Sustainable development by carbon emission reduction and its quantification: an overview of current methods and best practices

Article *in* Asian Journal of Civil Engineering · June 2023

DOI: 10.1007/s42107-023-00732-z

Neha Singh
Lovely Professional University

Kundan Yadav
Lovely Professional University

Asian Journal of Civil Engineering
https://doi.org/10.1007/s42107-023-00732-z

REVIEW

Sustainable development by carbon emission reduction and its quantification: an overview of current methods and best practices

Neha Singh[1] · R. L. Sharma[1] · Kundan Yadav[1]

Received: 15 May 2023 / Accepted: 22 May 2023

Abstract
The construction sector accounts for 36% of global energy consumption and 39% of global carbon dioxide emissions. Sustainable development, which entails reducing and quantifying carbon emissions, is essential to address climate change and the depletion of non-renewable resources. This review paper examines a range of strategies and methodologies, including green building rating systems, sustainable materials and renewable energy, smart building management systems, carbon capture and storage, life cycle assessments, and greenhouse protocols, that can facilitate sustainable development by reducing and quantifying carbon emissions. The paper underscores the need for up-to-date information and more precise techniques to achieve sustainable development goals. Additionally, the paper highlights the potential advantages of sustainable construction practices, such as lower energy costs, better indoor air quality, and more efficient use of resources.

Keywords Construction sector · Carbon dioxide emissions · Quantifying carbon emissions · Sustainable construction practices · Efficient use of resources

Introduction

India is a rapidly developing country with a large population, urbanization, and increasing wealth, leading to high energy consumption and greenhouse gas emissions (Zhang et al., 2023). Population growth is the leading cause of carbon emissions and greenhouses (Li et al., 2017). Sustainable development (SD) is one of the global environmental movement's orientations, with the goal of conserving and repairing the environment and it includes economic, environmental, and social impacts (GhaffarianHoseini et al., 2013; Peng et al., 2023; Zhao et al., 2021). According to the World Commission on Environment and Development (WCED) report, sustainable development is the “development that meets the need of the present without compromising the ability of future generations to meet their [own] needs” (Bruntland, 1987). The carbon footprint is the "total GHG emissions generated directly or indirectly by a person, event, organization, or product, resulting mostly in CO_2 emissions." According to the Intergovernmental Panel on Climate Change (IPCC), the generation of GHG from burning fossil fuels is a major factor in global warming (Jafary Nasab et al., 2020). Developed countries such as the United States, the United Kingdom, and Japan have committed to becoming carbon neutral by 2050 (Al-Obaidy et al., 2022). In India, construction and operation play a vital role in the economy, consuming 35% of global energy and contributing 29% of CO_2 emissions (Mahasenan et al., 2003). The construction sector is responsible for 30–40% of industrial CO_2 emissions globally, although this represents less than 7% of total global CO_2 emissions (Chen et al., 2010; Scrivener & Kirkpatrick, 2008; Worrell et al., 2001). Around 80% of energy usage and GHG (Qin & Kaewunruen, 2022) emissions are caused by building operations (including heating, cooling, ventilation, lighting, and appliances), whereas only 10–20% are caused by material manufacture, construction, and demolition (Nag & Parikh, 2000).

Carbon Footprint Analysis: Promoting Sustainable Development. Available from: https://www.researchgate.net/publication/348390830_Carbon_Footprint_Analysis_Promoting_Sustainable_Development [accessed Apr 24 2023].

✉ Neha Singh
neha707867@gmail.com

R. L. Sharma
sharma.23743@lpu.co.in

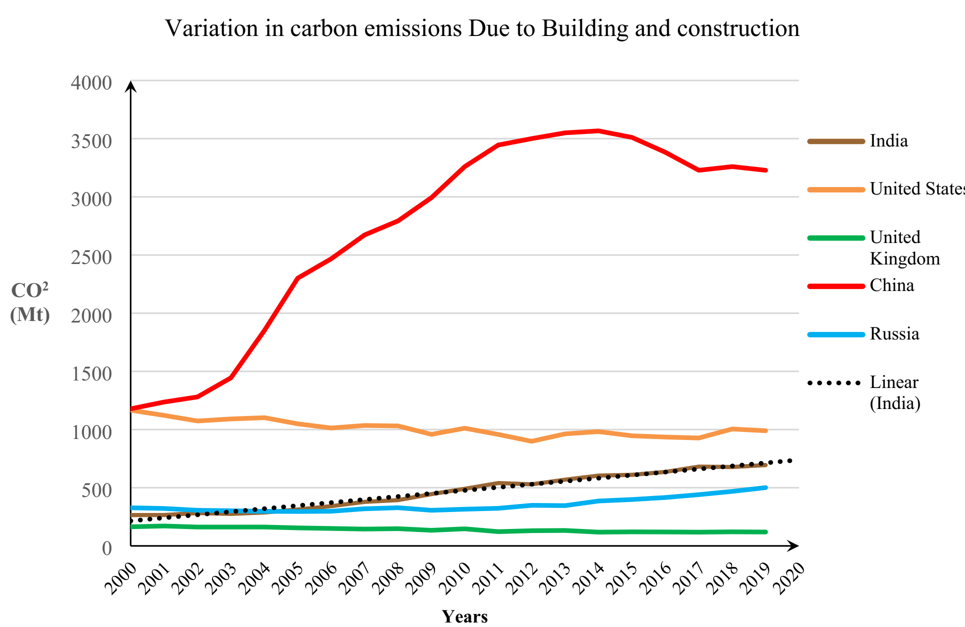
Kundan Yadav
en.kundan@gmail.com

[1] School of Civil Engineering, Lovely Professional University, Phagwara, Punjab 144411, India

Low-carbon management is a strategic approach to reduce carbon emissions and has become increasingly important in recent years (Zhang et al., 2023). The production of building materials and components, transport, and construction processes all require embodied energy, which contributes to carbon emissions (Li et al., 2017). Amount of renewable energy produced by India is 38.5, 29, 25.7, and 6.4% by solar energy, hydropower energy, wind energy, and biofuels respectively (International Renewable Energy Agency, 2023). The IPCC study revealed that while the deployment of solar technology expanded more than tenfold and the use of electric vehicles increased one 100-fold between 2010 and 2019, the unit costs of solar energy, wind energy, and lithium-ion batteries decreased by 85, 55, and 85%, respectively (Mikulčić et al., 2023). Various tools and technologies have been developed to support sustainable construction, such as building information modeling (BIM), which can improve project planning (Somogyi et al., 2017) and reduce carbon emissions (Liu et al., 2022; Onososen et al., 2022; Zhao et al., 2022). India is the third largest carbon emitter country in world and still rising continuously. 60% of carbon emissions come from the top 10 countries and the rest countries contribute even less than 3% while the 100 least-emitting contributed less than 3%, Fig. 1 showing contribution of countries in carbon emission. Energy is the largest emitting sector (~75%), followed by agriculture, transportation, and manufacturing (Climate Watch, n.d.). Global CO_2 emissions declined by 5.8% in 2020, making it the largest-ever decline and five times greater than the 2009 decline (IEA, 2021).

This paper highlights various energy-saving measures to achieve sustainable development in the built environment. These measures include insulating such as insulating the building envelope, glazed windows, and reflective materials can significantly reduce a building's energy consumption (Wong, 2017). Glued and sawn wood value chains are sustainable options for reinforced concrete in both cast-in-situ and precast forms (Y. Wang et al., 2023). Technological installations like energy-efficient HVAC systems, solar panels, and heat pumps can further reduce a building's embodied energy and global warming potential (Chastas et al., 2018; Krarti & Aldubyan, 2021). By-products such as ceramic tiles, glass, copper slag, and rubber have been successfully used as aggregates in concrete (Mithun & Narasimhan, 2016; Pham et al., 2019, 2020; Saloni et al., 2021). Renewable materials like bamboo, cork, straw, flax, recycled rubber, cardboard-based panels, and hempcrete have minimal embodied energy and are desirable for building design (Schiavoni et al., 2016). Building orientation is important for maximizing natural light and heat gain, eliminating the need for artificial lighting and heating, thereby saving electricity consumption (Mostafavi et al., 2021). Sustainable building materials and design can help lower a building's embodied energy, while planning the roof, walls, and floor for maximum energy efficiency and airtightness is essential for sustainable development (Song et al., 2023). The use of precast concrete can reduce carbon emissions by up to 15% compared to the cast-in-situ method (Hao et al., 2020; Xiang et al., 2023). Life cycle analysis (LCA) reviews show that as a building's energy efficiency increases, its operating energy decreases, but its embodied energy increases (Al-Obaidy et al., 2022). Low-energy buildings and passive houses with high envelope insulation and minimal energy needs are popular among building designers (Grazieschi et al., 2021). Resource utilization must be monitored to ensure sustainable development (Janssens et al., 2017), and rating systems such as LEED and GRIHA can help achieve lower carbon

Fig. 1 Variation of carbon emission of countries



emissions. Smart sensors for building management systems can also monitor and analyze energy consumption (Krarti & Aldubyan, 2021; Wong, 2017).

This review paper provides a comprehensive overview of current methods and best practices for achieving sustainable development through carbon emission reduction and quantification. The aim is to provide updated information to researchers, policymakers, and professionals in the economy and culture sectors, in one place. Strategies and techniques for carbon emission reduction include the use of green building rating systems, sustainable energy sources, sustainable materials, insulation of buildings, and smart building management systems. The paper also covers strategies for carbon quantification, such as life cycle assessment, the GRIHA Decarbonizing Program, carbon capture and storage, GHG emission protocol, and carbon calculators. Each section of the paper covers different aspects, including definitions, scope, role in sustainable development, and the latest research solutions. This paper tries to cover all possible aspects and review different methodologies to achieve objectives, i.e., sustainable development. The results of different publications have different ideas for sustainable development, and they also say how much carbon dioxide the building industry puts into the air. This paper will be a step toward SD through a carbon–neutral structure.

Sustainable development by carbon emission reduction

According to present energy consumption and emission intensity, the construction sector's portion of total carbon emissions could reach 50% by 2050 (Rhodes, 2016; Xu et al., 2020). The primary goals of sustainable design are to reduce the consumption of scarce resources such as energy, water, and raw materials; to prevent long-term environmental damage caused by buildings and other infrastructure; and to create safe, productive, and water- and light-efficient living environments (Chel & Kaushik, 2018). To achieve SD in the building industry (as shown in Fig. 2), it is essential to reduce carbon emissions and their quantifications point out sector carrying major carbon emissions (Lee et al., 2018). Both during construction and operation, buildings use up a lot of resources and it leads to carbon emissions (Li et al., 2013). A few foreign countries have also changed their policies from focusing on sustainable development to focusing on controlling carbon (Higgins, 2013). The aim of the Paris climate conference is to promote sustainability and reduce carbon emission T (Adebayo et al., 2023). SD and climate change mitigation have focused the world on reducing carbon emissions and improving environmental quality (Cheng et al., 2019; Raihan, 2023). Pollution, ecological degradation, and climate change are just a few of the severe issues for the environment that a high carbon footprint can cause (Li et al., 2023). There are 17 sustainable goals adopted by United Nations and goals like good health and well-being, clean energy, sustainable cities, and climate actions can be achieved by reducing carbon emissions. In goal 13, i.e., climate actions clearly mentioned that GHG emissions will continue till carbon neutrality is achieved and for this, world must cut its emissions of carbon dioxide by 45 percent from their 2010 levels by 2030 and zero emissions by 2050 (Purnell, 2022; United Nations, 2021). From the works reviewed, design techniques and technologies include energy-efficient measures, building envelope, renewable sources of energy are well established and will be crucial to any future SD strategy (Li et al., 2013; Xu et al., 2020).

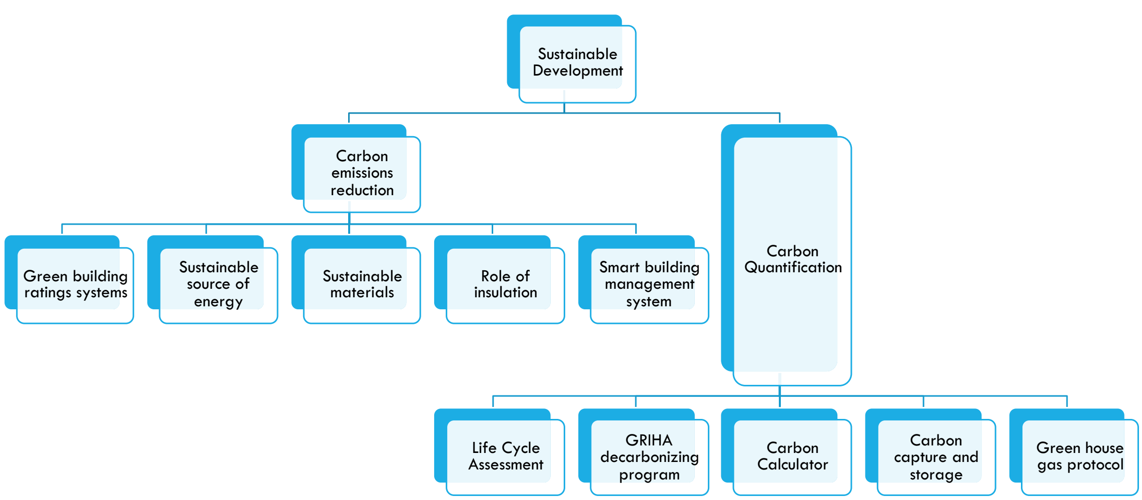


Fig. 2 Strategies for sustainable development

Strategies for carbon reduction

The objective of this assessment is to explore diverse strategies and methodologies for managing carbon footprints and their quantification. The study begins with a comprehensive literature search of relevant keywords such as "carbon emissions," "carbon quantification," "sustainable development," "green building," "embodied energy," "solar plant," "energy consumption," and "sustainable materials," among others. Subsequently, extensive research is conducted to identify pertinent policies and methodologies for carbon emission reduction and quantification, available in academic journals, official websites, and other credible sources.

Green building rating systems

Green building (GB) rating systems is a tool for minimizing the negative consequences of the built environment on society, economy, and the environment (Zuo & Zhao, 2014). Green buildings consume less water and energy, conserve natural resources, generate less waste, use recyclable materials, and provide a better living environment for their occupants (Manna & Banerjee, 2019; Sharma et al., 2021; Wang et al., 2015; Zhao et al., 2021). According to USGBC (United Nations Economic Commission for Europe, n.d.), GB consumes 30% less energy and reduces carbon emissions and cost by 35% and 50–90%, respectively. The buildings can be designed to maximize natural ventilation, daylighting, sunshine, energy collection, green spaces (Ying, 2022). Some of the strategies used in construction of green buildings that reduced their negative impact on the environment are indicated below.

The walls and roof

They act as an insulator and prevent heat transfer from outside to inside and vice versa. The most cost-effective insulation material is 2.2 cm fiber glass-urethane, which reduces carbon emissions by 16.4 kg/m^2 (Shekarchian et al., 2012). According to literature, high-heat walls delay heat transmission to the interior space and increase the surface temperature of the interior, although insulation prevents these effects (Kubota & Zakaria, 2019). Daytime structural cooling may be prevented by internal insulation (Kubota & Zakaria, 2019). The cool roof system can reduce 15 °C temperature with various building design techniques, roof structures, cavity ventilation, thermal reflecting coating, and orientation (Rawat & Singh, 2022; Tuck et al., 2020). The roof design and green roofs reduce heat transfer and reduce temperature fluctuations in which high-albedo materials can be used that reflects more sunlight (Bretado-de los Rios et al., 2021; Permpituck & Namprakai, 2012; Sangkakool et al., 2018).

Windows

The light transmittance and thermal qualities of glass strongly affect solar transmission efficiency and indoor heat gain, it should be wide, fully open windows with equal entrances on opposite walls for maximum day light and ventilation (Hien et al., 2005). Double-glazed facades with natural ventilation can improve thermal comfort and reduce energy consumption by adding extra layers of glass, applying coatings, and filling gaps between layers with low-thermal-conductivity gasses like argon or krypton (Somasundaram et al., 2020). Research conducted in Singapore revealed that retrofit double glazing has the potential to yield energy cost savings of up to 4% annually for clear glass and up to 7.5% for tinted glass. Aerogel granulate glazing systems exhibited superior energy efficiency demand due to the importance of cooling in the region (Hien et al., 2005; Qahtan et al., 2014; Somasundaram et al., 2020). Low-e coating on glass reduces UV and solar heat while maintaining visibility and reflecting long-wave infrared light, lowering SHGC and U-Value (Pawar et al., 2019; Shabunko et al., 2021).

Envelope

Indoor temperature and energy usage are heavily influenced by shading with the right glass and envelope. After testing various sizes, it was found that horizontal shade device 30 cm in length lowered energy cooling demand by 2.62–3.24% (Wong & Li, 2007). The horizontal shade mechanism lowers temperature by 0.61–0.88 °C (Al-Tamimi & Fadzil, 2012; Tzempelikos & Athienitis, 2007). Literature says that self-shading projection (SSP) reduces with a projection with a 45° self-shading angle (Kandar et al., 2019). Sustainable glazed water film (SGWF) is being investigated as a low-cost tropical alternative to selective glazing in Malaysia's hot and humid environment (Al-Tamimi & Fadzil, 2011; Huang et al., 2015; Qahtan et al., 2014).

Natural ventilation

The wind surface squeezes airflow in an above or open space to increase air pressure, while air on the lee side is not squeezed and the air pressure is reduced, speeding up air circulation to ventilate. This can improve health of occupants and temperature of building get balanced which can reduce requirement of cooling and heating cost (Siva et al., 2017). High-density polyethylene (HDPE) netting has been added to the roof to create ventilation. It is easy to get to, does not need any energy, and does not cost anything. Saving

35.7% of energy costs in tropical regions, cool roofs reduced surface temperature by 2.4 °C (Rawat & Singh, 2022).

AC Refrigerant

A prospective chiller system innovation is district cooling, which includes centrally generating chilled water and piping it to adjacent buildings (Arab et al., 2018; Chun et al., 2021). According to statistics, the district cooling system can service over 20 buildings with 1.6 million square feet of commercial floor space and save over 40% on energy use (Butters et al., 2018; Shi et al., 2021). The Singapore World Cinema Project used 143 eco-coolers to reduce temperatures by 3–8 °C while saving 80% power. In 2021, DAV-cooling was launched, which combines dew point evaporative cooling, air-carrying energy radiant air conditioning, and vacuum membrane-based dehumidification (Song et al., 2023). R290 refrigerants are ideal for cooling due to their low GWP and no ozone depletion potential (ODP) (Shaik et al., 2023). R32 systems are more energy efficient, cost effective, and single component refrigerant than R410A systems due to their 20% less refrigerant and easier recycling (Hsu et al., 2023). Hydra carbon is like hydrochlorofluorocarbon, and flammability issues can be avoided with proper design (Koh & Zakaria, 2017; Tian et al., 2015; P. Wang et al., 2023). Here are few options with zero ODP (Kasi & Cheralathan, 2023)-

- HFC- R466A- ODP = 0, GWP-733
- HFC- R32- ODP = 0, GWP-677
- HFO- R-515B- ODP = 0, GWP-299
- HC-R-170- ODP = 0, GWP-5.5

Lighting

GB rating system has a point for energy consumption to make it efficient and economical. Light-emitting diodes (LEDs) are gradually replacing traditional bulbs. High-frequency ballasts are essential in offices, classrooms, and other settings where people spend long periods of time working under fluorescent lighting (Siva et al., 2017). Building is designed from three basic factors for lighting; the first is to maximize natural lighting by installing mirror ducts, roof light tubes, window wall ration, slope of roof, orientation of building, and light shelves; the second is to use LED lamps and energy-efficient devices; and the third is to develop an intelligent lamp control system and smart sensor lighting to save over 60% on artificial lighting energy (Sun et al., 2018).

Use of renewable source of energy

Solar water heating systems are now commonly installed in homes due to their improved adaptability (Zain Ahmed et al., 2021). Industrial firms may scale up solar thermal systems using government and international agency subsidies (Ismail et al., 2015). TRNSYS simulated tropical office building solar absorption refrigeration systems cooling capability (Mat Wajid et al., 2021). Solar energy also used as refrigerators in Thailand during life cycle study results showed the system's environmental benefits and application potential (Bukoski et al., 2014; Siecker et al., 2017).

Water saving techniques

Today's water-saving appliances: anticorrosion chemicals reduce scale first and pressurization stabilizes water flow. Developers and residents must encourage smart control, metering, leak detection, measurement high-efficiency and water-saving appliances decreases water waste (Huisingh et al., 2015). It includes faucets, toilets, urinals, washing machines, showers, dishwashers, and other water-saving devices (Sizirici et al., 2021). Smart water metering systems are used to measure usage and prevent leakage, smart monitoring of distribution systems and water-efficient appliances (Geetha Varma, 2022).

Rainwater harvesting

GB gathers rainwater and employs water-efficient appliances. Downspouts transport roof rain to artificial culverts and collection pipes to pre-sedimentation and storage tanks. When precipitation exceeds the planned flow, it runs via the drainage pipe network, cofferdam, and sea. Various natural techniques, including shallow grass ditches, infiltration pavement, rain gardens, green roofs, rainwater storage ponds, and other methods, are used for storing and collecting rainwater.

Roof gardening

Roof gardens should be safe and cost-effective for usage, beautification, and environmental benefits. Above all, design and build should intelligently use the roof of main body building, platform, balcony, windowsill, parapet, and metope to wait for open woodland and produce garden art. Evaluate the building's structural limitations and opportunities for rooftop gardening (Wong et al., 2003). In the subsequent maintenance and management process, dead leaves should be handled and used locally, save water, protect the environment and attractiveness, and decrease rubbish. Green roofs reduce summer heat transfer by 80%, and it uses 2.2–16.7% less energy in summer (Ismail et al., 2018). Modular planting roof technology can reduce construction costs and promotes green cities (W. Z. W. Ismail et al., 2018). Singapore in 2017, 32,359 hectares green space 45% of the land area has ecological continuity, complex strata, and natural shapes (Akram et al., 2023; Nugroho et al., 2022).

Rating systems for green building certifications

Rating systems are a set of criteria with points with the pre-mentioned methodology and based on points, they provide certifications. The evaluation of actual energy and environmental performance is done using variety of rating techniques (Song et al., 2023). Rating systems prioritize indoor environmental quality, materials, and energy (Manna & Banerjee, 2019). In addition to points, some of which are mandatory, and some are points basis, each rating system (as mentioned in Table 1) has own criteria as well as certification requirements, comparison given here.

Use of sustainable sources of energy

Since the primary source of carbon emission pollution, energy use and energy management are seen as a crucial component of carbon management. The amount of energy used has a significant impact on resources and increases carbon pollution. In 2022, the sustainable options listed below could support sustainable growth (Rietbergen et al., 2017).

Solar panels

Solar panels are a widely used source of sustainable energy that can generate electricity by transforming light energy into electrons and positrons (Krarti & Aldubyan, 2021; Wachter et al., 2023; H. Wang et al., 2023). Solar photovoltaic (PV) modules can generate electricity, while solar thermal collectors (STCs) can generate heat. Photovoltaic thermal systems can generate both heat and electricity (Islam & Hasanuzzaman, 2020). In countries where concentrating solar power (CSP) systems are prevalent, each square meter of surface area can offset the emissions of 200–300 kg of carbon dioxide per year (Islam & Hasanuzzaman, 2020; Shahsavari & Akbari, 2018). A study conducted in Tibet found that CSP plants offer high carbon neutrality (88.8%) and renewability (86.4%) (Ye et al., 2023), making them a promising solution for carbon reduction. In 2022, China was the largest producer of solar energy, generating approximately 400,000 MW, while India ranked fifth with a production of 63,146.1 MW (International Renewable Energy Agency, 2023). CSP plants are notable for their dependable power supply and environmental benefits, including reducing carbon emissions and inducing energy savings (Ye et al., 2023).Solar panels have two types of grid systems:

(1) On-grid solar systems: These systems are connected to the utility grid and have lower upfront costs. They are simpler to maintain and reduce carbon footprint. However, they give limited control over the energy source and require a distribution panel, net metering device, and on-grid solar charger. When the sun goes down,

Table 1 Comparison of different rating systems

	BREEAM	LEED	CASBEE	Green star NZ	GRIHA
Country	UK	US	Japan	New Zealand	India
Organization	BRE	USGBC	JSBC	NZGBC	TERI
Average reduction in carbon emission	22% (Tom Taylor, 2015)	18–39% (Scofield, 2013)	~30% (Kimoto & Ikaga, n.d.)	~20% (New Zealand Green Building Council, n.d.)	35% (Rohan et al., 2016)
Factors considering	Energy, health and well-being, innovation, land use, material, management, pollution, transport, waste, water	Conserve energy and water life cycle impacts, support sustainable strategies, reduce carbon footprint, green infrastructure placement, water-embodied energy source	Conservation, local environment, recycling, CO2 sinks, housing, social services, social, industrial, and financial vitality, emission trading	management indoor environment quality energy transport water material land use and ecology emissions innovation	Site parameters, maintenance and housekeeping, energy, water, human health and comfort, social aspects, and bonus points

the utility grid powers the home or business (Aelenei & Gonçalves, 2014; Z. Chen et al., 2023).

(2) Off-grid solar systems: These systems offer energy independence, allowing homeowners to generate their own power without relying on the utility grid. They require batteries for storage, making them more expensive initially, but have battery storage for backup (Marszal et al., 2010). This system reduces carbon footprint since they do not require power from the utility grid, which may be generated from non-renewable sources (Aelenei & Gonçalves, 2014)

Wind turbine

Wind turbines are made of lightweight, durable materials like composites and fiber glass. A wind turbine converts the kinetic energy of wind into usable electricity using wind to generate energy (Krarti & Aldubyan, 2021). To generate electricity, a turbine's rotor and blades, which mimic rotors, rotate a generator. To generate electricity, a generator is turned by a turbine's propeller-shaped blade (Ahmed et al., 2022). The 8.0 MW, 164 m blade is the biggest commercially accessible wind turbine today. Nearly 4% of the world's electricity comes from wind power, which hits 539 GW by year's close and 10 to 15 megawatts (MW) is the predicted number for 2030s (Hasan & Trianni, 2020). Wind power's energy structure benefits: sustainable, environmentally friendly, and inexpensive, massive amounts of wind power incorporated into the electricity system have become an effective low-carbon strategy (Jin et al., 2021). As low-carbon techniques have arisen, and carbon emission is one of the key indicators for low-carbon power development, investigating their joint influence on carbon emission is relevant (Lv & Bai, 2021). The rise in emissions of greenhouse gasses and carbon dioxide has become a threat to human health and the sustainability of all forms of life (Magazzino et al., 2021). The relationship between CO_2 emission and wind energy consumption, coal energy consumption, total globalization, and growth is statistically significant. Wind energy consumption has a negative and significant effect on carbon emissions, with a 1% increase in wind energy use reducing carbon emissions by 0.018% (Güney & Üstündağ, 2022) Another independent variable, globalization, correlates positively with emissions of carbon dioxide. Carbon emissions rise by 0.10% for every one percentage point an indicator of globalization rises (M. Liu et al., 2020; Nguyen & Le, 2020). By the end of 2017, using wind energy had stopped at least 600 million tons and as much as 1100 million tons of CO_2 from going into the air (Yousefi et al., 2019).

Biofuels

IPCC report on renewable energy initiatives found that biomass can sustainably produce up to 300 exajoules by the middle of the century, greater than four times what is required to reach the International Energy Agency's target of 27% biofuels in transportation fuel (Fairley, 2011). Bioenergy is the process of turning biomass into energy. Biomass can be obtained from a variety of sources, including unused plant material from forests and farms (straw, forest thinning, etc.), sewage sludge from industrial facilities, and household compost and garbage. Around 3.4% of all worldwide transportation fuels are biofuels (Jeswani et al., 2020). Biomass is a potential source of renewable energy and involves the transformation of plant materials into a usable form of energy (Brandão et al., 2022). It includes a wide range of biomass types and sources, conversion technologies, end uses, and infrastructure needs (Ritu et al., 2022). Short rotation coppice (SRC), perennial grasses, and other energy crops have been particularly developed for biomass production. Before it can be converted into energy via the preferred technique, it must be gathered and processed, the biomass feedstock must be harvested or collected, transported, and sometimes even stored each time (McKendry, 2002). Biodiesels made from rapeseed, palm oil, soybeans, and spent cooking oil account for 75% of the biofuel market in the European Union. Biofuels have been crucial to the success of renewable energy, reducing carbon emissions by 589.3 million tons as of 2015 alone (Angelidaki et al., 2018). Producing biofuels from agricultural and forest leftovers or white wood chips offers financial benefits over crop production, and their net carbon footprint can be neutral or even zero (Christian, 2011; Field et al., 2020). Reduced GHG emissions from concrete through alternative binders and increased biomass fuel substitution could add 13% abatement to 2025 (Karlsson et al., 2020).

Geothermal system

Geothermal energy is a renewable energy source that harnesses the heat stored deep beneath the earth's surface to generate electricity, offering benefits for both humans and the environment. Energy generation methods that do not involve burning processes emit very little pollution (Ball, 2021). Unlike renewable energy sources, such as solar or wind, geothermal power plants do not have to shut down when bad weather rolls in. Three deep geothermal systems in the Netherlands produce 72,000 MWhth (megawatt-hours of thermal energy) annually, but if carbon intensities were calculated and geothermal heat displaced natural gas heating, they could save 13,200 t(CO_2e) Pa (Victor Van Heekeren et al., 2005). China has extensive direct-use geothermal plants with a capacity of 6089 MWth, producing 20,000

GWhth/Pa (Lund & Boyd, 2016), resulting in large emission savings from implementing deep geothermal heat systems (Lund & Toth, 2021). This means that the country that hosts these plants always has access to the electricity or other useful output they generate.

Advantages of geothermal system (GS):

- GS is environmentally beneficial.
- These systems are not dependent on fossil fuels.
- GS is inexpensive to operate.
- These are not weather dependent.

Disadvantages of geothermal systems (GS):

- The installation cost of GS is high.
- It is hard to reach consumers.
- GS can suffer surface issue like earthquake (Dincer & Ozturk, 2021).

Sustainable materials in construction

Sustainable materials emit lower carbon emission in comparison to conventional material (Attahiru et al., 2019). The building industry employs substances that produce gasses that are hazardous to the environment (Sudarsan et al., 2022). According to studies on how selecting ecologically responsible materials or goods may improve energy savings and decrease carbon emissions from energy production, energy savings due to environmental choice could be as high as 20% (Dixit et al., 2012). Materials such as, i.e., mentioned in Table 2, impact less carbon emission percentage of construction. Cement is the most essential building material; however, it emits a significant quantity of carbon during calcination which accounts for 50% of total emissions (Al-Obaidy et al., 2022; Benhelal et al., 2012). The concrete industry is also one of the greatest generators of carbon, emits roughly 5, 50, and 40% from man-made gasses, chemical processes, and fuel combustion, respectively (Zhang & Wang, 2016). Approximately 900 kg of CO_2 is emitted for every ton of cement (Ambapkar & Ravi, 2013).

Role of insulation in carbon emission

Insulation prevents heat transfer, reduces carbon emissions, and promotes sustainability. It reduces non-renewable energy use, reduces energy imports, and reduces energy use and costs, freeing up money for renewable energy and energy-efficient items. It also prolongs building life and lowers maintenance, reducing waste, resource use, and environmental impact. The insulation value of different insulating materials is expressed as an R-value (Wang et al., 2018). Thermal insulation in building exterior walls can reduce heat loss and gain in the winter, reducing costs and carbon footprint (Purnell, 2022; Yuan et al., 2016). The single components of windows do not affect the thermal insulation of buildings (Baldinelli et al., 2014), but the acoustic properties will be affected by a unique constituent (Granzotto et al., 2017). Studies suggest that the glazing size in the south facade has a significant impact on energy efficiency, which has a direct impact on energy consumption during the heating and cooling period. It is recommended to have south-facing windows enlarged to an optimal size (Kunič, 2017).

Thermal insulation materials include cork, fiberglass, mineral wool, cellulose, polyurethane, polystyrene, rice husk, crumb rubber, sheep wool, date palm, Perlite, phase change materials, and aerogels (Ijjada & Nayaka, 2022). Insulating materials such as rock wool and cellulose fiber reduce energy use and carbon emissions by 6 and 7%, respectively (Tettey et al., 2014). The variable U is used for windows and lower value makes the window better at insulating, unlike the R-value (Grazieschi et al., 2021). There are some methods used in construction, mentioned in Table 3, and each method has its own advantages and disadvantages and the best method will depend on factors such as climate, budget, and building type.

Smart building management system

Advanced artificial intelligence techniques and machine learning algorithms can use data collected from smart meters, building management systems, and weather stations to infer complex relationships between energy consumption and variables such as temperature, indoor conditions, comfort criteria, daylighting, cost, and occupancy.

Smart metering system

To find out effective ways and major source of usage measurement is necessary. A smart meter is used to make building smart because these devices can monitor, record, communicate, and optimize. The major aims of a smart grid are to reduce energy usage, especially during peak hours, unify and automate the regulation of production and demand and limit CO_2 emissions (Haider et al., 2016). A metering system works on the amount of carbon emitted per unit of resource used and then calculates total units. This gives schedule and analyze whole consumption of resources and leads to reduction in consumption (Amin et al., 2017). From the report of Department of energy, USA, the widespread implementation of wireless sensors is predicted to increase manufacturing output and energy efficiency by 10% and decrease emissions by 25% (Elkhorchani & Grayaa, 2016). Technologies used in these smart buildings are the internet of things (IoT), artificial intelligence, machine learning. IoT allows tracking and data collection to happen all the time and in real time. When IoT devices are put into use, analyzing systems can collect a

Table 2 List of sustainable material for construction sector

S/N	Materials	A brief description
1	Bamboo	Bamboo is a fast-growing, pesticide-free, water-efficient, and biodegradable plant with many advantages over other materials. Buildings with bamboo may increase its carbon sequestration and economic benefits (Shu et al., 2020). Bamboo structural and engineering solutions are energy efficient and durable, with a thin layer of protective coating made from materials such as epoxy, neem seed oil, negrolin-sand-wire, borax, or boric acid to prevent degradation (Sikder & Bera, n.d.). However, bamboo's anisotropy and performance limitations limit its use as a building element despite its sufficient structural qualities (Gatóo et al., 2014). Assembled bamboo has a 37% probability of lowering atmospheric carbon dioxide levels (Xu et al., 2022). One cubic meter of integrated bamboo components may offset 249.92 kg of carbon dioxide when all stages of production are included (Xu et al., 2022)
2	Recycled steel	Steel is a material widely used in the construction sector, but its production contributes to carbon emissions. Recycled steel offers many benefits, such as reduced energy consumption, resource conservation, waste reduction, durability, economic benefits, and versatility, making it an ideal choice for sustainable development (Qin & Kaewunruen, 2022). Recycled steel fibers (RSF) obtained from used tires have been proposed as an alternative to industrial steel fibers (ISF). Steel-fiber-reinforced concrete has long been used in structural construction because of its ability to resist cracking and provide ductility (Liew & Akbar, 2020). Using recycled steel produced from low-emission electricity is preferred for reinforcement (Karlsson et al., 2020). Mixing recycled steel fibers in concrete to control cracking and provide toughness is an environmentally friendly method that contributes to sustainable development (Centonze et al., 2016)
3	Straw bales	Straw bale construction is an inexpensive and ecologically friendly alternative to conventional building materials (Cascone et al., 2019). It provides effective insulation and can be combined with render or another dense covering to improve its performance. While there is no reliable empirical relationship between moisture content and the various approaches for monitoring it, a study has found an empirical equation that relates to moisture resistance (Lecompte & Le Duigou, 2017; Robinson et al., 2017).This makes straw bale construction suitable for use in areas where moisture resistance is required with a low GHG footprint. Additionally, researchers have found that straw insulation performs substantially better at reducing heat transfer compared to wood frame walls (Cascone et al., 2019)
4	Cross-laminated timber (CLT)	Cross-laminated timber (CLT) is a sustainable engineered wood product that has a small carbon footprint and is strong, durable, lightweight, easy to install, low GWP, and energy efficient (Younis & Dodoo, 2022). It can be used as a full-size wall or floor panel or as a linear wood element that can support loads in both the plane and orthogonal to it (Brandner et al., 2016). The unique feature of CLT is its significant size, both in-plane and in thickness, which makes it a viable and widely used independent structural element (Brandner et al., 2016).The crosswise stacking of plywood, core board, and three-layer solid wood boards reduces the rate of swelling and shrinking and provides good dimensional stability in-plane, which is an important characteristic of CLT (Flatscher et al., 2015)
5	Construction waste powder (CWP)	Reusing construction waste powder (CWP) to make cementitious materials that are good for the environment is a good way to cut down on the amount of waste made during construction. The size and number of voids in the mixed paste grew when CWP added, but the structure of the pores in the CWP-mixed paste can be improved by adding an active admixture. As the CWP replacement rate and particle size went up, so did the free chloride concentration. However, as the chloride exposure time went up, the chloride diffusion coefficient went down, and the chloride diffusion of mortar went up (Z. Ma et al., 2023)
6	Steel slag	Steel slag is a synthetic aggregate created as a waste product in the steelmaking process that has been recycled for decades in various nations throughout the world (Loureiro et al., 2022). It is being studied as a sustainable alternative to traditional waste products, and in some countries, it has almost fully replaced them as a raw material in various industries (Loureiro et al., 2022). The use of steel slag in concrete and mortar with coarse/fine aggregate/cementitious material can conserve natural resources (Baalamurugan et al., 2023). Additionally, steel slag is being explored as a potential material for CO2 storage, GHG emissions reduction, and recycling and valorization of steel industry waste (Humbert & Castro-Gomes, 2019)

Table 2 (continued)

S/N	Materials	A brief description
7	Different wall material	Different wall materials can be used in sustainable construction, including concrete, bricks, hollow bricks, and sandstone bricks. In addition, shredded wood scraps can be turned into blocks, and prefabricated concrete panels and mass wood panels and beams offer a more environmentally friendly alternative to concrete and steel, with the added benefit of reducing construction installation times by prefabricating many pieces (Greene et al., 2023). In Poland, ceramic materials such as bricks, hollow blocks, and light expanded clay aggregate concrete blocks are popular for building walls due to their low cost, low thermal conductivity, and rapid construction time
	Geopolymer concrete (GPC)	Geopolymer concrete (GPC) is a renewable resource made by mixing metakaolin with sodium silicate solution at room temperature (Assi et al., 2020; Zhao et al., 2021). It has shown performance benefits and may become a promising cementitious material. Compared to OPC, GPC can reduce carbon emissions by 30 to 80% (Assi et al., 2020; Turner & Collins, 2013; Xie et al., 2020). Previous studies have demonstrated that GPC has comparable performance to OPC, with some research highlighting material properties while others focused on structural properties (Tran et al., 2020, 2022). GPC has a compressive strength of up to 80 MPa, while mortar geopolymer has a strength of up to 108 MPa (Khan et al., 2016). Initially, GPC was generated by mixing solid gradients with activation solution. For ease of mixing, a new generation of GPC called "just add water GPC" has been created (Luukkonen et al., 2018; Sturm et al., 2016)
9	Mining waste (MW)	MW can be used as raw material and can be mixed with aggregate and clay to make bricks, roads, and building materials (Segui et al., 2023). MW used in construction after geo polymerization treatment include lead zinc (Desogus et al., 2013), tungsten (Pacheco-Torgal et al., 2007), copper (Ahmari et al., 2012). Copper (Oluwasola et al., 2015), taconite (Velasquez et al., 2009), and phosphate (Amrani et al., 2020) are examples of mining waste used in highway construction as asphalt. MW-replaced fiber-cement has lower porosity than traditional fiber-cement, making it a promising material for the manufacture of alternate building products that promote waste reduction and sustainable construction practices (Eugenio et al., 2023)
10	Supplementary cementitious material (SCM)	Fly ash, silica fume, and pulverized granulated blast furnace slag are the most common SCMs (Firdous & Singh, 2021; Luukkonen et al., 2018). Volcanic materials such as perlites, zeolites, pumices, and ashes with high amorphous silica and alumina concentrations are a natural alternative to synthetic chemical binders (Diaz-Loya et al., 2019). Materials such as glass and agricultural ashes are by-products that can be used in place of natural resources (Alanazi et al., 2019), can utilized as SCMs (Soliman & Tagnit-Hamou, 2016). The mechanical properties of concrete have also been enhanced using ash derived from rice husks, corn cobs, and wood (Saloni et al., 2020, 2021; Saloni, Parveen, Yan Lim, et al., 2021; Siddique, 2012). SCM affects cement filler early and offers chemical benefits later, but more detailed studies are needed to determine its specific response on the mechanical properties of concrete

huge amount of data to analyze, and building software can do advanced tests and find faults accurately (G. Liu et al., 2020). It monitors and analyzes carbon emission in construction. Smart water metering system monitors leakage and water consumption.

Building energy management systems (BEMS)

Building energy management systems (BEMS) are advanced systems that monitor and control energy usage within buildings, including heating, cooling, lighting, and other systems. BEMS can provide real-time data on energy consumption and allow building managers to adjust energy usage in response to changing conditions or occupancy levels. One effective way to reduce energy use is by utilizing smart lighting, which takes advantage of both natural and artificial light to illuminate a given space. BEMS can also include home appliances, power generation systems, power storage, and utilization. Using cloud computing to provide helpful software models, building managers can better monitor, measure, and optimize resources in the building (Mohamed et al., 2018). Additionally, studies have shown that dimming light bulbs can save up to 30% more energy than light bulbs that cannot be dimmed (Jitendra & Edle, 2011). To detect human presence, passive infrared sensors (PIR) are simple and cost-effective, making them an ideal choice for intelligent lighting systems (Riyanto et al., 2018). By implementing BEMS, energy management and building efficiency can save up to 715 million tons of carbon dioxide annually (Yang et al., 2022). Moreover, a consumer-dependent energy management system in micro-grid can reduce carbon impact and energy cost, whether using renewable or non-renewable

Table 3 Methods used in construction for insulation

S/No	Insulation materials	A brief description
1	Wall materials	Building walls provide structural support and some sound and heat insulation. Wall materials are costly, but they are economical in the long term. This section discusses recycled construction materials and green cement reinforcing weight-bearing wall materials (Wang et al., 2018). Palm wood particle size (0.42–0.84 mm) bio-insulation panels provide excellent thermal insulation and sound absorption (Dong et al., 2023). A thermal insulation cement is made of magnesium phosphate cement and corn stalk, and walls with this material can better regulate temperature and relative humidity, improving indoor comfort (Zhang et al., 2021). Sandstone brick walls lose some of their minimal embodied effects, because of their limited endurance (Asdrubali et al., 2023). Brick walls have the highest non-renewable energy and second highest GWP (Asdrubali et al., 2023)
2	Natural fibers for concrete reinforcement	Concrete is essential to engineering, but it requires a lot of resources despite its cost, durability, and compressive strength. Grinding slag, fly ash, silica fume, and recycled aggregates can be used to replace cement in concrete to reduce pollution. Water-retted kenaf fibers reinforced mortar composites. Natural fibers are stronger than glass fiber, yet their modulus is the same (Qin & Kaewunruen, 2022), and their density varies from 1.3 to 1.6 g/cm^3, and each fiber has a unique tensile strength and Young's modulus. As plant fiber has a lower heat conductivity than other materials, it provides superior thermal insulation (Qin & Kaewunruen, 2022), plant fiber research focuses on the mechanical and physical properties of concrete, with acid soaking and fly ash/silica fume cement modification being common methods (Wang et al., 2018)
3	Recycled waste construction materials	Most traditional construction materials are sand, wood scraps, things that have been burned, and concrete. Because of this, when bricks, wood, and concrete are used to build or tear down buildings, there is often a lot of trash left over (Qin & Kaewunruen, 2022). Construction waste includes soil and stone, industrial sludge, reservoir sludge, and nonhazardous inorganic trash. Recycling procedures vary from 15 to 90%, with wood scraps being the most recyclable. Wood is used for boards, wooden doors and windows, construction materials, furniture, flooring, and more (Liew & Akbar, 2020)
4	Wood-based panel	Reclaimed wood is a valuable material with high recycling potential. It can be used for various purposes, including building materials, furniture, flooring, and other wood-based panels (Wachter et al., 2023). Wood-based panels can be processed from reclaimed wood to reduce the use of new timber supplies. Moreover, wood constructions have lower embodied GHG emissions and life cycle primary energy than reinforced concrete and steel buildings (Duan et al., 2022). Mass wood structures have been found to have lower GWP than RC structures, despite having 23% more mass energy (Duan et al., 2022)
5	Composite material processing	Composite materials can be generated by utilizing rubber and wood scraps from building operations. This composite wood glue product is durable and has high economic value (Sudarsan et al., 2022). It can be used for various purposes, such as floor coverings, automobile components, traffic guardrails, and door and window frames. Additionally, it can be a sustainable substitute for standard paving and packaging materials
6	Electrochromic and thermochromic glass	The brightness of a room can be controlled with this glass or transparent material-based smart device that includes a substrate and dimming material. The colors fade as it reacts to different environmental conditions (such as light, electric field, and temperature). So, it can selectively absorb or reflect heat radiation from the outside environment while stopping the spread of heat inside. This helps save energy by controlling the amount of light and the temperature inside (H. Wang et al., 2018)
7	Insulation	Insulation plays a crucial role in reducing heat loss and energy consumption in buildings. The spray form of insulation is a popular option due to its high R-value and airtight seal, which makes it long-lasting, resilient, and resistant to moisture, mold, and pests (Abu-Jdayil et al., 2019). Thermal transmittance measures the steady-state heat flow across a unit surface area caused by a 1 K temperature difference and is expressed in W/m^2 K. The hot-box method is commonly used for measuring it (Asdrubali et al., 2015). There are several natural insulating options available, such as stone wool, glass wool (Hill et al., 2018), glass foam (Hill et al., 2018), perlite, vermiculite, expanded clay, aerogels, cotton, hemp, and flax (Grazieschi et al., 2021). These materials offer a better future for sustainable building insulation (Hill et al., 2018; Wang et al., 2018). Cork is another raw material that can be used for sustainable building insulation, thanks to its insulation, abrasion resistance, and durability. Instead of burning cork, natural bark panels with minimal formaldehyde emissions and enough heat conductivity can be used (Wiprächtiger et al., 2020)

energy, resulting in a reduction of approximately 7.3 and 55.7% in energy cost and carbon emissions, respectively (Haidar et al., 2018).

Automated lighting systems

Automated lighting systems use sensors and timers to control lighting usage within buildings. These systems can turn-off lights when no occupants are in the room and turn them on automatically when someone is detected by a smart occupancy sensor. The brightness can also be controlled through a smart mobile or computer. Lighting consumes ~ 17% energy of a commercial building that means lighting is one of the major sources of energy consumption (U.S. Energy Information Administration, 2023). This lighting system includes smart sensors sense about occupancy, smart architecture like network base architecture and intelligent control technique like artificial intelligence (Wagiman et al., 2020). This improves visual comfort for occupants, saves electricity by turning off lights when not in use, and reduces carbon emissions and costs. A comfortable illuminance level can be set earlier, and it also considers daylight whenever level reaches to that level, it automatically turns off the light, hence there is direct reduction in energy consumption and reduce maintenance cost by increasing life of bulb. Another advantage is a reduction of carbon emissions associated with energy production in power plants (Mahmoud, 2018). The lighting system has two strategies based on input: (1) occupancy-based input (2) illuminance-based input. Sensor will turn either on/off light or dimming (Wagiman et al., 2020). Main controller with light sensors and infrared sensors to detect lighting environment, dimming condition, delay in lighting, and control in turn-off to give low carbon and cheap cost for environmentally friendly lighting (Z. Li et al., 2020). According to the Electric Power Research Institute, using sunshine can save up to about 40% more energy (Figueiro, n.d.).

Smart thermostats

Smart thermostats use sensors and algorithms to adjust heating and cooling levels within buildings. These systems can learn occupants' behavior patterns and adjust temperature settings, accordingly reducing energy usage and improving comfort. In a study, it is found that the cumulative power is reduced when temperature of indoor and outdoor is same (Irshad et al., 2020). Heating, ventilation, and air conditioning (HVAC) uses ~ 30% of energy consumption of commercial building (U.S. Energy Information Administration, 2023). Due to global warming commercial building demand for cooling, to reduce carbon, some smart measures need to be taken like programmable smart thermostats, building automation system, IoT smart thermostats, and dedicated outside air system which are all smart techniques to optimize energy usage and reduce cost and carbon emission. The town hall of Zaanstad, Netherlands was monitored and simulated in real time using the HVAC system, and the results revealed a 14% decrease in power use (Capozzoli et al., 2017). The smart thermostat's control software may be set to automatically heat or cool a room at certain times or to monitor the air quality and keep the CO_2 concentration below a user-defined limit (Correia et al., 2022). Multiple smart thermostats can be put in the same building and communicate with the building management system, which coordinates the building's activities to meet fluctuating energy needs. The microprocessor in a smart thermostat takes readings from several sensors to determine things like the current temperature, humidity, carbon dioxide levels, and energy use (Correia et al., 2022).

Energy monitoring systems

Energy monitoring systems provide real-time data on energy consumption within buildings, allowing building owners and occupants to track usage, identify inefficiencies, and take action to reduce energy consumption. These systems can also provide alerts when energy usage exceeds certain thresholds or when energy costs are higher than expected. In Finland, energy monitoring system leads to enhance ~ 7% energy efficiency in building (Bae et al., 2014). Smart meters, smart plugs, renewable home generation, and energy storage all work together to make for energy-efficient smart buildings; together, they support demand-side load management, distributed generation, and energy storage provisions in the smart grids of the future (Zhao & Magoulès, 2012). The Annual Energy Outlook from the U.S. Energy Information Administration (EIA) says that business buildings waste about 30% of the energy they use (U.S. Energy Information Administration, 2023), there is need to monitor the energy for efficient use of resources and reduce carbon impact. While an energy management system may help cut down on expenses, carbon emissions, and energy waste, it still has certain shortcomings that might use some refinement. These include its high price tag, its complicated interface, and its limited capacity for maintenance. Therefore, it can provide smart buildings with superior energy consumption support via cutting-edge IoT and big-data analysis (Al-Ali et al., 2017).

Water management

As the global population continues to grow, so does the demand for food and water. As a result, water scarcity has become a major threat in many countries, including India. To combat this, effective water management is crucial (Gupta et al., 2017). This system monitors leakage and quantifies the amount of water supply to the main tank and then further sub tanks and pipelines. Internet of Things (IoT) and cloud computing are being used in conjunction with cutting-edge wireless technologies and machine learning to improve water management in the smart home (Gupta et al., 2017). Communication between smart homes and smart cities is enabled through the IoT, protocols, artificial intelligence, and wireless technologies. To better manage water resources, several sensors and actuators were used for automated decision-making to forecast future water use. Nanotechnology, quantum technology, and sustainable practices are only some of the other cutting-edge innovations that have been implemented (Ahad et al., 2020). Leakage is wastage of water and smart sensors like acoustic sensor (Brennan et al., 2016), ground penetrating radar (Li et al., 2022), infrared thermography and electromagnetic sensors are used for leakage detection. Pressure sensors are used for pressure management, flow meter used for flow management, pH sensor used for water quality monitoring, smart meters for internal leakage. Data from smart meters may be used to develop water use prediction systems. The use of smart meters will result in enhanced service standards, more trustworthy data, and less need for human intervention in data gathering processes (Amaxilatis et al., 2020). With the additional data provided by a smart meter, water distribution system losses, also known as "post-meter leakages," may be reduced through better forecasting of demand and the identification of leaks. It raises people's consciousness about how much water they use (Gupta et al., 2020; Mounce et al., 2007).

Carbon quantification for promoting sustainable development

Carbon footprint is the total amount of greenhouse gasses (including carbon dioxide and methane) that are generated by our lifestyle and actions. Its overview analysis measures the amount of potential impact our daily life has on the environment. By reducing the amount of greenhouse gases produced by our lifestyle, we can decrease our carbon footprint and contribute to slowing climate change on Earth. Additionally, we can identify sustainability patterns by examining per capita carbon emissions in $MtCO_2$ for different countries and their underlying causes. The average carbon footprint for a person in the Qatar is 35.6 metric tons, one of the highest rates in the world. Today, the world's top three emitters—China, the United States, and India—account for around 50% of global CO_2 emissions, and the world's top 20 emitters account for 80%. A per capita view offers an important perspective on the global CO_2 challenge. It shows that developed countries along with some high-income oil-producing developing countries have the highest emissions per capita. Almost all are above the global average. Although the developed countries have demonstrated a downward trend in per capita emissions, they remain well above those of developing countries—and the difference is stark.

Globally, the average carbon footprint is closer to 4 tons.

Calculating carbon emission is a requirement for sustainability analysis and optimization (Xiang et al., 2023). If carbon is measured at each stage, it is possible to determine which sources are primarily responsible for emissions and then focus efforts and resources on those sources rather than the minor ones. It can also help identify inefficiencies in resource use and highlight opportunities for optimization. This leads to greater efficiency and more accurate results. Quantification will reveal how much of a reduction is achieved through which measure and will aid in locating areas where emissions can be reduced, and sustainable practices can be implemented. This method looks at both the product's direct and indirect carbon emissions from many operations and activities (Carrasco-Amador et al., 2022). This paper gives methods for calculating carbon and approach is in two ways:

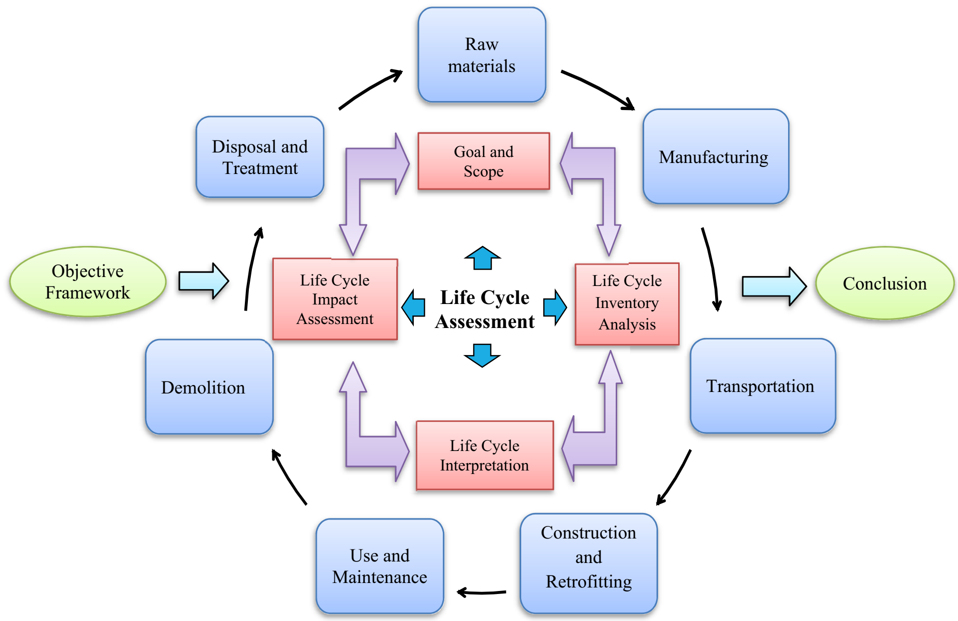
(1) Carbon emission in production and manufacturing—The building industry's impact on the environment may be quantified using embodied carbon by figuring out how much greenhouse gas is released during raw material extraction, production, during transportation, building process, repair and maintenance, and construction of materials (Jayasinghe et al., 2022).
(2) Carbon emission during product or operation of building—The amount of carbon emitted during operating a building like in lighting, heating, ventilation, air conditioning, water system, elevator, electric equipments.

There are tools also available for analyzing like building information modeling (BIM), Ecotect, carbonnetwork, one clicks LCA, etc. (Solís-Guzmán et al., 2020). Carbon quantification can help organizations demonstrate their commitment to sustainability and corporate social responsibility and provide valuable information for policymakers when developing climate change policies and regulations. By understanding the carbon footprint of different sectors and activities, policymakers can design policies that encourage sustainable practices and reduce emissions.

Life cycle assessment (LCA)

Life cycle assessment (LCA) is a valuable method for calculating the carbon footprint of construction supplies and equipment over their entire lifespan, including

Fig. 3 Life Cycle Assessment



manufacturing, transportation, construction, and operation stages (Fig. 3). LCA is widely used by industries and corporations to evaluate the environmental impact of products or processes based on cost, performance, and data (Hellweg & Milà i Canals, 2014). It can be carried out in different phases, such as cradle-to-grave, gate-to-gate, or cradle-to-disposal, and can help identify supply chain "hotspots" for improvement and compare interventions based on several sustainability objectives (Takacs & Borrion, 2020). An LCA typically consists of four stages: the establishment of goals and parameters, the compilation of a list of relevant processes and materials, the impact assessment, and interpretation (Hussien et al., 2023). This tool is useful for policy formulation, decision-making, monitoring technology environmental performance, and choosing the greenest product or process (Kemper, 2015; Valencia-Barba et al., 2023).

There are four components for analysis of LCA.

Goal and scope

The goal of life cycle assessment (LCA) is to evaluate the environmental impact of buildings throughout their entire life cycle, from raw material extraction and processing to construction, use, maintenance, and disposal or recycling at the end of its useful life (R. Chen et al., 2023). The scope of an LCA study defines the criteria and assumptions that characterize the system under consideration. This includes defining the functional unit, system boundaries, and effect categories to be analyzed (Brandão et al., 2022).

Life cycle inventory (LCI)

The life cycle assessment (LCA) approach relies on the life cycle inventory (LCI) to identify the environmental impacts of a product or system over its entire life cycle (Bisinella et al., 2021). LCI is used to measure the environmental effects of a structure at every stage of its existence, including raw materials, energy use, carbon emissions, waste, and water consumption. This information is used to evaluate a building's environmental performance and identify areas for improvement (Bisinella et al., 2021). Understanding the building's architecture, materials, and systems, as well as local climatic and operating conditions, is crucial for creating an accurate LCI (Bisinella et al., 2021). LCI data are essential for reducing the environmental impact of products and systems, improving design decisions, and identifying areas for improvement (Bisinella et al., 2021).

Impact assessment

The impact assessment (IA) phase of life cycle assessment (LCA) involves applying recognized methodologies and models to evaluate the environmental implications of emissions (Bisinella et al., 2021). Each impact is assigned a weight based on its potential harm to the environment or human health, with some impacts, such as carbon emissions, being weighted more heavily than others (Bisinella et al., 2021). Carbon quantification in LCA involves using standardized emission factors for materials manufacturing, transportation, construction, usage, and disposal to determine the carbon footprint at each step of the building's life cycle (Bisinella et al., 2021). Direct emissions from on-site fossil fuel combustion and indirect emissions from the production of building materials and energy used in the building's operation must both be considered for an accurate quantification of the building's carbon footprint. Using this data to guide design, material, and operational decisions, the environmental impact of the building can be reduced (Bisinella et al., 2021).

Interpretation

The interpretation stage of the LCA process involves drawing conclusions regarding the environmental impact of a product or service based on the results of the LCI and LCIA. Comparing the effects of each step in the product's life cycle can help pinpoint the most environmentally damaging points. It is essential to understand the uncertainties and limitations of the findings to ensure that they are trustworthy and can be used as a basis for making decisions. The interpretation stage also involves presenting the findings in an accessible way and identifying areas for improvement to reduce the product's environmental impact (Kemper, 2015).

Carbon quantification is a crucial part of LCA, providing a full picture of a building's greenhouse gas emissions. Standardized emission factors for materials manufacturing, transportation, construction, usage, and disposal are used to determine the carbon footprint at each step of the building's life cycle (Bisinella et al., 2021). Direct and indirect emissions must both be considered to obtain an accurate quantification of the building's carbon footprint. Architects, engineers, and building owners can benefit from using LCA to evaluate a project's environmental impact (Liu, 2019; Ma et al., 2022). LCA can also be useful for environmental policy support, strategic decision-making, product comparisons, quality development, and eco-labeling, among other things (Wang et al., 2022).

GRIHA Carbon Decarbonizing Program

An indigenous grading system called GRIHA (Green ratings for Integrated Habitat Assessment) assesses a building's environmental performance and its effect on global warming. It started its initiative toward carbon–neutral structures. The aim of this program is to quantify carbon emission and implement strategies for higher carbon emitting sources and reduce carbon in future. Assessment of carbon in this program would consider parameters like, water efficiency, energy efficiency, waste management, transportation, lifestyle, social activities. Project carbon emissions and carbon sequestration strategies would be evaluated. Certification scale of this program is 0 to 2, zero is carbon neutral and 2 is super carbon negative (Ramirez-Corredores et al., 2023). As part of the GRIHA grading system, the GRIHA Decarbonizing Program endeavors to quantify carbon emissions from buildings. By encouraging more eco-friendly and low-energy construction methods, the program hopes to cut down on greenhouse gas emissions.

Carbon assessment, carbon reduction strategy, and carbon–neutral building are the three stages of the program. In the first stage, referred to as the "Carbon Footprint Assessment," the total amount of carbon dioxide equivalents released by the structure is calculated. All emissions from the building's construction, use, and eventual demolition are factored in. International standards like ISO 14064 serve as the basis for the assessment's standardized approach. In the second stage, titled "Carbon Reduction Strategy," a strategy is formulated to lower the building's carbon footprint. Energy-saving features like LED bulbs, heat pumps, and foam insulation are all part of the plan. It also incorporates eco-friendly power sources like solar and wind. The plan is based on a cost–benefit analysis and is tailored to the building's unique requirements. Carbon neutral construction is the third and final step, and it entails using carbon credits or other offset methods to cancel out any leftover carbon emissions. This guarantees that the structure generates no more greenhouse gasses than it consumes. There are several upsides to implementing the GRIHA Decarbonizing Program. It is useful for lowering a building's carbon footprint, a key factor in global warming. It also encourages energy efficiency, which is great for the wallet and the comfort of the residents. Furthermore, it encourages alternative energy sources, thereby decreasing demand for fossil fuels (Francis & Thomas, 2023). To sum up, the GRIHA Decarbonizing Program is a crucial program for advancing green building and cutting down on carbon emissions. The software gives a thorough structure for determining how much carbon a building emits and how to cut that number. It is a big deal for fighting climate change and making the future more sustainable (Shrivastava, 2023).

Carbon calculator

Another option to make the building sector more sustainable is to properly quantify the effect of existing technology. Using a quantitative method, the carbon emission was determined by multiplying the volume of the substance by its emission coefficient. The information required to determine the material amounts was obtained from building plans, bills of quantities, and technical specifications (O'Hegarty & Kinnane, 2022). The carbon footprint coefficient approach calculates embodied carbon. Construction projects measure CO_2. Two techniques calculate carbon. Users manually type each item or substance into a sheet, and the application calculates a carbon emission factor. Another method automatically allocates emissions to quantity inventory or modeling data set (Jackson, 2020).

Carbon emission coefficient method for calculation

Let for material (x)

O_2embodied = carbon emission coefficient(x) $*$ mass of material(x)

To calculate embodied carbon for the life cycle modules under consideration, the quantity of material is multiplied by a carbon factor as follows: embodied carbon = material quantity (kg) × carbon factor (kgCO_2e/kg). The mass of construction material and the carbon emission coefficient of the substance (measured in kgCO_2/kg and in kg). The study's findings are expressed as embodied carbon per square meter of building's gross floor space (kgCO_2/m^2) (O'Hegarty & Kinnane, 2022).

Carbon capture and storage

Carbon capture and storage (CCS), a method that prevents CO_2 emissions (emits from different sources) from entering the atmosphere, is essential for reducing global warming caused by CO_2 emissions in a timely way (Xu et al., 2021). The International Energy Agency estimates that carbon capture systems yearly absorb 30 million tons of CO_2 and 90% of those 30 million tons are recovered from the oil and gas sectors, which generate streams of high-density CO_2 (Liyanage et al., 2021). CCS may reduce CO_2 emissions by around 90% and it is the primary approach for reducing CO_2 emissions from conventional power plants (Alaux et al., 2023). Although CCS is effective in reducing climate change, it has varying degrees of detrimental consequences on other environmental variables and increases energy costs by 15–45% (Alaux et al., 2023). The GHG emissions from the power plant are reduced by 40–80% (Wu et al., 2022). It entails a few procedures, mostly broken down into the three steps of capture, transit, and storage (Wang et al., 2022). One of the methods is chemical absorption, which commonly uses an amine-based solution as the absorption solvent, is one of the most established and widely used methods for separating CO_2. Low-temperature distillation, adsorption, and membrane separation are further approaches for separation (Wu et al., 2022). Depending on where the storage facility is located, the correct transportation option can be chosen after the CO_2 has been caught and compressed (Prabu & Geeta, 2015). For long-distance CO_2 transport, pipeline transmission is usually the most efficient option. The two most common methods for safely storing carbon dioxide are geological storage and marine storage (Alaux et al., 2023). The manufacturing, transportation, usage, maintenance, and end of life of the product are all included in the life cycle of the product, as well as the extraction, processing, and transportation of raw materials (Mandova et al., 2019). CCS has the potential to greatly lessen the carbon footprint intensity; however, it is met with public hostility and has a low carbon storage capacity (Ding et al., 2020). The captured CO_2 can be buried CCS, preventing it from reentering the atmosphere (Pour et al., 2018). Capturing 6 billion metric tons of carbon dioxide per year by 2050 is projected to help bring the world average temperature down by 2 °C (Islam & Hasanuzzaman, 2020). Carbon sinking refers to the practice of reducing atmospheric concentrations of carbon dioxide by means of reforestation, replanting of native flora, and other means. Carbon sinks include both land-based and marine facilities. Forest carbon sinks, farmland carbon sinks, and so on are all examples of terrestrial carbon sinks. Forests may act as carbon sinks, which can have monetary value and help speed up the process of achieving carbon emissions reduction goals (Li et al., 2020). Furthermore, ocean carbon sinks play an indispensable role in lowering the concentration of GHG in the atmosphere (Wu et al., 2022). To store CO_2 on a large scale, it has been shown that carbonization of concrete transforms it into a suitable carbon sink by transforming minerals rich in calcium or magnesium into stable carbonates (Lippiatt et al., 2020).

Greenhouse Gas Protocol and its Role

These are internationally accepted rules and guidelines for government, organizations, and researchers to quantify carbon emission: like product life cycle standard, GHG protocols for cities, project protocol, mitigation goal standard, etc. Many tools are developed by protocol to reduce carbon emissions. Cross sector tool is developed to calculate carbon and available in beta version, country-specific tool is different for every country, sector-specific tool designed for every sector (Ranganathan et al., 1998). This standard offers an important accounting policy option that greatly influences firms' reported emissions by allowing them to utilize alternative consolidation approaches: the equity share, operational control, and financial control approach (EFRAG PTF-ESRS, 2022). GHG protocol is a management approach that is consistent with the standards set by the International Organization for Standardization (ISO) and the IPCC's approach to quantifying climate change. The World Business Council for Sustainable Development and the World Resources Institute created it. The GHG protocol incorporates computations using component-specific emission factors. Greenhouse gas emissions are determined using established emission factors (Sotos, 2015). The emission factor is a numerical representation of the total GHG emissions from a specific point source. To quantify the emission, the tool's formula and emission factor were coded into each spreadsheet, presenting, ultimately, the scope emission and its condensation. The global warming potential (GWP) of each GHG is considered in the tool's model for converting emissions from different sources into a common unit of CO2 equivalent (CO_2eq).

Step 1: Define the boundaries.

The first step in carbon measurement for a building is to establish its limits. The construction site, envelope, and infrastructure all make up these limits. The limits also encompass emissions produced throughout the building's design, construction, operation, and eventual demolition.

Step 2: Collect data.

The next thing to do is to keep track of how much energy the building uses and how much greenhouse gas it emits. Billing information, fuel use, and greenhouse gas emissions from the building systems are all included.

Step 3: Calculate emissions.

Third, the building's greenhouse gas emissions must be estimated. The GHG protocol's emission factors are used to determine the total emissions. The energy consumption and fuel type utilized by the building systems are the foundations for the emission factors.

Step 4: Report emissions.

The final stage is to submit a report detailing the structure's greenhouse gas output. Tons of carbon dioxide equivalent are used to measure emissions. (tCO_2e).

Conclusion

The construction sector is a significant contributor to global greenhouse gas emissions, accounting for nearly 30–40% of energy-related CO_2 emissions. As such, achieving sustainable development in this sector is crucial to meet global climate targets and mitigate the effects of climate change. In this review paper, we have examined the current state of knowledge and literature available on sustainable development in the construction sector with a focus on carbon emission reduction and its quantification. We have highlighted various energy-efficient technologies, renewable energy sources, and passive design strategies that can help achieve sustainable development. However, we have also identified challenges in quantifying carbon emissions, including data availability, quality, and consistency.

Therefore, to achieve sustainable development in the construction sector, a holistic and interdisciplinary approach is required, with a focus on carbon emission reduction. Stakeholder collaboration, including governments, businesses, and civil society, is necessary to develop and implement effective carbon emission reduction policies and strategies. Additionally, investment in renewable energy infrastructure and technologies, along with policy support to incentivize cleaner energy sources, is crucial.

Based on our review, we have identified the following findings and recommendations:

Findings:

- Carbon emission reduction is fundamental to achieving sustainable development in the construction sector.
- Carbon quantification is important to reduce carbon emissions in the construction sector.
- Energy-efficient technologies, renewable energy sources, and passive design strategies are effective in reducing building energy consumption and achieving sustainable development.
- The use of low-carbon materials, low-GWP AC refrigerants, building insulation, and thermochromic windows can help to reduce carbon emissions and save energy.
- Smart sensors and building management systems can be utilized to monitor and measure carbon emissions.
- Certification programs such as LEED and GRIHA can help construction projects meet sustainability goals.
- Life cycle assessment (LCA), carbon capture and storage, the GRIHA Decarbonizing Program, and the greenhouse gas protocol are recommended methods for quantifying carbon emissions.
- Challenges in quantifying carbon emissions include data availability, quality, and consistency.
- Decarbonizing hard-to-electrify sectors like steel, cement, and chemicals, as well as the energy sector, are significant challenges that require ongoing research and development, policy support, and investment in renewable energy infrastructure and technologies.

Recommendations:

- Stakeholder collaboration is necessary to achieve sustainable development in the construction sector. Governments, businesses, and civil society must work together to develop and implement effective carbon emission reduction policies and strategies.
- Further research and development is required to address challenges and capitalize on trends in the field of sustainable development in the construction sector.
- To achieve sustainable development, a holistic and interdisciplinary approach is needed, with a focus on carbon emission reduction.
- To effectively reduce carbon emissions in the construction sector, there is a need for an international carbon measurement standard that can also provide certification.
- Priority should be given to the sources that emit the most carbon, to save resources from sources that emit negligible carbon.
- Investment in renewable energy infrastructure and technologies, along with policy support to incentivize cleaner energy sources, is necessary to achieve sustainable development.
- It is important to promote sustainable business, government, and personal practices to reduce carbon footprints.

- There is a need to decarbonize hard-to-electrify sectors like steel, cement, and chemicals, as well as the energy sector, to achieve significant carbon reduction.

In conclusion, achieving sustainable development through carbon emission reduction and its quantification is a complex and multifaceted task that requires significant investment and policy support. However, with a willingness to innovate and adapt to new technologies and strategies, we can create a just and equitable transition to a low-carbon future and achieve sustainable development in the construction sector.

Author contributions Neha Singh wrote the main manuscript text. Dr. R. L. Sharma reviewed the paper. Kundan Yadav reviewed, composed, and formatted the paper. All authors reviewed the manuscript.

Funding We acknowledge the financial support provided by Lovely Professional University for conducting and developing this review paper. The funding has facilitated the gathering of relevant data, analysis, and the synthesis of information to present a comprehensive overview of current methods and best practices in the field of carbon emission reduction for sustainable development. We express our gratitude to Lovely Professional University for their support, which has enabled us to contribute to the scientific literature in this important area of study.

Declarations

Conflict of interest Neha Singh (PhD Student), Dr. R. L. Sharma (Professor), and Kundan Yadav (M. Tech Student) affirm their adherence to ethical standards. No conflicts of interest exist, and the review was conducted objectively, free from external influences. All sources and permissions have been appropriately cited.

References

Abu-Jdayil, B., Mourad, A.-H., Hittini, W., Hassan, M., & Hameedi, S. (2019). Traditional, state-of-the-art and renewable thermal building insulation materials: An overview. *Construction and Building Materials, 214*, 709–735. https://doi.org/10.1016/j.conbuildmat.2019.04.102

Adebayo, T. S., Ullah, S., Kartal, M. T., Ali, K., Pata, U. K., & Ağa, M. (2023). Endorsing sustainable development in BRICS: The role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. *Science of the Total Environment, 859*, 160181. https://doi.org/10.1016/j.scitotenv.2022.160181

Aelenei, L., & Gonçalves, H. (2014). From solar building design to net zero energy buildings: Performance insights of an office building. *Energy Procedia, 48*, 1236–1243. https://doi.org/10.1016/j.egypro.2014.02.140

Ahad, M. A., Paiva, S., Tripathi, G., & Feroz, N. (2020). Enabling technologies and sustainable smart cities. *Sustainable Cities and Society, 61*, 102301. https://doi.org/10.1016/j.scs.2020.102301

Ahmari, S., Chen, R., & Zhang, L. (2012). Utilization of mine tailings as road base material. *GeoCongress, 2012*, 3654–3661. https://doi.org/10.1061/9780784412121.374

Ahmed, A., Ge, T., Peng, J., Yan, W.-C., Tee, B. T., & You, S. (2022). Assessment of the renewable energy generation towards net-zero energy buildings: A review. *Energy and Buildings, 256*, 111755. https://doi.org/10.1016/j.enbuild.2021.111755

Akram, M. W., Hasannuzaman, M., Cuce, E., & Cuce, P. M. (2023). Global technological advancement and challenges of glazed window, facade system and vertical greenery-based energy savings in buildings: A comprehensive review. *Energy and Built Environment, 4*(2), 206–226. https://doi.org/10.1016/j.enbenv.2021.11.003

Al-Ali, A. R., Zualkernan, I. A., Rashid, M., Gupta, R., & Alikarar, M. (2017). A smart home energy management system using IoT and big data analytics approach. *IEEE Transactions on Consumer Electronics, 63*(4), 426–434. https://doi.org/10.1109/TCE.2017.015014

Alanazi, H., Hu, J., & Kim, Y.-R. (2019). Effect of slag, silica fume, and metakaolin on properties and performance of alkali-activated fly ash cured at ambient temperature. *Construction and Building Materials, 197*, 747–756. https://doi.org/10.1016/j.conbuildmat.2018.11.172

Alaux, N., Ruschi Mendes Saade, M., Hoxha, E., Truger, B., & Passer, A. (2023). Future trends in materials manufacturing for low carbon building stocks: A prospective macro-scale analysis at the provincial level. *Journal of Cleaner Production, 382*, 135278. https://doi.org/10.1016/j.jclepro.2022.135278

Al-Obaidy, M., Courard, L., & Attia, S. (2022). A parametric approach to optimizing building construction systems and carbon footprint: A case study inspired by circularity principles. *Sustainability, 14*, 3370. https://doi.org/10.3390/su14063370

Al-Tamimi, N. A., & Fadzil, S. F. S. (2011). The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics. *Procedia Engineering, 21*, 273–282. https://doi.org/10.1016/j.proeng.2011.11.2015

Al-Tamimi, N., & Fadzil, S. F. S. (2012). Energy-efficient envelope design for high-rise residential buildings in Malaysia. *Architectural Science Review, 55*(2), 119–127. https://doi.org/10.1080/00038628.2012.667938

Amaxilatis, D., Chatzigiannakis, I., Tselios, C., Tsironis, N., Niakas, N., & Papadogeorgos, S. (2020). A smart water metering deployment based on the fog computing paradigm. *Applied Sciences, 10*(6), 1965. https://doi.org/10.3390/app10061965

Ambapkar, R. V, & Ravi, K. (2013). Energy retrofitting: The technique to reduce carbon emission. *International Journal of Science and Research*, *5*, 2014–2017.

Amin, U., Hossain, M. J., Lu, J., & Fernandez, E. (2017). Performance analysis of an experimental smart building: Expectations and outcomes. *Energy, 135*, 740–753. https://doi.org/10.1016/j.energy.2017.06.149

Amrani, M., El Haloui, Y., Hajikarimi, P., Sehaqui, H., Hakkou, R., Barbachi, M., & Taha, Y. (2020). Feasibility of using phosphate wastes for enhancing high-temperature rheological characteristics of asphalt binder. *Journal of Material Cycles and Waste Management, 22*(5), 1407–1417. https://doi.org/10.1007/s10163-020-01026-1

Angelidaki, I., Treu, L., Tsapekos, P., Luo, G., Campanaro, S., Wenzel, H., & Kougias, P. G. (2018). Biogas upgrading and utilization: Current status and perspectives. *Biotechnology Advances, 36*(2), 452–466. https://doi.org/10.1016/j.biotechadv.2018.01.011

Arab, Y., Hassan, A. S., & Qanaa, B. (2018). *Comparative study on shading performance between traditional and neo-minimalist style apartment in Malaysia*. http://TuEngr.com.

Asdrubali, F., D'Alessandro, F., & Schiavoni, S. (2015). A review of unconventional sustainable building insulation materials. *Sustainable Materials and Technologies, 4*, 1–17. https://doi.org/10.1016/j.susmat.2015.05.002

Asdrubali, F., Grazieschi, G., Roncone, M., Thiebat, F., & Carbonaro, C. (2023). Sustainability of building materials: Embodied energy and embodied carbon of masonry. *Energies, 16*(4), 1846. https://doi.org/10.3390/en16041846

Assi, L. N., Carter, K., Deaver, E., & Ziehl, P. (2020). Review of availability of source materials for geopolymer/sustainable concrete. *Journal of Cleaner Production, 263*, 121477. https://doi.org/10.1016/j.jclepro.2020.121477

Attahiru, Y. B., Aziz, M. M. A., Kassim, K. A., Shahid, S., Wan Abu Bakar, W. A., NSashruddin, T. F., Rahman, F. A., & Ahamed, M. I. (2019). A review on green economy and development of green roads and highways using carbon neutral materials. *Renewable and Sustainable Energy Reviews, 101*, 600–613. https://doi.org/10.1016/j.rser.2018.11.036

Baalamurugan, J., Kumar, V. G., Padmapriya, R., & Raja, V. K. B. (2023). Recent applications of steel slag in construction industry. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02894-3

Bae, M., Kim, H., Kim, E., Chung, A. Y., Kim, H., & Roh, J. H. (2014). Toward electricity retail competition: Survey and case study on technical infrastructure for advanced electricity market system. *Applied Energy, 133*, 252–273. https://doi.org/10.1016/j.apenergy.2014.07.044

Baldinelli, G., Asdrubali, F., Baldassarri, C., Bianchi, F., D'Alessandro, F., Schiavoni, S., & Basilicata, C. (2014). Energy and environmental performance optimization of a wooden window: A holistic approach. *Energy and Buildings, 79*, 114–131. https://doi.org/10.1016/j.enbuild.2014.05.010

Ball, P. J. (2021). A review of geothermal technologies and their role in reducing greenhouse gas emissions in the USA. *Journal of Energy Resources Technology, 143*(1), 010903. https://doi.org/10.1115/1.4048187

Benhelal, E., Zahedi, G., & Hashim, H. (2012). A novel design for green and economical cement manufacturing. *Journal of Cleaner Production, 22*(1), 60–66. https://doi.org/10.1016/j.jclepro.2011.09.019

Bisinella, V., Christensen, T. H., & Astrup, T. F. (2021). Future scenarios and life cycle assessment: Systematic review and recommendations. *The International Journal of Life Cycle Assessment, 26*(11), 2143–2170. https://doi.org/10.1007/s11367-021-01954-6

Bisinella, V., Hulgaard, T., Riber, C., Damgaard, A., & Christensen, T. H. (2021). Environmental assessment of carbon capture and storage (CCS) as a post-treatment technology in waste incineration. *Waste Management, 128*, 99–113. https://doi.org/10.1016/j.wasman.2021.04.046

Brandão, M., Heijungs, R., & Cowie, A. L. (2022). On quantifying sources of uncertainty in the carbon footprint of biofuels: Crop/feedstock, LCA modelling approach, land-use change, and GHG metrics. *Biofuel Research Journal, 9*(2), 1608–1616. https://doi.org/10.18331/BRJ2022.9.2.2

Brandner, R., Flatscher, G., Ringhofer, A., Schickhofer, G., & Thiel, A. (2016). Cross laminated timber (CLT): Overview and development. *European Journal of Wood and Wood Products, 74*(3), 331–351. https://doi.org/10.1007/s00107-015-0999-5

Brennan, M. J., Kroll de Lima, F., de Almeida, F. C. L., Joseph, P. F., & Paschoalini, A. T. (2016). A virtual pipe rig for testing acoustic leak detection correlators: Proof of concept. *Applied Acoustics, 102*, 137–145. https://doi.org/10.1016/j.apacoust.2015.09.015

Bretado de los Rios, M. S., Rivera-Solorio, C. I., & Nigam, K. D. P. (2021). An overview of sustainability of heat exchangers and solar thermal applications with nanofluids: A review. *Renewable and Sustainable Energy Reviews, 142*, 110855. https://doi.org/10.1016/j.rser.2021.110855

Bruntland, G. H. (1987). Our common future. *The World Commission on Environment 1 and Development*, 45–65. https://cir.nii.ac.jp/crid/1573668925548842624.

Bukoski, J., Gheewala, S. H., Mui, A., Smead, M., & Chirarattananon, S. (2014). The life cycle assessment of a solar-assisted absorption chilling system in Bangkok, Thailand. *Energy and Buildings, 72*, 150–156. https://doi.org/10.1016/j.enbuild.2013.12.034

Butters, C., Nordin, A., & Khai, D. T. H. (2018). District cooling: A key solution for hot climate cities. *Designing cooler cities* (pp. 151–171). Singapore: Springer.

Capozzoli, A., Piscitelli, M. S., Gorrino, A., Ballarini, I., & Corrado, V. (2017). Data analytics for occupancy pattern learning to reduce the energy consumption of HVAC systems in office buildings. *Sustainable Cities and Society, 35*, 191–208. https://doi.org/10.1016/j.scs.2017.07.016

Carrasco-Amador, J. P., Canito-Lobo, J. L., Castaño-Liberal, A., Rodríguez-Rego, J. M., & Matamoros-Pacheco, M. (2022). Actions to reduce carbon footprint in materials to healthcare buildings. *Heliyon, 8*(11), e11281. https://doi.org/10.1016/j.heliyon.2022.e11281

Cascone, S., Rapisarda, R., & Cascone, D. (2019). Physical properties of straw bales as a construction material: A review. *Sustainability, 11*(12), 3388. https://doi.org/10.3390/su11123388

Centonze, G., Leone, M., Micelli, F., Colonna, D., & Aiello, M. A. (2016). Concrete reinforced with recycled steel fibers from end of life tires: Mix-design and application. *Key Engineering Materials, 711*, 224–231. https://doi.org/10.4028/www.scientific.net/KEM.711.224

Chastas, P., Theodosiou, T., Kontoleon, K. J., & Bikas, D. (2018). Normalising and assessing carbon emissions in the building sector: A review on the embodied CO_2 emissions of residential buildings. *Building and Environment, 130*, 212–226. https://doi.org/10.1016/j.buildenv.2017.12.032

Chel, A., & Kaushik, G. (2018). Renewable energy technologies for sustainable development of energy efficient building. *Alexandria Engineering Journal, 57*(2), 655–669. https://doi.org/10.1016/j.aej.2017.02.027

Chen, C., Habert, G., Bouzidi, Y., & Jullien, A. (2010). Environmental impact of cement production: Detail of the different processes and cement plant variability evaluation. *Journal of Cleaner Production, 18*(5), 478–485. https://doi.org/10.1016/j.jclepro.2009.12.014

Chen, R., Tsay, Y.-S., & Zhang, T. (2023). A multi-objective optimization strategy for building carbon emission from the whole life cycle perspective. *Energy, 262*, 125373. https://doi.org/10.1016/j.energy.2022.125373

Chen, Z., Yiliang, X., Hongxia, Z., Yujie, G., & Xiongwen, Z. (2023). Optimal design and performance assessment for a solar powered electricity, heating and hydrogen integrated energy system. *Energy, 262*, 125453. https://doi.org/10.1016/j.energy.2022.125453

Cheng, J., Yi, J., Dai, S., & Xiong, Y. (2019). Can low-carbon city construction facilitate green growth? Evidence from China's pilot low-carbon city initiative. *Journal of Cleaner Production, 231*, 1158–1170. https://doi.org/10.1016/j.jclepro.2019.05.327

Christian, P. (2011). 2 - Polymer chemistry. In L. A. Bosworth & S. Downes (Eds.), *Electrospinning for tissue regeneration* (pp. 34–50). Sawston: Woodhead Publishing.

Chun, L., Gong, G., Peng, P., Wan, Y., Chua, K. J., Fang, X., & Li, W. (2021). Research on thermodynamic performance of a novel building cooling system integrating dew point evaporative cooling, air-carrying energy radiant air conditioning and vacuum membrane-based dehumidification (DAV-cooling system). *Energy Conversion and Management, 245*, 114551. https://doi.org/10.1016/j.enconman.2021.114551

Correia, A., Ferreira, L. M., Coimbra, P., Moura, P., & de Almeida, A. T. (2022). Smart thermostats for a campus microgrid: Demand control and improving air quality. *Energies, 15*(4), 1359. https://doi.org/10.3390/en15041359

Desogus, P., Manca, P. P., Orrù, G., & Zucca, A. (2013). Stabilization–solidification treatment of mine tailings using Portland cement, potassium dihydrogen phosphate and ferric chloride hexahydrate. *Minerals Engineering, 45*, 47–54. https://doi.org/10.1016/j.mineng.2013.01.003

Diaz-Loya, I., Juenger, M., Seraj, S., & Minkara, R. (2019). Extending supplementary cementitious material resources: Reclaimed and remediated fly ash and natural pozzolans. *Cement and Concrete Composites, 101*, 44–51. https://doi.org/10.1016/j.cemconcomp.2017.06.011

Dincer, I., & Ozturk, M. (2021). Basic geothermal energy systems. *Geothermal energy systems* (pp. 137–217). Amsterdam: Elsevier.

Ding, H., Zheng, H., Liang, X., & Ren, L. (2020). Getting ready for carbon capture and storage in the iron and steel sector in China: Assessing the value of capture readiness. *Journal of Cleaner Production, 244*, 118953. https://doi.org/10.1016/j.jclepro.2019.118953

Dixit, M. K., Fernández-Solís, J. L., Lavy, S., & Culp, C. H. (2012). Need for an embodied energy measurement protocol for buildings: A review paper. *Renewable and Sustainable Energy Reviews, 16*(6), 3730–3743. https://doi.org/10.1016/j.rser.2012.03.021

Dong, Y., Kong, J., Mousavi, S., Rismanchi, B., & Yap, P.-S. (2023). Wall insulation materials in different climate zones: A review on challenges and opportunities of available alternatives. *Thermo, 3*(1), 38–65. https://doi.org/10.3390/thermo3010003

Duan, Z., Huang, Q., & Zhang, Q. (2022). Life cycle assessment of mass timber construction: A review. *Building and Environment, 221*, 109320. https://doi.org/10.1016/j.buildenv.2022.109320

EFRAG PTF-ESRS. (2022). *Exposure Draft: ESRS E1 Climate Change*. 44. https://www.efrag.org/Assets/Download?assetUrl=%2Fsites%2Fwebpublishing%2FSiteAssets%2FED_ESRS_E1.pdf&AspxAutoDetectCookieSupport=1.

Elkhorchani, H., & Grayaa, K. (2016). Novel home energy management system using wireless communication technologies for carbon emission reduction within a smart grid. *Journal of Cleaner Production, 135*, 950–962. https://doi.org/10.1016/j.jclepro.2016.06.179

Eugenio, T. M. C., Narciso, C. R. P., Fagundes, J. F., Henriques, A. B., & Mendes, R. F. (2023). Study on the use of mining waste as raw material for extruded fiber cement production. *Journal of Building Engineering, 63*, 105547. https://doi.org/10.1016/j.jobe.2022.105547

Fairley, P. (2011). Introduction: Next generation biofuels. *Nature, 474*(7352), S2–S5. https://doi.org/10.1038/474S02a

Field, J. L., Richard, T. L., Smithwick, E. A. H., Cai, H., Laser, M. S., LeBauer, D. S., Long, S. P., Paustian, K., Qin, Z., Sheehan, J. J., Smith, P., Wang, M. Q., & Lynd, L. R. (2020). Robust paths to net greenhouse gas mitigation and negative emissions via advanced biofuels. *Proceedings of the National Academy of Sciences of United States of America, 117*(36), 21968–21977. https://doi.org/10.1073/pnas.1920877117

Figueiro, M. G. (n.d.). *Daylight and productivity-A field study*.

Firdous, M., & Singh, B. (2021). Supplementary cementitious materials in concrete and associated structural and environmental benefits: A review. *IOP Conference Series: Earth and Environmental Science, 889*(1), 012077. https://doi.org/10.1088/1755-1315/889/1/012077

Flatscher, G., Bratulic, K., & Schickhofer, G. (2015). Experimental tests on cross-laminated timber joints and walls. *Proceedings of the Institution of Civil Engineers - Structures and Buildings, 168*(11), 868–877. https://doi.org/10.1680/stbu.13.00085

Francis, A., & Thomas, A. (2023). Sustainability assessment and benchmarking framework for buildings using a system dynamics modeling and simulation approach. *Journal of Computing in Civil Engineering*. https://doi.org/10.1061/JCCEE5.CPENG-5146

Gatóo, A., Sharma, B., Bock, M., Mulligan, H., & Ramage, M. H. (2014). Sustainable structures: Bamboo standards and building codes. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability, 167*(5), 189–196. https://doi.org/10.1680/ensu.14.00009

Geethavarma, V. (2022). Water-efficient technologies for sustainable development. *Urban water crisis and management. Strategies for sustainable development* (pp. 101–128). Amsterdam: Elsevier.

GhaffarianHoseini, A., Dahlan, N. D., Berardi, U., GhaffarianHoseini, A., Makaremi, N., & GhaffarianHoseini, M. (2013). Sustainable energy performances of green buildings: A review of current theories, implementations and challenges. *Renewable and Sustainable Energy Reviews, 25*, 1–17. https://doi.org/10.1016/j.rser.2013.01.010

Granzotto, N., Bettarello, F., Ferluga, A., Marsich, L., Schmid, C., Fausti, P., & Caniato, M. (2017). Energy and acoustic performances of windows and their correlation. *Energy and Buildings, 136*, 189–198. https://doi.org/10.1016/j.enbuild.2016.12.024

Grazieschi, G., Asdrubali, F., & Thomas, G. (2021). Embodied energy and carbon of building insulating materials: A critical review. *Cleaner Environmental Systems, 2*, 100032. https://doi.org/10.1016/j.cesys.2021.100032

Greene, J. M., Hosanna, H. R., Willson, B., & Quinn, J. C. (2023). Whole life embodied emissions and net-zero emissions potential for a mid-rise office building constructed with mass timber. *Sustainable Materials and Technologies, 35*, e00528. https://doi.org/10.1016/j.susmat.2022.e00528

Güney, T., & Üstündağ, E. (2022). Wind energy and CO_2 emissions: AMG estimations for selected countries. *Environmental Science and Pollution Research, 29*(15), 21303–21313. https://doi.org/10.1007/s11356-021-17382-w

Gupta, P., Singh, D., Purwar, A., & Patel, M. (2017). *Automated learning based water management and healthcare system using cloud computing and IoT* (pp. 457–470). Doi: https://doi.org/10.1007/978-981-10-5427-3_48

Gupta, A. D., Pandey, P., Feijóo, A., Yaseen, Z. M., & Bokde, N. D. (2020). Smart water technology for efficient water resource management: A review. *Energies, 13*(23), 6268. https://doi.org/10.3390/en13236268

Haidar, N., Attia, M., Senouci, S.-M., Aglzim, E.-H., Kribeche, A., & Asus, Z. B. (2018). New consumer-dependent energy management system to reduce cost and carbon impact in smart buildings. *Sustainable Cities and Society, 39*, 740–750. https://doi.org/10.1016/j.scs.2017.11.033

Haider, H. T., See, O. H., & Elmenreich, W. (2016). A review of residential demand response of smart grid. *Renewable and Sustainable Energy Reviews, 59*, 166–178. https://doi.org/10.1016/j.rser.2016.01.016

Hao, J. L., Cheng, B., Lu, W., Xu, J., Wang, J., Bu, W., & Guo, Z. (2020). Carbon emission reduction in prefabrication construction during materialization stage: A BIM-based life-cycle assessment approach. *Science of the Total Environment, 723*, 137870. https://doi.org/10.1016/j.scitotenv.2020.137870

Hasan, A. S. M. M., & Trianni, A. (2020). A review of energy management assessment models for industrial energy efficiency. *Energies, 13*(21), 5713. https://doi.org/10.3390/en13215713

Hellweg, S., & Milà i Canals, L. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. *Science, 344*(6188), 1109–1113. https://doi.org/10.1126/science.1248361

Hien, W. N., Liping, W., Chandra, A. N., Pandey, A. R., & Xiaolin, W. (2005). Effects of double glazed facade on energy consumption, thermal comfort and condensation for a typical office building in Singapore. *Energy and Buildings, 37*(6), 563–572. https://doi.org/10.1016/j.enbuild.2004.08.004

Higgins, P. (2013). From sustainable development to carbon control: Urban transformation in Hong Kong and London. *Journal of Cleaner Production, 50*, 56–67. https://doi.org/10.1016/j.jclepro.2012.11.025

Hill, C., Norton, A., & Dibdiakova, J. (2018). A comparison of the environmental impacts of different categories of insulation materials. *Energy and Buildings, 162*, 12–20. https://doi.org/10.1016/j.enbuild.2017.12.009

Hsu, C.-Y., Chien, L.-H., & Chang, J.-C. (2023). Experimental study of falling film evaporation of refrigerants, R32, R1234yf, R410A, R452B and R454B on horizontal tubes. *International Journal of Heat and Mass Transfer, 205*, 123914. https://doi.org/10.1016/j.ijheatmasstransfer.2023.123914

Huang, H., Ng, M., Wu, Y., & Kong, L. (2015). Solvothermal synthesis of Sb:SnO_2 nanoparticles and IR shielding coating for smart window. *Materials & Design, 88*, 384–389. https://doi.org/10.1016/j.matdes.2015.09.013

Huisingh, D., Zhang, Z., Moore, J. C., Qiao, Q., & Li, Q. (2015). Recent advances in carbon emissions reduction: Policies, technologies, monitoring, assessment and modeling. *Journal of Cleaner Production, 103*, 1–12. https://doi.org/10.1016/j.jclepro.2015.04.098

Humbert, P. S., & Castro-Gomes, J. (2019). CO2 activated steel slag-based materials: A review. *Journal of Cleaner Production, 208*, 448–457. https://doi.org/10.1016/j.jclepro.2018.10.058

Hussien, A., Abdeen Saleem, A., Mushtaha, E., Jannat, N., Al-Shammaa, A., Bin Ali, S., Assi, S., & Al-Jumeily, D. (2023). A statistical analysis of life cycle assessment for buildings and buildings' refurbishment research. *Ain Shams Engineering Journal, 14*, 102143. https://doi.org/10.1016/j.asej.2023.102143

IEA. (2021). CO_2 Emissions. *Global Energy Review 2021*. https://www.iea.org/reports/global-energy-review-2021/co2-emissions.

Ijjada, N., & Nayaka, R. R. (2022). Review on properties of some thermal insulating materials providing more comfort in the building. *Materials Today: Proceedings, 58*, 1354–1359. https://doi.org/10.1016/j.matpr.2022.02.230

International Renewable Energy Agency. (2023). Technologies. https://www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Technologies.

Irshad, K., Almalawi, A., Khan, A. I., Alam, M. M., Zahir, Md. H., & Ali, A. (2020). An IoT-based thermoelectric air management framework for smart building applications: A case study for tropical climate. *Sustainability, 12*(4), 1564. https://doi.org/10.3390/su12041564

Islam, M. M., & Hasanuzzaman, M. (2020). Introduction to energy and sustainable development. *Energy for sustainable development* (pp. 1–18). Amsterdam: Elsevier.

Ismail, A. M., Ramirez-Iniguez, R., Asif, M., Munir, A. B., & Muhammad-Sukki, F. (2015). Progress of solar photovoltaic in ASEAN countries: A review. *Renewable and Sustainable Energy Reviews, 48*, 399–412. https://doi.org/10.1016/j.rser.2015.04.010

Ismail, W. Z. W., Abdullah, M. N., Hashim, H., & Rani, W. S. W. (2018). An overview of green roof development in Malaysia and a way forward. *AIP Conference Proceedings*. https://doi.org/10.1063/1.5055460

Jackson, D. J. (2020). Addressing the challenges of reducing greenhouse gas emissions in the construction industry: a multi-perspective approach.

Jafary Nasab, T., Monavari, S. M., Jozi, S. A., & Majedi, H. (2020). Assessment of carbon footprint in the construction phase of high-rise constructions in Tehran. *International Journal of Environmental Science and Technology, 17*(6), 3153–3164. https://doi.org/10.1007/s13762-019-02557-3

Janssens, A., Rebollar, J. V., Himpe, E., & Delghust, M. (2017). Transforming social housing neighbourhoods into sustainable carbon neutral districts. *Energy Procedia, 132*, 549–554. https://doi.org/10.1016/j.egypro.2017.09.732

Jayasinghe, A., Orr, J., Hawkins, W., Ibell, T., & Boshoff, W. P. (2022). Comparing different strategies of minimising embodied carbon in concrete floors. *Journal of Cleaner Production, 345*, 131177. https://doi.org/10.1016/j.jclepro.2022.131177

Jeswani, H. K., Chilvers, A., & Azapagic, A. (2020). Environmental sustainability of biofuels: A review. *Proceedings of the Royal Society a: Mathematical, Physical and Engineering Sciences, 476*(2243), 20200351. https://doi.org/10.1098/rspa.2020.0351

Jin, J., Zhang, X., Xu, L., Wen, Q., & Guo, X. (2021). Impacts of carbon trading and wind power integration on carbon emission in the power dispatching process. *Energy Reports, 7*, 3887–3897. https://doi.org/10.1016/j.egyr.2021.06.077

Jitendra, M., & Edle, J. (2011). Intelligent illumination system to prevail over possible diseases due to over-and under-illumination. *International Journal of Enterprise Computing and Business System, 1*, 1–15.

Kandar, M. Z., Nimlyat, P. S., Abdullahi, M. G., & Dodo, Y. A. (2019). Influence of inclined wall self-shading strategy on office building heat gain and energy performance in hot humid climate of Malaysia. *Heliyon, 5*(7), e02077. https://doi.org/10.1016/j.heliyon.2019.e02077

Karlsson, I., Rootzén, J., & Johnsson, F. (2020). Reaching net-zero carbon emissions in construction supply chains – Analysis of a Swedish road construction project. *Renewable and Sustainable Energy Reviews, 120*, 109651. https://doi.org/10.1016/j.rser.2019.109651

Kasi, P., & Cheralathan, M. (2023). Performance analysis of cascade refrigeration system with alternative refrigerants to reduce carbon emission. *Journal of Thermal Analysis and Calorimetry, 148*(10), 4389–4399. https://doi.org/10.1007/s10973-023-11989-6

Kemper, J. (2015). Biomass and carbon dioxide capture and storage: A review. *International Journal of Greenhouse Gas Control, 40*, 401–430. https://doi.org/10.1016/j.ijggc.2015.06.012

Khan, M. Z. N., Shaikh, F., & uddin A., Hao, Y., & Hao, H. (2016). Synthesis of high strength ambient cured geopolymer composite by using low calcium fly ash. *Construction and Building Materials, 125*, 809–820. https://doi.org/10.1016/j.conbuildmat.2016.08.097

Kimoto, K., & Ikaga, T. (n.d.). *Development of Life Cycle CO_2 Database for CASBEE-New Construction and Assessment of Honeycomb Tube High-rise Building*. Retrieved from https://www.irbnet.de/daten/iconda/CIB17261.pdf.

Koh, J. H., & Zakaria, Z. (2017). Hydrocarbons as refrigerants—A review. *ASEAN Journal on Science and Technology for Development, 34*(1), 35. https://doi.org/10.29037/ajstd.73

Krarti, M., & Aldubyan, M. (2021). Role of energy efficiency and distributed renewable energy in designing carbon neutral residential buildings and communities: Case study of Saudi Arabia. *Energy and Buildings, 250*, 111309. https://doi.org/10.1016/j.enbuild.2021.111309

Kubota, T., & Zakaria, M. A. (2019). Full-scale experiment on energy-saving effects of thermal insulation for urban houses in Malaysia. *IOP Conference Series: Earth and Environmental Science, 294*(1), 012089. https://doi.org/10.1088/1755-1315/294/1/012089

Kunič, R. (2017). Carbon footprint of thermal insulation materials in building envelopes. *Energy Efficiency, 10*(6), 1511–1528. https://doi.org/10.1007/s12053-017-9536-1

Lecompte, T., & Le Duigou, A. (2017). Mechanics of straw bales for building applications. *Journal of Building Engineering, 9*, 84–90. https://doi.org/10.1016/j.jobe.2016.12.001

Lee, J., Tae, S., & Kim, R. (2018). A study on the analysis of CO_2 emissions of apartment housing in the construction process. *Sustainability, 10*(2), 365. https://doi.org/10.3390/su10020365

Li, D., Bae, J. H., & Rishi, M. (2023). Sustainable Development and SDG-7 in Sub-Saharan Africa: Balancing energy access, economic growth, and carbon emissions. *The European Journal of Development Research, 35*(1), 112–137. https://doi.org/10.1057/s41287-021-00502-0

Li, D. H. W., Yang, L., & Lam, J. C. (2013). Zero energy buildings and sustainable development implications – A review. *Energy, 54*, 1–10. https://doi.org/10.1016/j.energy.2013.01.070

Li, Y., Chen, X., Wang, X., Xu, Y., & Chen, P.-H. (2017). A review of studies on green building assessment methods by comparative analysis. *Energy and Buildings, 146*, 152–159. https://doi.org/10.1016/j.enbuild.2017.04.076

Li, Y., Liu, C., Yue, G., Gao, Q., & Du, Y. (2022). Deep learning-based pavement subsurface distress detection via ground penetrating radar data. *Automation in Construction, 142*, 104516. https://doi.org/10.1016/j.autcon.2022.104516

Li, Z., Chen, Y., Zhang, Q., & Li, Y. (2020). Spatial patterns of vegetation carbon sinks and sources under water constraint in Central Asia. *Journal of Hydrology, 590*, 125355. https://doi.org/10.1016/j.jhydrol.2020.125355

Li, Z., Li, J., Li, X., Yang, Y., Xiao, J., & Xu, B. (2020). Design of office intelligent lighting system based on Arduino. *Procedia Computer Science, 166*, 134–138. https://doi.org/10.1016/j.procs.2020.02.035

Liew, K. M., & Akbar, A. (2020). The recent progress of recycled steel fiber reinforced concrete. *Construction and Building Materials, 232*, 117232. https://doi.org/10.1016/j.conbuildmat.2019.117232

Lippiatt, N., Ling, T.-C., & Pan, S.-Y. (2020). Towards carbon-neutral construction materials: Carbonation of cement-based materials and the future perspective. *Journal of Building Engineering, 28*, 101062. https://doi.org/10.1016/j.jobe.2019.101062

Liu, G., Chen, R., Xu, P., Fu, Y., Mao, C., & Hong, J. (2020). Real-time carbon emission monitoring in prefabricated construction. *Automation in Construction, 110*, 102945. https://doi.org/10.1016/j.autcon.2019.102945

Liu, H.-Y. (2019). Building a dwelling that remains carbon-neutral over its lifetime – A case study in Kinmen. *Journal of Cleaner Production, 208*, 522–529. https://doi.org/10.1016/j.jclepro.2018.10.101

Liu, M., Ren, X., Cheng, C., & Wang, Z. (2020). The role of globalization in CO_2 emissions: A semi-parametric panel data analysis for G7. *Science of the Total Environment, 718*, 137379. https://doi.org/10.1016/j.scitotenv.2020.137379

Liu, Z., Li, P., Wang, F., Osmani, M., & Demian, P. (2022). Building information modeling (BIM) driven carbon emission reduction research: A 14-year bibliometric analysis. *International Journal of Environmental Research and Public Health, 19*(19), 12820. https://doi.org/10.3390/ijerph191912820

Liyanage, D. R., Hewage, K., Karunathilake, H., Chhipi-Shrestha, G., & Sadiq, R. (2021). Carbon capture systems for building-level heating systems—A socio-economic and environmental evaluation. *Sustainability, 13*(19), 10681. https://doi.org/10.3390/su131910681

Loureiro, C. D. A., Moura, C. F. N., Rodrigues, M., Martinho, F. C. G., Silva, H. M. R. D., & Oliveira, J. R. M. (2022). Steel slag and recycled concrete aggregates: Replacing quarries to supply sustainable materials for the asphalt paving industry. *Sustainability, 14*(9), 5022. https://doi.org/10.3390/su14095022

Lund, J. W., & Boyd, T. L. (2016). Direct utilization of geothermal energy 2015 worldwide review. *Geothermics, 60*, 66–93. https://doi.org/10.1016/j.geothermics.2015.11.004

Lund, J. W., & Toth, A. N. (2021). Direct utilization of geothermal energy 2020 worldwide review. *Geothermics, 90*, 101915. https://doi.org/10.1016/j.geothermics.2020.101915

Luukkonen, T., Abdollahnejad, Z., Yliniemi, J., Kinnunen, P., & Illikainen, M. (2018). One-part alkali-activated materials: A review. *Cement and Concrete Research, 103*, 21–34. https://doi.org/10.1016/j.cemconres.2017.10.001

Lv, M., & Bai, M. (2021). Evaluation of China's carbon emission trading policy from corporate innovation. *Finance Research Letters, 39*, 101565. https://doi.org/10.1016/j.frl.2020.101565

Ma, W., Hao, J. L., Zhang, C., Di Sarno, L., & Mannis, A. (2022). Evaluating carbon emissions of China's waste management strategies for building refurbishment projects: Contributing to a circular economy. *Environmental Science and Pollution Research, 30*(4), 8657–8671. https://doi.org/10.1007/s11356-021-18188-6

Ma, Z., Hu, R., Shen, J., Wang, C., & Wu, H. (2023). Chloride diffusion and binding capacity of sustainable cementitious materials with construction waste powder as cement replacement. *Construction and Building Materials, 368*, 130352. https://doi.org/10.1016/j.conbuildmat.2023.130352

Magazzino, C., Mele, M., & Schneider, N. (2021). A machine learning approach on the relationship among solar and wind energy production, coal consumption, GDP, and CO_2 emissions. *Renewable Energy, 167*, 99–115. https://doi.org/10.1016/j.renene.2020.11.050

Mahasenan, N., Smith, S., & Humphreys, K. (2003). The cement industry and global climate change current and potential future cement industry CO_2 emissions. In: *Greenhouse gas control technologies - 6th International Conference* (pp. 995–1000). Amsterdam: Elsevier.

Mahmoud, M. M. A. S. (2018). Typical economic model for calculating the saving norm of replacement HPS street lighting by LED fixtures in access road of gas production company at GCC. In: *2018 5th International Conference on Electrical and Electronic Engineering (ICEEE)*, 189–192. https://doi.org/10.1109/ICEEE2.2018.8391327

Mandova, H., Patrizio, P., Leduc, S., Kjärstad, J., Wang, C., Wetterlund, E., Kraxner, F., & Gale, W. (2019). Achieving carbon-neutral iron and steelmaking in Europe through the deployment of bioenergy with carbon capture and storage. *Journal of Cleaner Production, 218*, 118–129. https://doi.org/10.1016/j.jclepro.2019.01.247

Manna, D., & Banerjee, S. (2019). A review on green building movement in India. *International Journal of Scientific & Technology Research, 8*, 1980–1986.

Marszal, A. J., Bourrelle, J., Musall, E., Heiselberg, P., Gustavsen, A., & Voss, K. (2010). Net zero energy buildings - calculation methodologies versus national building codes. In: *Proceedings of the EuroSun 2010 Conference*, 1–8. https://doi.org/10.18086/eurosun.2010.06.14

Mat Wajid, N., Zainal Abidin, A. M., Hakemzadeh, M., Jarimi, H., Fazlizan, A., Fauzan, M. F., Ibrahim, A., Al-Waeli, A. H. A., & Sopian, K. (2021). Solar adsorption air conditioning system – Recent advances and its potential for cooling an office building in tropical climate. *Case Studies in Thermal Engineering, 27*, 101275. https://doi.org/10.1016/j.csite.2021.101275

McKendry, P. (2002). Energy production from biomass (part 2): Conversion technologies. *Bioresource Technology, 83*(1), 47–54. https://doi.org/10.1016/S0960-8524(01)00119-5

Mikulčić, H., Baleta, J., Zhang, Z., & Klemeš, J. J. (2023). Sustainable development of energy, water and environmental systems in the changing world. *Journal of Cleaner Production, 390*, 135945. https://doi.org/10.1016/j.jclepro.2023.135945

Mithun, B. M., & Narasimhan, M. C. (2016). Performance of alkali activated slag concrete mixes incorporating copper slag as fine aggregate. *Journal of Cleaner Production, 112*, 837–844. https://doi.org/10.1016/j.jclepro.2015.06.026

Mohamed, N., Al-Jaroodi, J., & Lazarova-Molnar, S. (2018). Energy cloud: Services for smart buildings. *Sustainable cloud and energy services* (pp. 117–134). Cham: Springer.

Mostafavi, F., Tahsildoost, M., & Zomorodian, Z. (2021). Energy efficiency and carbon emission in high-rise buildings: A review (2005–2020). *Building and Environment, 206*, 108329. https://doi.org/10.1016/j.buildenv.2021.108329

Mounce, S., Boxall, J., & Machell, J. (2007). An artificial neural network/fuzzy logic system for DMA flow meter data analysis providing burst identification and size estimation. In: Proc. Water Management Challenges in Global Change.

Nag, B., & Parikh, J. (2000). Indicators of carbon emission intensity from commercial energy use in India. *Energy Economics, 22*(4), 441–461. https://doi.org/10.1016/S0140-9883(99)00032-8

New Zealand Green Building Council. (n.d.). *Green Star*. Retrieved from https://www.nzgbc.org.nz/greenstar.

Nugroho, N. Y., Triyadi, S., & Wonorahardjo, S. (2022). Effect of high-rise buildings on the surrounding thermal environment. *Building and Environment, 207*, 108393. https://doi.org/10.1016/j.buildenv.2021.108393

O'Hegarty, R., & Kinnane, O. (2022). Whole life carbon quantification of the built environment: Case study Ireland. *Building and Environment, 226*, 109730. https://doi.org/10.1016/j.buildenv.2022.109730

Oluwasola, E., Hainin, M. R., Aziz, Md. M. A., & Singh, S. (2015). Effect of aging on the resilient modulus of stone mastic asphalt incorporating electric arc furnace steel slag and copper mine tailings. In: InCIEC (pp. 1199–1208). https://doi.org/10.1007/978-981-287-290-6_106

Oluwasola, E., Hainin, M. R., Aziz, M. M. A., & Aziz, A. (2015). Evaluation of rutting potential and skid resistance of hot mix asphalt incorporating electric arc furnace steel slag and copper mine tailing. *Indian Journal of Engineering and Materials Sciences, 22*, 550–558.

Onososen, A., Musonda, I., & Tjebane, M. M. (2022). Drivers of BIM-based life cycle sustainability assessment of buildings: An interpretive structural modelling approach. *Sustainability, 14*(17), 11052. https://doi.org/10.3390/su141711052

Pacheco-Torgal, F., Castro-Gomes, J., & Jalali, S. (2007). Investigations about the effect of aggregates on strength and microstructure of geopolymeric mine waste mud binders. *Cement and Concrete Research, 37*(6), 933–941. https://doi.org/10.1016/j.cemconres.2007.02.006

Pawar, P., Boranian, A., & Lang, W. (2019). Impact of solar insulation film on the cooling load of an office building in Singapore - A simulation study. *Journal of Physics: Conference Series, 1343*(1), 012120. https://doi.org/10.1088/1742-6596/1343/1/012120

Peng, R., Liu, T., & Cao, G. (2023). Valuating multifunctionality of land use for sustainable development: Framework, method, and application. *Land, 12*(1), 222. https://doi.org/10.3390/land12010222

Permpituck, S., & Namprakai, P. (2012). The energy consumption performance of roof lawn gardens in Thailand. *Renewable Energy, 40*(1), 98–103. https://doi.org/10.1016/j.renene.2011.09.023

Pham, T. M., Chen, W., Elchalakani, M., Karrech, A., & Hao, H. (2020). Experimental investigation on lightweight rubberized concrete beams strengthened with BFRP sheets subjected to impact loads. *Engineering Structures, 205*, 110095. https://doi.org/10.1016/j.engstruct.2019.110095

Pham, T. M., Elchalakani, M., Hao, H., Lai, J., Ameduri, S., & Tran, T. M. (2019). Durability characteristics of lightweight rubberized concrete. *Construction and Building Materials, 224*, 584–599. https://doi.org/10.1016/j.conbuildmat.2019.07.048

Pour, N., Webley, P. A., & Cook, P. J. (2018). Potential for using municipal solid waste as a resource for bioenergy with carbon capture and storage (BECCS). *International Journal of Greenhouse Gas Control, 68*, 1–15. https://doi.org/10.1016/j.ijggc.2017.11.007

Prabu, V., & Geeta, K. (2015). CO_2 enhanced in-situ oxy-coal gasification based carbon-neutral conventional power generating systems. *Energy, 84*, 672–683. https://doi.org/10.1016/j.energy.2015.03.029

Purnell, P. J. (2022). A comparison of different methods of identifying publications related to the United Nations Sustainable Development Goals: Case study of SDG 13—Climate Action. *Quantitative Science Studies, 3*(4), 976–1002. https://doi.org/10.1162/qss_a_00215

Qahtan, A., Rao, S. P., & Keumala, N. (2014). The effectiveness of the sustainable flowing water film in improving the solar-optical properties of glazing in the tropics. *Energy and Buildings, 77*, 247–255. https://doi.org/10.1016/j.enbuild.2014.03.051

Qin, X., & Kaewunruen, S. (2022). Environment-friendly recycled steel fibre reinforced concrete. *Construction and Building Materials, 327*, 126967. https://doi.org/10.1016/j.conbuildmat.2022.126967

Raihan, A. (2023). Innovation and Green Development Toward sustainable and green development in Chile: Dynamic influences of carbon emission reduction variables. *Innovation and Green Development, 2*(2), 100038. https://doi.org/10.1016/j.igd.2023.100038

Ramirez-Corredores, M. M., Goldwasser, M. R., de Sousa, F., & Aguiar, E. (2023). Sustainable circularity. *Decarbonization as a route towards sustainable circularity* (pp. 103–125). Cham: Springer.

Ranganathan, J., Corbier, L., Schmitz, S., Oren, K., Dawson, B., Spannagle, M., Bp, M. M., Boileau, P., Canada, E., Frederick, R., Vanderborght, B., Thomson, H. F., Kitamura, K., Woo, C. M., Naseem, P., Miner, R., Pricewaterhousecoopers, L. S., Koch, J., Bhattacharjee, S.… Camobreco, V. (1998). *The Greenhouse Gas Protocol*. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

Rawat, M., & Singh, R. N. (2022). A study on the comparative review of cool roof thermal performance in various regions. *Energy and Built Environment, 3*(3), 327–347. https://doi.org/10.1016/j.enbenv.2021.03.001

Rhodes, C. J. (2016). The 2015 Paris Climate Change Conference: Cop21. *Science Progress, 99*(1), 97–104. https://doi.org/10.3184/003685016X14528569315192

Rietbergen, M. G., Opstelten, I. J., & Blok, K. (2017). Improving energy and carbon management in construction and civil engineering companies—evaluating the impacts of the CO_2 Performance Ladder. *Energy Efficiency, 10*(1), 55–79. https://doi.org/10.1007/s12053-016-9436-9

Ritu, J. R., Khan, S., Ambati, R. R., & Gokare Aswathanarayana, R. (2022). Biofuels an option for reducing ecological footprint. *Biofuels in circular economy* (pp. 89–101). Singapore: Springer.

Riyanto, I., Margatama, L., Hakim, H., Martini, & Hindarto, D. (2018). Motion sensor application on building lighting installation for energy saving and carbon reduction joint crediting mechanism. *Applied System Innovation, 1*(3), 23. https://doi.org/10.3390/asi1030023

Robinson, J., Aoun, H. K., & Davison, M. (2017). Determining moisture levels in straw bale construction. *Procedia Engineering, 171*, 1526–1534. https://doi.org/10.1016/j.proeng.2017.01.390

Rohan, M., Nalawade, V., & Sonar, S. G. (2016). Comparative review criteria utilization by LEED and GRIHA: Green building rating systems for new construction in India. *International Journal of Scientific and Research Publications, 6*(10), 116.

Saloni, Parveen, Lim, Y. Y., Pham, T. M., & Kumar, J. (2021). Sustainable alkali activated concrete with fly ash and waste marble aggregates: Strength and durability studies. *Construction and Building Materials, 283*, 122795. https://doi.org/10.1016/j.conbuildmat.2021.122795

Saloni, Parveen, & Pham, T. M. (2020). Enhanced properties of high-silica rice husk ash-based geopolymer paste by incorporating basalt fibers. *Construction and Building Materials, 245*, 118422. https://doi.org/10.1016/j.conbuildmat.2020.118422

Saloni, Parveen, Pham, T. M., Lim, Y. Y., Pradhan, S. S., Jatin, & Kumar, J. (2021). Performance of rice husk ash-based sustainable geopolymer concrete with ultra-fine slag and corn cob ash. *Construction and Building Materials, 279*, 122526. https://doi.org/10.1016/j.conbuildmat.2021.122526

Saloni, Parveen, Yan Lim, Y., & Pham, T. M. (2021). Influence of Portland cement on performance of fine rice husk ash geopolymer concrete: Strength and permeability properties. *Construction and Building Materials, 300*, 124321. https://doi.org/10.1016/j.conbuildmat.2021.124321

Sangkakool, T., Techato, K., Zaman, R., & Brudermann, T. (2018). Prospects of green roofs in urban Thailand – A multi-criteria decision analysis. *Journal of Cleaner Production, 196*, 400–410. https://doi.org/10.1016/j.jclepro.2018.06.060

Schiavoni, S., D'Alessandro, F., Bianchi, F., & Asdrubali, F. (2016). Insulation materials for the building sector: A review and comparative analysis. *Renewable and Sustainable Energy Reviews, 62*, 988–1011. https://doi.org/10.1016/j.rser.2016.05.045

Scofield, J. H. (2013). Efficacy of LEED-certification in reducing energy consumption and greenhouse gas emission for large New York City office buildings. *Energy and Buildings, 67*, 517–524. https://doi.org/10.1016/j.enbuild.2013.08.032

Scrivener, K. L., & Kirkpatrick, R. J. (2008). Innovation in use and research on cementitious material. *Cement and Concrete Research, 38*(2), 128–136. https://doi.org/10.1016/j.cemconres.2007.09.025

Segui, P., Safhi el Mahdi, A., Amrani, M., & Benzaazoua, M. (2023). Mining wastes as road construction material: A review. *Minerals, 13*(1), 90. https://doi.org/10.3390/min13010090

Shabunko, V., Badrinarayanan, S., & Pillai, D. S. (2021). Evaluation of in-situ thermal transmittance of innovative building integrated photovoltaic modules: Application to thermal performance assessment for green mark certification in the tropics. *Energy, 235*, 121316. https://doi.org/10.1016/j.energy.2021.121316

Shahsavari, A., & Akbari, M. (2018). Potential of solar energy in developing countries for reducing energy-related emissions. *Renewable and Sustainable Energy Reviews, 90*, 275–291. https://doi.org/10.1016/j.rser.2018.03.065

Shaik, S. V., Gorantla, K., Shaik, S., Afzal, A., Rajhi, A. A., & Cuce, E. (2023). Experimental and theoretical examination of the energy performance and CO_2 emissions of room air conditioners utilizing natural refrigerant R290 as a substitute for R22. *Journal of Thermal Analysis and Calorimetry*. https://doi.org/10.1007/s10973-022-11888-2

Sharma, A. K., Nigrawal, A., & Baredar, P. (2021). Sustainable development by constructing green buildings in India: A review. *Materials Today: Proceedings, 46*, 5329–5332. https://doi.org/10.1016/j.matpr.2020.08.788

Shekarchian, M., Moghavvemi, M., Rismanchi, B., Mahlia, T. M. I., & Olofsson, T. (2012). The cost benefit analysis and potential emission reduction evaluation of applying wall insulation for buildings in Malaysia. *Renewable and Sustainable Energy Reviews, 16*(7), 4708–4718. https://doi.org/10.1016/j.rser.2012.04.045

Shi, Z., Fonseca, J. A., & Schlueter, A. (2021). Floor area density and land uses for efficient district cooling systems in high-density cities. *Sustainable Cities and Society, 65*, 102601. https://doi.org/10.1016/j.scs.2020.102601

Shrivastava, M. (2023). *Dilemmas in dealing with climate change in India*. Shakti Sustainable Energy Foundation: New Delhi.

Shu, B., Xiao, Z., Hong, L., Zhang, S., Li, C., Fu, N., & Lu, X. (2020). Review on the application of bamboo-based materials in construction engineering. *Journal of Renewable Materials, 8*(10), 1215–1242. https://doi.org/10.32604/jrm.2020.011263

Siddique, R. (2012). Utilization of wood ash in concrete manufacturing. *Resources, Conservation and Recycling, 67*, 27–33. https://doi.org/10.1016/j.resconrec.2012.07.004

Siecker, J., Kusakana, K., & Numbi, B. P. (2017). A review of solar photovoltaic systems cooling technologies. *Renewable and Sustainable Energy Reviews, 79*, 192–203. https://doi.org/10.1016/j.rser.2017.05.053

Sikder, A., & Bera, D. (n.d.). Bamboo as a green building material in construction industry-a review Sustainable Material View project Enhancing the properties of cement concrete composites by adding nano material by replacing some percentages of cement. View project. https://www.researchgate.net/publication/367051393.

Siva, V., Hoppe, T., & Jain, M. (2017). Green buildings in Singapore; Analyzing a frontrunner's sectoral innovation system. *Sustainability, 9*(6), 919. https://doi.org/10.3390/su9060919

Sizirici, B., Fseha, Y., Cho, C.-S., Yildiz, I., & Byon, Y.-J. (2021). A review of carbon footprint reduction in construction industry, from design to operation. *Materials, 14*(20), 6094. https://doi.org/10.3390/ma14206094

Soliman, N. A., & Tagnit-Hamou, A. (2016). Development of ultra-high-performance concrete using glass powder – Towards eco-friendly concrete. *Construction and Building Materials, 125*, 600–612. https://doi.org/10.1016/j.conbuildmat.2016.08.073

Solís-Guzmán, J., Rivero-Camacho, C., Tristancho, M., Martínez-Rocamora, A., & Marrero, M. (2020). Software for calculation of carbon footprint for residential buildings. In S. Muthu (Ed.), *Carbon footprints. Environmental footprints and eco-design of products and processes* (pp. 55–79). Singapore: Springer.

Somasundaram, S., Chong, A., Wei, Z., & Thangavelu, S. R. (2020). Energy saving potential of low-e coating based retrofit double glazing for tropical climate. *Energy and Buildings, 206*, 109570. https://doi.org/10.1016/j.enbuild.2019.109570

Somogyi, Á. J., Fehér, K., Lovas, T., Halmos, B., & Barsi, Á. (2017). Analysis of gothic architectural details by spatial object reconstruction techniques. *Periodica Polytechnica Civil Engineering*. https://doi.org/10.3311/PPci.10418

Song, Y., Lau, S.-K., Lau, S. S. Y., & Song, D. (2023). A comparative study on architectural design-related requirements of green building rating systems for new buildings. *Buildings, 13*(1), 124. https://doi.org/10.3390/buildings13010124

Sotos, M. (2015). An amendment to the GHG Protocol Corporate Standard GHG Protocol Scope 2 Guidance.

Sturm, P., Gluth, G. J. G., Brouwers, H. J. H., & Kühne, H.-C. (2016). Synthesizing one-part geopolymers from rice husk ash. *Construction and Building Materials, 124*, 961–966. https://doi.org/10.1016/j.conbuildmat.2016.08.017

Sudarsan, J. S., Vaishampayan, S., & Parija, P. (2022). Making a case for sustainable building materials to promote carbon neutrality in Indian scenario. *Clean Technologies and Environmental Policy, 24*(5), 1609–1617. https://doi.org/10.1007/s10098-021-02251-4

Sun, X., Gou, Z., & Lau, S.S.-Y. (2018). Cost-effectiveness of active and passive design strategies for existing building retrofits in tropical climate: Case study of a zero energy building. *Journal of Cleaner Production, 183*, 35–45. https://doi.org/10.1016/j.jclepro.2018.02.137

Takacs, B., & Borrion, A. (2020). The use of life cycle-based approaches in the food service sector to improve sustainability:

A systematic review. *Sustainability, 12*(9), 3504. https://doi.org/10.3390/su12093504

Taylor, T. (2015). *Assessing carbon emissions in BREEAM*. Watford: BRE Global.

Tettey, U. Y. A., Dodoo, A., & Gustavsson, L. (2014). Effects of different insulation materials on primary energy and CO_2 emission of a multi-storey residential building. *Energy and Buildings, 82*, 369–377. https://doi.org/10.1016/j.enbuild.2014.07.009

Tian, Q., Cai, D., Ren, L., Tang, W., Xie, Y., He, G., & Liu, F. (2015). An experimental investigation of refrigerant mixture R32/R290 as drop-in replacement for HFC410A in household air conditioners. *International Journal of Refrigeration, 57*, 216–228. https://doi.org/10.1016/j.ijrefrig.2015.05.005

Tran, T. T., Pham, T. M., & Hao, H. (2020). Effect of hybrid fibers on shear behaviour of geopolymer concrete beams reinforced by basalt fiber reinforced polymer (BFRP) bars without stirrups. *Composite Structures, 243*, 112236. https://doi.org/10.1016/j.compstruct.2020.112236

Tran, T. T., Pham, T. M., Huang, Z., Chen, W., Ngo, T. T., Hao, H., & Elchalakani, M. (2022). Effect of fibre reinforcements on shear capacity of geopolymer concrete beams subjected to impact load. *International Journal of Impact Engineering, 159*, 104056. https://doi.org/10.1016/j.ijimpeng.2021.104056

Tuck, N. W., Zaki, S. A., Hagishima, A., Rijal, H. B., & Yakub, F. (2020). Affordable retrofitting methods to achieve thermal comfort for a terrace house in Malaysia with a hot–humid climate. *Energy and Buildings, 223*, 110072. https://doi.org/10.1016/j.enbuild.2020.110072

Turner, L. K., & Collins, F. G. (2013). Carbon dioxide equivalent (CO_2-e) emissions: A comparison between geopolymer and OPC cement concrete. *Construction and Building Materials, 43*, 125–130. https://doi.org/10.1016/j.conbuildmat.2013.01.023

Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy, 81*(3), 369–382. https://doi.org/10.1016/j.solener.2006.06.015

U.S. Energy Information Administration. (2023). *Commercial Buildings Energy Consumption Survey (CBECS)*. https://www.eia.gov/consumption/commercial/.

United Nations. (2021). Goal 13: Climate action. *Sustainable Development Goals Report 2021*. https://unstats.un.org/sdgs/report/2021/goal-13/.

United Nations Economic Commission for Europe. (n.d.). *Green Building*. Retrieved from https://unece.org/forests/green-building.

Valencia-Barba, Y. E., Gómez-Soberón, J. M., & Gómez-Soberón, M. C. (2023). Dynamic life cycle assessment of the recurring embodied emissions from interior walls: Cradle to grave assessment. *Journal of Building Engineering, 65*, 105794. https://doi.org/10.1016/j.jobe.2022.105794

Van Nguyen, T. C., & Le, Q. H. (2020). Impact of globalization on CO_2 emissions in Vietnam: An autoregressive distributed lag approach. *Decision Science Letters, 9*, 257–270. https://doi.org/10.5267/j.dsl.2019.10.001

Velasquez, R., Turos, M., Moon, K. H., Zanko, L., & Marasteanu, M. (2009). Using recycled taconite as alternative aggregate in asphalt pavements. *Construction and Building Materials, 23*(9), 3070–3078. https://doi.org/10.1016/j.conbuildmat.2009.04.003

Victor Van Heekeren, E., Snijders, A. L., & Harms, H. J. (2005). The Netherlands Country update on geothermal energy. In *Proceedings World Geothermal Congress*.

Wachter, I., Rantuch, P., & Štefko, T. (2023). Solar cells. *Transparent wood materials* (pp. 59–69). Cham: Springer.

Wagiman, K. R., Abdullah, M. N., Hassan, M. Y., Mohammad Radzi, N. H., Abu Bakar, A. H., & Kwang, T. C. (2020). Lighting system control techniques in commercial buildings: Current trends and future directions. *Journal of Building Engineering, 31*, 101342. https://doi.org/10.1016/j.jobe.2020.101342

Wang, G., Quan, Z., Zhao, Y., Xu, P., & Sun, C. (2015). Experimental study of a novel PV/T- air composite heat pump hot water system. *Energy Procedia, 70*, 537–543. https://doi.org/10.1016/j.egypro.2015.02.158

Wang, H., Chiang, P.-C., Cai, Y., Li, C., Wang, X., Chen, T.-L., Wei, S., & Huang, Q. (2018). Application of wall and insulation materials on green building: A review. *Sustainability, 10*(9), 3331. https://doi.org/10.3390/su10093331

Wang, H., Lin, C., Hu, Y., Zhang, X., Han, J., & Cheng, Y. (2023). Study on indoor adaptive thermal comfort evaluation method for buildings integrated with semi-transparent photovoltaic window. *Building and Environment, 228*, 109834. https://doi.org/10.1016/j.buildenv.2022.109834

Wang, P., Li, M., Dai, B., Wang, Q., Ma, Y., Dang, C., & Tian, H. (2023). Experimental and analytical investigation of CO_2/R32 condensation heat transfer in a microchannel. *International Journal of Refrigeration, 145*, 338–352. https://doi.org/10.1016/j.ijrefrig.2022.08.023

Wang, Y., Jiang, Z., Li, L., Qi, Y., Sun, J., & Jiang, Z. (2023). A bibliometric and content review of carbon emission analysis for building construction. *Buildings, 13*(1), 205. https://doi.org/10.3390/buildings13010205

Wang, Y., Pan, Z., Zhang, W., Borhani, T. N., Li, R., & Zhang, Z. (2022). Life cycle assessment of combustion-based electricity generation technologies integrated with carbon capture and storage: A review. *Environmental Research, 207*, 112219. https://doi.org/10.1016/j.envres.2021.112219

Climate Watch. (n.d.). CO_2 Emissions by Country and Sector. Retrieved from https://www.climatewatchdata.org/ghg-emissions?breakBy=countries&calculation=ABSOLUTE_VALUE&end_year=2019&gases=co2&regions=WORLD&sectors=building%2Cmanufacturing-construction&start_year=1990

Wiprächtiger, M., Haupt, M., Heeren, N., Waser, E., & Hellweg, S. (2020). A framework for sustainable and circular system design: Development and application on thermal insulation materials. *Resources, Conservation and Recycling, 154*, 104631. https://doi.org/10.1016/j.resconrec.2019.104631

Wong, I. L. (2017). A review of daylighting design and implementation in buildings. *Renewable and Sustainable Energy Reviews, 74*, 959–968. https://doi.org/10.1016/j.rser.2017.03.061

Wong, N. H., Chen, Y., Ong, C. L., & Sia, A. (2003). Investigation of thermal benefits of rooftop garden in the tropical environment. *Building and Environment, 38*(2), 261–270. https://doi.org/10.1016/S0360-1323(02)00066-5

Wong, N. H., & Li, S. (2007). A study of the effectiveness of passive climate control in naturally ventilated residential buildings in Singapore. *Building and Environment, 42*(3), 1395–1405. https://doi.org/10.1016/j.buildenv.2005.11.032

Worrell, E., Price, L., Martin, N., Hendriks, C., & Meida, L. O. (2001). Carbon dioxide emissions from the global cement industry. *Annual Review of Energy and the Environment, 26*(1), 303–329. https://doi.org/10.1146/annurev.energy.26.1.303

Wu, X., Tian, Z., & Guo, J. (2022). A review of the theoretical research and practical progress of carbon neutrality. *Sustainable Operations and Computers, 3*, 54–66. https://doi.org/10.1016/j.susoc.2021.10.001

Xiang, Y., Ma, K., Mahamadu, A.-M., Florez-Perez, L., Zhu, K., & Wu, Y. (2023). Embodied carbon determination in the transportation stage of prefabricated constructions: A micro-level model using the bin-packing algorithm and modal analysis model. *Energy and Buildings, 279*, 112640. https://doi.org/10.1016/j.enbuild.2022.112640

Xie, T., Visintin, P., Zhao, X., & Gravina, R. (2020). Mix design and mechanical properties of geopolymer and alkali activated concrete: Review of the state-of-the-art and the development of a new unified approach. *Construction and Building Materials, 256*, 119380. https://doi.org/10.1016/j.conbuildmat.2020.119380

Xu, C., Yang, J., He, L., Wei, W., Yang, Y., Yin, X., Yang, W., & Lin, A. (2021). Carbon capture and storage as a strategic reserve against China's CO_2 emissions. *Environmental Development, 37*, 100608. https://doi.org/10.1016/j.envdev.2020.100608

Xu, J., Deng, Y., Shi, Y., & Huang, Y. (2020). A bi-level optimization approach for sustainable development and carbon emissions reduction towards construction materials industry: A case study from China. *Sustainable Cities and Society, 53*, 101828. https://doi.org/10.1016/j.scs.2019.101828

Xu, X., Xu, P., Zhu, J., Li, H., & Xiong, Z. (2022). Bamboo construction materials: Carbon storage and potential to reduce associated CO_2 emissions. *Science of the Total Environment, 814*, 152697. https://doi.org/10.1016/j.scitotenv.2021.152697

Yang, B., Lv, Z., & Wang, F. (2022). Digital twins for intelligent green buildings. *Buildings, 12*(6), 856. https://doi.org/10.3390/buildings12060856

Ye, H., Peng, H., Li, C., Li, Y., Li, Z., Yang, Q., & Chen, G. (2023). A demonstration concentrating solar power plant in China: Carbon neutrality, energy renewability and policy perspectives. *Journal of Environmental Management, 328*, 117003. https://doi.org/10.1016/j.jenvman.2022.117003

Ying, S. (2022). Application of passive green building energy-saving technology in rural construction. *Advances in petrochemical engineering and green development* (pp. 267–275). Boca Raton: CRC Press.

Younis, A., & Dodoo, A. (2022). Cross-laminated timber for building construction: A life-cycle-assessment overview. *Journal of Building Engineering, 52*, 104482. https://doi.org/10.1016/j.jobe.2022.104482

Yousefi, H., Abbaspour, A., & Seraj, H. (2019). Worldwide development of wind energy and CO_2 emission reduction. *Environmental Energy and Economic Research, 3*(1), 1–9. https://doi.org/10.22097/eeer.2019.164295.1064

Yuan, J., Farnham, C., Emura, K., & Alam, M. A. (2016). Proposal for optimum combination of reflectivity and insulation thickness of building exterior walls for annual thermal load in Japan. *Building and Environment, 103*, 228–237. https://doi.org/10.1016/j.buildenv.2016.04.019

Zain Ahmed, A., Ridzuan, A. R., Mohd Azmi, A., A/L Bathal Singh, B. S., & Zailani, R. (2021). Energy and environmental security in developing countries case studies of countries in Southeast Asia. *Energy and environmental security in developing countries* (pp. 19–48). Cham: Springer.

Zhang, H., Peng, J., Wang, R., Guo, Y., He, J., Yu, D., & Zhang, J. (2023). Efficiency and potential evaluation to promote differentiated low-carbon management in Chinese counties. *International Journal of Environmental Research and Public Health, 20*(4), 3715. https://doi.org/10.3390/ijerph20043715

Zhang, X., Chen, B., & Riaz Ahmad, M. (2021). Characterization of a novel bio-insulation material for multilayer wall and research on hysteresis effect. *Construction and Building Materials, 290*, 123162. https://doi.org/10.1016/j.conbuildmat.2021.123162

Zhang, X., & Wang, F. (2016). Assessment of embodied carbon emissions for building construction in China: Comparative case studies using alternative methods. *Energy and Buildings, 130*, 330–340. https://doi.org/10.1016/j.enbuild.2016.08.080

Zhao, H., & Magoulès, F. (2012). A review on the prediction of building energy consumption. *Renewable and Sustainable Energy Reviews, 16*(6), 3586–3592. https://doi.org/10.1016/j.rser.2012.02.049

Zhao, J., Tong, L., Li, B., Chen, T., Wang, C., Yang, G., & Zheng, Y. (2021). Eco-friendly geopolymer materials: A review of performance improvement, potential application and sustainability assessment. *Journal of Cleaner Production, 307*, 127085. https://doi.org/10.1016/j.jclepro.2021.127085

Zhao, L., Zhang, W., & Wang, W. (2022). BIM-based multi-objective optimization of low-carbon and energy-saving buildings. *Sustainability, 14*(20), 13064. https://doi.org/10.3390/su142013064

Zuo, J., & Zhao, Z.-Y. (2014). Green building research–current status and future agenda: A review. *Renewable and Sustainable Energy Reviews, 30*, 271–281. https://doi.org/10.1016/j.rser.2013.10.021

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.