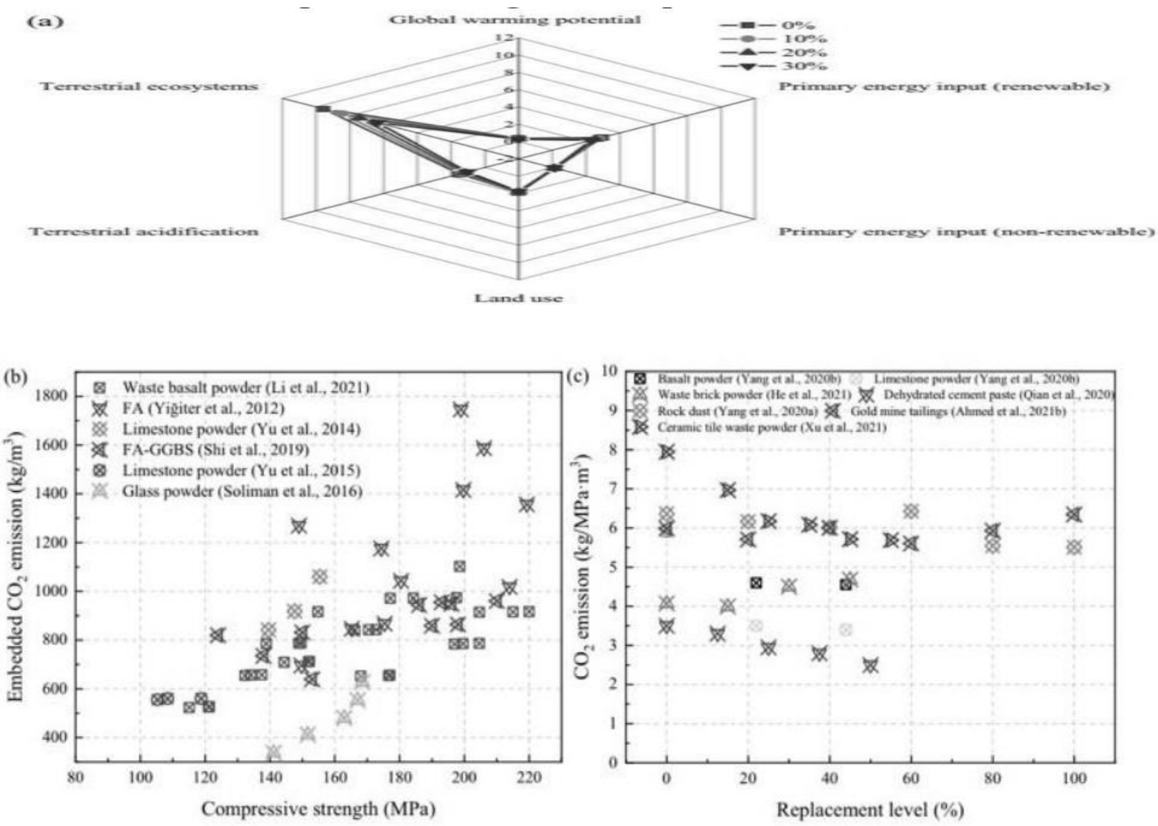


Figure 1-Environmental Benefits(a) and CO2 (b and c) Emissions of UHPC with Solid Waste

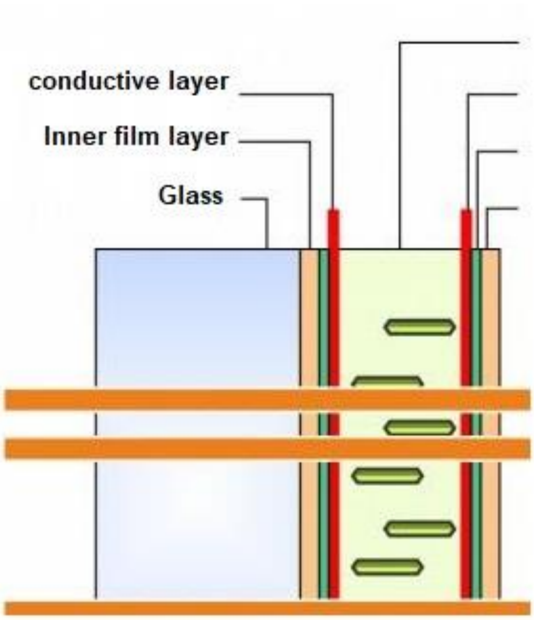
-Smart Materials

Intelligent materials are a new term for materials and products that have the ability to perceive and process environmental events and react appropriately to them. In other words, these materials are changeable and are able to change their shape, form, color, and internal energy in a reversible way in response to the physical or chemical effects of the surrounding environment. The first group, i.e. non-intelligent materials, do not have the above special feature, semi-intelligent materials are only able to change their shape and shape for a time or a short time in response to environmental influences, but in smart materials, these changes will be repeatable and reversible.Smart materials are also known as "flexible" and "adaptable" materials, due to their special feature in adapting to environmental conditions..

-Intelligent energy-saving materials

These materials store energy in the form of light, heat, hydrogen, or electricity. Intelligent heat-storing materialsare the most popular in this group, which have an intrinsic feature that enables them to store energy in the form of heat or cold in the form of latent energy. The most widely used are under the category of transforming materials, which can act as a medium for regulating temperature. They change their state from liquid to solid by crystallization, releasing a certain amount of heat energy that they had previously stored at higher temperatures, and in reverse, by changing from solid to liquid at the time of the entry of heat energy, they keep the amount of heat or temperature constant (Figure 2).

Figure 2. Smart glass with a layer of crystal liquid sandwiched between them



3. Discussion and Conclusion:

The use of the right amount of solid waste to replace traditional aggregates is beneficial for improving the performance of UHPC, which takes advantage of the uneven surface and water storage capacity of the aggregates. The use of secondary aggregates in UHPC has the potential to address the environmental and economic challenges associated with UHPC production while improving the yield and durability of the material. Solid waste replacement level 10% – 30% The potential value ofglobal warming was 10.8% – 32.5%. Therefore, this could be a potential method for the future concrete industry. Careful attention to the quality and availability of recycled materials is essential to ensure that UHPC is suitable for specific occasions.

Future research should focus on developing standardized test protocols for recycled materials and investigating the long-term performance and durability of UHPC with secondary materials. Integrating energy-efficient design, passive strategies, and renewable energy systems into sustainable architectural practices can significantly reduce energy consumption and greenhouse gas emissions, while improving the performance of buildings in different climate zones. optimizes. The advancement of environmentally friendly building materials, such as recycled and biodegradable options, low-carbon concrete, and advanced insulation systems, contributes to climate resilience by minimizing environmental impact and increasing durability. However, the downside of these advanced applications, such as the emissions of greenhouse gases during the production of UHPCs, must also be considered.

Also, due to the fact that the resources available in the land for its inhabitants are limited and running out, therefore, it is very important and necessary to try to provide solutions for sustainable design and development in architecture. Research and Research on Materials Intelligent presents a new challenge for architectural designers. Smartening, and especially the use of smart materials and materials that react to environmental issues, facilitates the maintenance of buildings, increases the useful life of buildings, prevents excessive energy consumption, and more innovative architectural designs. The realization of architectural goals becomes sustainable

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