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Modern Technological Means of Carbon Emission Reduction and Energy Efficiency Through Use of Sustainable Building Materials

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ABSTRACT
The application and promotion of sustainable materials in the construction industry provides for huge consumption of energy and carbon dioxide emission globally. Sustainable building materials requires the measurement and reduction of carbon emission, which is an essential factor in the consideration of climate change, depletion of the ozone layer, a resultant effect of the use of non-renewable materials. The implementation of the utilization of these sustainable materials further addresses the environmental impact caused by these non-sustainable materials on our environment. This paper undertakes the various strategies and methods which includes sustainable building materials, sustainable construction methods, renewable energy, green space, green house protocols, building management systems, Life Cycle Analysis (LCA), Management of smart building system that engender sustainable development goals by calculation (measurement) and reduction of carbon emissions.
Keywords: Sustainable materials, Technology, Sustainable Construction, Carbon Emission, Green House Gases (GHG), Carbon Foot Print, Embodied Carbon, Operational Carbon, Energy Efficiency, Photovoltaics.

INTRODUCTION

As Nigeria rapidly develops with increased population and urbanization, the country is faced with high demand of energy consumption, green house gases emitted through use of non-renewable resources has negative environmental impact on our society. Increase in population is the major cause of carbon emission and Green house gases (GHG). Sustainable construction method with renewable material usage elevates the importance of the Global Sustainable Development Agenda with a goal to conserve and repair the environment and prevent environmental, social and economic impacts. Application of sustainable construction materials into building projects demands a comprehensive proposition considering the materials' life span, from the time of extraction and production to construction and demolition. By this means, the project team can effectively assess the environmental and social impact of material choices, leading to an organized decision-making and an enhanced eco-friendliness. The life cycle assessment method gives a detailed comprehension of how various construction materials impact the environment as they undergo different life cycle stages. This call for various stakeholders to weigh their options based on a holistic view of the environmental impact of these materials, their energy efficiency, and social deliberations. As sustainable construction practices continue to gain momentum, investing life cycle assessment as a conditional instrument will significantly encourage the implementation of more sustainable and renewable construction projects. By allowing Environmental, social and governance (ESG) methods in the choice and usage of sustainable construction materials,

Architects and Engineers and their counterparts can effectively reduce their building projects' environmental impacts while contributing to a more sustainable and resilient built environment.

This paper highlights various energy-saving measures to achieve sustainable development goal in the built environment. Insulation of building envelope, glazed windows and reflective materials can contribute massively in the reduction of buildings' energy usage and loss of energy within the building components.

Offering a range of environmental benefits. They help minimize the reduction of natural resources by utilizing sustainable materials and minimizing waste production. These materials have a lower carbon footprint estimated to conventional building materials, as they require less energy for building performance and contribute to reducing greenhouse gas emissions. Sustainable Construction Materials (SCMs) frequently have better insulation properties, enhances energy efficiency and reducing reliance on heating and cooling systems. Additionally, these materials contribute to the overall goal of sustainable development as outlined by the UNSDGs.

LITERATURE REVIEW

From the World Commission on Environment and Development (WCED) report, the use of sustainable materials is the "development that meets the need of both present and future without a compromise of the ability of the future generation from meeting their needs". (Bruntland 1987). So every individual, organization and events, materials or products has specific carbon foot print which is the overall green house gases generated directly or indirectly that is caused by carbon dioxide emission. This calls for Low carbon management; a strategic approach to reduce emission of carbon which is increasingly relevant over the years with the invention of solar technology, electric cars, wind and hydro energy to enhance energy efficiency in rural and urban centres. Green house gases generated from fossil fuels is the leading factor in global warming; this is according to the Intergovernmental Panel on Climate Change (IPCC) submission. (Jafary Nasab et al., 2020). This Global Sustainable Agenda has called for developed countries of the world such as United States, United Kingdom, Japan; South Africa, to expand their green space and avoid carbon emission, which Nigeria is a part. The construction industry being a major contributor to the nation's economy, requires a huge energy to facilitate its operation. Such building operation includes heating, lighting, ventilation, installations of equipment and appliances where a little fraction is caused by manufacture of building materials, demolition and construction of new projects. Different techniques have been developed to support sustainable construction, such as Building Information Model (BIM), which can improve the design flexibility, project planning, Building aesthetics and promote eco-friendliness.

METHODOLOGY

A Qualitative methodology will be adopted in this Architectural research that involves an in-depth analysis of relevant case studies and scientific materials that will be explored to give relevance to the significance of energy efficiency in office buildings and carbon emission reduction. This Qualitative methodology aim to explain the potential energy efficient and carbon emission measures on a large scale in an area within district heating, combining Building Energy Simulation (BES), Energy System Simulation (ESS) and Building Environment Assessment Tool (BEAT)., to make overall Building Information Model (BIM), a Software using ARCHICAD 2026 that should be used to calibrate the necessary data in to the design package from the planning stage to construction and operation stages of the project.. This design method is used to evaluate the performance of the building in terms of energy production, and consumption, smartness, building intelligence and mobility (kinetics).

The combination of the above strategies; BES, ESS, BEAT; is a proposed methodology to provide an overview of how different energy efficiency improvement within the photovoltaic system would affect the generation of Green House Gases reduction and the environmental performance of the system.

1. This has to do with the construction and computation of the selected Building Information Model. That involves the collection of all relevant information required to make the comprehensive model of the selected building components.
2. All data that is related to the energy balance of the building should be utilized. Temperatures, heat flow and heat gain, indoor and outdoor temperatures, are necessary data to be used. Application of this data enable the possibility of the method called "Energy Demand Signature" which refer to the heat demand of the building under selected period of the year. A calculation method used to measure the building's heat demand. Using the result of this evaluation, it is therefore necessary to adjust parameters in the BIM Technology that may be difficult to collect, such as cold bridges and air tightness. Cold bridges also known as thermal bridges; are weak points or areas in the building envelope which allow heat to penetrate the building. It occur where materials which are better conductors of heat are allowed to form a 'bridge' between the inner and outer face of a construction. The outcome of this analysis is the energy demand of the buildings with the proposed measures and its application in the system.
3. The Simulation of renovation method that will involve simulating the desired renovation alternatives to reduce the energy demand of the building, using available performance data of installations and sustainable materials that are usually common practice within the construction industry.

Definition of Terms

Technology

Is the application of conceptual mode to obtain practical goals, especially in a replicable ways. The word technology can also connote the products resulting from such efforts, including both tangible tools such as utensils or machines, and intangible ones such as software. Technology plays a critical role in science, engineering, and everyday life.

Advancements of Technology have led to significant changes in society. The earliest known technology is the stone tool, used during prehistoric times, followed by the control of fire, which contributed to the growth of the human brain and the development of language during the Ice Age. The invention of the wheel in the Bronze Age allowed greater travel and the creation of more complex machines. More recent technological inventions, including the printing press, telephone, and the Internet, have lowered barriers to communication and ushered in the knowledge economy. As technology contributes to economic development and improves human capacity, it can also have negative impacts like pollution and resource depletion, and can cause social harms like technological unemployment resulting from automation. As a result, there are ongoing philosophical and political debates about the role and use of technology, the ethics of technology, and ways to mitigate its downsides.

Energy Efficiency

Is the process of reducing the amount of energy required to provide product and services. There are many technologies and methods available that are more energy efficient than conventional systems. For example, insulating a building allows it to use less heating and cooling energy while still maintaining a comfortable temperature. Another method is to remove energy subsidies that promote high energy consumption and inefficient energy use. Improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third.

There are two main motivations to improve energy efficiency. Firstly, one motivation is to achieve cost savings aspect during the application of the appliance. However, installing an energy-efficient technology comes with an upfront cost, the capital cost. The different types of costs can be assessed and compared with a Life Cycle Analysis. Another contribution to the world's energy efficiency is to reduce greenhouse gas emissions and hence work towards adverse effect of the climate. A view on energy efficiency can also have a national security benefit since it can reduce the amount of energy that has to be imported from other countries. Energy efficiency and renewable energy go side by side with sustainable energy policies.

Carbon Emission in Construction Sector

The increasing rate of emission of carbon dioxide in the construction industry have been alarming; this is also referred to as the embodied carbon. 75% of these embodied carbon is generated from steel, concrete

and other finishing materials during the building process. The essence of addressing these embodied carbon is to avert the consequences it will generate in the nearest future. Carbon emission simply means the overall energy utilized or the amount of Greenhouse gases (GHG) emitted from the products and materials or the services needed to bring the building into existence or implement the building plan according to the design objective. The building process always goes through various process of extraction and refining of raw materials, manufacturing and transportation of these materials or products, the workforce (energy) required to transport them. In this case, the amount of carbon dioxide which is equivalent to global warming measured in Kg CO2 we are referring to. Kg eCO2e, Kilograms embodied carbon dioxide equivalent or Global warming potential of the product (GWP) is embedded in every building material.

Carbon Foot Print

Refers to the amount of carbon emitted from the various activities such as; exploration, manufacture and transportation of construction materials, construction process and the building life span. This term is interchangeably used as embodied carbon which defines the rate of carbon emission and life cycle analysis of materials. Other aspect that generate huge amount of Carbon dioxide is demolition and construction. Building carbon life cycle has two major aspects; i. Embodied carbon and ii. Operational carbon.

Embodied Carbon

In the construction industry, embodied carbon refers to the greenhouse gas emissions arising from the manufacturing, transportation, installation of equipment, maintenance, and disposal of building materials. Environmental product declarations (EPD) is considered as the most reliable source of information about the environmental impact of every product. It provides environmental information using a consistent and reliable methodology in reporting form. The use of EPDs is to achieve the amount of carbon emission of each product, this is carried out through calculation, mostly done by the manufacturer. Having a good knowledge of product EPDs enables the architect or builder to ascertain which type of material is most relevant for a specific building type. This is not same as Life Cycle Analysis as there is no period of measurement involved.

Operational Carbon

The amount of CO2 generated from heating, cooling and lighting. Concrete work has remains of CO2 especially from high rise buildings. On-site activities like concreting, hoisting of materials needs equipment such as tower crane, Mixer truck, and concrete pump. The construction of tall buildings anywhere in the world requires a tower crane that needs huge amount of energy and very significant rate of carbon emission at the construction stage.

According to fact obtained from study, each 6.13 billion square meters of buildings in the world are constructed and the carbon generated from the construction process is approximately 3729 million. The built environment records 75% of Greenhouse gases (GHG) yearly, as the building industry accounts for 41% globally. The amelioration of these Greenhouse gas emission is the best way of meeting target set by the Panel of Paris Climate Conference agreement for climate change. Taking into consideration the best way of promoting the Carbon neutral feature (a new climate target set by the United Kingdom ahead of the United Nation which stipulates; Net zero by 2050, 68% reduction in greenhouse gas emission by the end of the decade, fast reduction of emission of major economy and creating and support 250,000 jobs.

Life Cycle Analysis

This refers to all the stages of a project's life. A method used to measure and ascertain the amount of carbon foot print generated by the building components, time of operation, transportation and its construction activities. LCA studies the environmental impacts and potential impacts through the building life cycle from start to finishing and completion stages. Utilization of raw materials required for any construction process involves the various types of environmental impacts needing consideration which include resource use, human health, and ecological consequences.

Reduction of Carbon Footprint of Materials

In this study, two different analyses are used to address the calculation of material carbon foot print and the reduction of the CO2 emission. The analysis was carried to replace materials with high carbon potentials for materials with low emission. In the second analysis, the following assumptions were utilized, the rate of concrete usage was minimized. Sufficient use of timber & glass was employed for the construction of the interior and external parts of the building so as to enhance its energy efficiency. The building envelope drastically reduce the emission of carbon dioxide via the use of modern solar power technology, and to reduce energy consumption. Since it was a structure constructed with sustainable materials, it performed as insulating and energy efficient tool to cut down greenhouse gas emission. This is fast replacing the use of fossil fuel that is tremendously increasing global warming and environmental degradation. Its capacity cuts across maximizing and increasing the greenspace globally. For instance, data collected from the solar project executed by EMONE Energy Solutions, utilized 3968 solar panels having 1.5Megawatts capacity, to generate 2.45Gigawattshour electricity annually with the use of 2.28MWh Tesla lithium-ion energy storage system capacity, amounting to 2600 tons of carbon emission avoided annually. From other findings; the result of Kg CO2 from the Life Cycle Assessment was estimated as 830 tons with a Gross building floor area of 130.25m2. So to ascertain the Kilogram of CO2 per square meter (Kg CO2)/M2), the total CO2 which is 839 tons is divided by the Gross building floor area (1308.25m2) arrives at the 641.3Kg CO2e/m2. This method is used to regulate and set the required standard for global carbon emission targets. Respectively, the proposed ''Twin-Tower'' Federal secretariat complex has Gross Floor Area = 4800m2 each, if the Life Cycle Assessment estimate is 830 tons then; 839x1000/4800 =175 x 12 = Approximately 2100 tons of carbon would be avoided annually. This excludes the courtyard and surrounding activities around the facility. Please note the proposed federal secretariat design on the right top of this paper is a brainchild of the author used for basic energy analysis.

Study Area

Umuahia is the Capital of Abia State in the eastern part of Nigeria which is located along the rail ways that lies between Port Harcourt (South) and Enugu State (North) with a metro area population of Umuahia in 2024 is 947000, a 4.76% increase from 2023. The metro area population of Umuahia in 2023 was 904,000. Umuahia is known for being a railway and agriculture market center that attracts farmers and traders from neighboring towns to do their businesses. Other industries includes; Palm oil processing plants and brewery. Umudike is a town in Umuahia with the presence of National Root Crops Research Institute. Umuahia also has several colleges including Trinity College (theological), Government College Umuahia, Holy Rosary Girls Secondary School and hospitals like the Federal Medical Centre, Umuahia (formerly Queen Elizabeth Hospital). Umuahia comprises two local government areas: Umuahia North and Umuahia South. These local governments are also composed of clans such as the Umuopara, Ibeku, Olokoro, Ubakala and Ohuhu communities. This proposed building is located at the Public Building Area on the Port Harcourt-Enugu Express way. The proposed design has a modern technology to solve the challenges faced by inefficient buildings and the reduction of its carbon footprint at the study location.

Environmental Impact of Inefficient Buildings

- **Air Pollution**

The burning of fossil fuels to power inefficient buildings releases various air pollutants, including Volatile Organic compounds, Nitrogen oxides (NO2), and Sulfur II dioxide (SO2). These pollutants can lead to smog formation, respiratory problems, and other health challenges for living organisms.

- **High Fossil Fuel Consumption**

Energy-inefficient buildings demand more energy for heating, cooling, lighting, and appliances. As a result, more fossil fuels are consumed to meet this demand, releasing additional pollutants and greenhouse gases into the atmosphere. This not only contributes to climate change but also depletes fixed fossil fuel reserves.

- **Greenhouse Gas Emissions**

Energy inefficient buildings consume more energy than is required, leading to higher emissions of Greenhouse Gases (GHGs) such as Carbon dioxide (CO2), Methane (CH4) and Hydro-chlorofluorocarbons (HCFCs). These emissions absorb heat in the atmosphere, leading to global warming and climate change. The building sector contributes a significant part of global GHG emissions that makes energy efficiency improvements important in reducing its carbon footprint. The more carbon emission is curtail or reduced in our environment, the more the danger of the consequences resulting from the depletion of the ozone layer that cause Greenhouse effect and climate change globally.

- **Water Resource Depletion**

Energy-inefficient buildings mostly depend on energy-intensive systems such as cooling towers and water heaters. These systems increase water consumption, reducing local water resources and may technically cause water scarcity in dry regions with hotter climate. A cooling tower is defined as a heat removal device that uses water to transfer process waste heat into the atmosphere while water heater is a household appliance consisting of a gas or electric heating unit under a tank in which water is heated and stored for use.

- **Biodiversity Loss and destruction**

The extraction, production, and transportation of these fossil fuels for inefficient buildings can lead to biodiversity misplacement and habitat ruination. Ecosystems that are impacted negatively by these activities may find it difficult to survive, thereby affecting plant and animal and other wildlife that live on these habits.

DATA ANALYSIS

Synching to the information and data received from the Federal Ministry of Works, Federal Ministry of Housing and Urban Development regarding the solar project executed by EMONE Energy Solutions at Mabushi, Abuja, assuming 2600 tons of carbon could be avoided annually with the use of 3968 panels of 2m2 each, following the same method of calculation on the facade of the proposed Federal Secretariat, Umuahia, Abia State, Nigeria, 6400 tons of carbo dioxide would be avoided annually with the use of Kinetic Photovoltaic Systems which significantly enhances energy efficiency of the building and reduces the carbon emission responsibly.

Timber

The significant use of timber in the building industry is quite overwhelming, where architects, builders are tasked with responsibility to create a comfortable indoor climate due to its reduced carbon content so as to expand the green space. Timber has relatively small carbon footprints, particularly in comparison to other building materials such as concrete, steel, plastic all of which require large amount of energy to extract the raw materials. For every Tons timber produced 1.8 tons of CO2 is eliminated from the atmosphere. Through the life span of the timber the CO2 is stored in it enhancing to diminish greenhouse gas emission. The stages of timber carbon foot print included; Growth, curing and cutting, transportation and construction. During harvesting a process called deforestation takes place. As a deforestation poses a threat to the environment and ecological system, afforestation and horticulture contributes to the environmental management system that reduces the risk of global warming.

Glass

The performance and quality attributes of Glass in the modern technology, forms the complex and integral parts in the consistent operational functions of the building. Nonetheless, the embodied carbon foot print related to its production, installation and substitute contributes massively to the embodied carbon foot print of the facades. For building envelopes, it is very essential that the operational and embodied energy are considered side by side. Enhancing the thermal functions of the building envelope sometimes involves increasing the material strength which increases the embodied carbon. This becomes more difficult when glazing is involved. Every thermal insulation and shading properties of the glazing depends on both the strength, coatings, thickness of the Insulating Glazing Unit (IGU) depth, and the gases within the hollow space. These gases include; argon, xenon etc. Having a clear perspective of the

relationship between embodied carbon and operational carbon is the major factor needed to achieve the required target in the reduction of emission from the production stage to design stages. The use of glass in the facade design is dependent on the variability of embodied carbon for various facade designs, the technique and material used, and the shading factor. The entire life span of embodied carbon of building facades is observed to be significantly different based on its technique used. Another factor focuses on the evaluation of embodied energy on unified curtain wall systems and their impact on the building performance. In this study, a unified curtain wall system of facade has the potentials to move from East (Sun-rise) to West (Sun-set) in its search for sunlight to generate 3.5Megawatts of electricity, operating within the scope of Leadership in Environment and Engineering Design (LEED) criteria.

Investing in low carbon glass is one of the solution for facade de-carbonization because of its low carbon potential within its components besides its capacity to resist heat energy, wind energy, Enhance daylighting, Thermal comfort and reducing building energy consumption. Government should implement policies and strategic framework, create incentives, reduce taxation for manufacturing industries that pay attention to the factors surrounding operational carbon and embodied carbon so as to maximize the consistent application of glass in the field of construction especially if it encourages modern technological approach to solving global challenge, arising from energy consumption. No research was carried on the carbon connection between facades and glass in this publication.

RESULTS AND DISCUSSIONS

Building construction methods harnesses the carbon foot print analysis and reduction. This study made assumptions on a proposed Federal Secretariat, in Abia State, Nigeria, a Twin-Tower with the use of Building Information Modelling (BIM) that plays a vital role by creating a data regarding the design elements of the defined project and integrating into a ARCHICAD2026 software as by illustrating the Building Integrated Photovoltaics (BIPV) showing a kinetic facade system in its search for sunlight to generate electricity for the facility and adopting similar methods applied by Nestoil and Sterling Towers Nigeria, based other their installation of solar facades, to carefully analysis or evaluate the amount of CO2 generated by each solar panel on the facade and determine the building Life Cycle Analysis. Also the overall carbon dioxide avoided annually is calculated. The use of glass is promoted over concrete in the design provided as a case study providing more than 50% glass considered to construct a magnificent facade that has the capacity to slide in response to heat and other weather conditions to create indoor air quality, achieve daylighting and ventilation besides its shading benefits.

Respectively, the Twin-Tower has Total Floor Area = 4,800m2 each. A total floor area of 9700m2 offsets 6400 tons of Carbon emission annually following the derivation of EMONE Energy Solutions.

RECOMMENDATIONS

Every successful achievement in the construction of healthy buildings entails the application of sustainable materials, the introduction of governmental policies, implementation of strategic framework, adherence to Global Climate targets, formation of regulatory bodies that will carry out the actualization of target set by IPCC and European Union targets. Every building design that fails to conform to the set climate protocol should be obliterated, design and construction stages should be monitored to ensure strict adherence to global best practices especially in the reduction of carbon emission. The use of glass in the construction sector should be promoted over that of concrete, steel that has vast range of CO2 in their compositions. Considering the advantages of the use of glass in energy efficiency, reduction of energy consumption besides giving the building envelope unmatched aesthetic, configurative tendencies, the benefit of adapting to environmental conditions is very noteworthy. Encouraging more eco-friendly and low-energy construction methods, form program Green Ratings for Integrated Habitat Assessment (GRIHA) that tends to cut down on greenhouse gas emission. The paper also mimicked the sustainable energy building designed by Star-Architects like Rolf Disch (the German Architect) and Angelo Invenizzi (Italian Architect) in their designs of heliotrope and Villa Girasole.

CONCLUSIONS

This publication concludes that, in the selection and application of sustainable building materials, the assessment and analysis of building life cycle with BIM with specific approach to determining the amount of carbon emission each component generates annually play a major role. Generic method of evaluating, assessment and measuring the rate of carbon foot print each material possess and the various construction stages involved. Therefore, the use of more timber for interior designs, glass for solar panels (photovoltaics) and less concrete in the building industry with the aim to increase sustainable energy with Net Zero carbon emission aligns with Greenhouse Gas (GHG) Protocol management approach that is consistent with the standards set by the International Panel on Climate Change (IPCC) and International Standardization Organization (ISO) created by World Business Council and World Resources Institute, approaches formulated to address, measure, and mitigate climate change.

REFERENCES

[1] Omer MA, Noguchi T. 2020. A conceptual framework for understanding the contribution of building materials in the achievement of sustainable development goals (SDGs).

[2] Okoye PU, Odesola IA, Okolie KC. 2020. Evaluating the importance of construction activities for sustainable construction practices in building projects in Nigeria. J Sustainable Construction Material Technology.

[3] Joseph P, Tretsiakova McNally S.2010. Sustainable non-metallic building materials. Sustainability

[4] Sfakianaki E. 2019.Critical success factors for sustainable construction: a literature review. Manage Environ Qual.

[5] Prameswari FR, Rachamawati F, Wiguna IPA, et al.2021. Importance and performance ratings analysis for implementation of green construction on building project. IOP Conf Ser Earth Environ Sci.

[6] T. Boermans, A. Hermelink, S. Schimschar, J. Grozinger, M Offermann. Danish Building Research Institute (DBRI): Kirsten Engelund Thomsen, Jorgen Rose, Soren O. Aggerholm. (2011), Buildings Performance Institute [Principles for Nearly Zero-energy Buildings. Ecofys Germany GmbH:

[7] Trovato, M.R., Nocera, F., Giuffrida, S. (2020). "Life-Cycle Assessment and Monetary Measurements for the Carbon Footprint Reduction of Public Buildings" Sustainability 12, no. 8: 3460. https://doi.org/10.3390/su12083460

[8]World's fastest Building Life Cycle Assessment software – One Click LCA

https://mantledev.com/insights/embodiedcarbon/mass-timber-carbon-impact/Life cycle assessment (LCA) of building refurbishment: A literature review (researchgate.net)

[9] 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.

[10] 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.scito tenv.2022.160181

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

[12] 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

[13] 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

[14] 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

[15] 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

[16] 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. https://doi.org/10.1109/TCE.2017.

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

[18] 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.

[19] 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

[20] 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

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

[22] 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

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

[24] 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

[25] Amrani, M., El Haloui, Y., Hajikarimi, P., Sehaqui, H., Hakkou, R., Barbachi, M., & Taha, Y. (2020). Feasibility of using phosphate wastes for

[27] "ta.jpg (JPEG-bild, 3264 × 2400 pixlar) - Skalad (20%)." [Online]. Available: https:// ostenssons.files.wordpress.com/2009/06/ta.jpg. [Accessed: 01-Dec-2015].

[28] J. G, F. Martinsson, L. Hagberg, and D. Palm, "Miljöfaktaboken 2011 [Estimated emission factors for fuels, electricity, heat and transport in Sweden]," p. 145..

[29] Tina L., Ricardo R., Thomas O., and Ola E., 2014"An approach to illustrate strategies for improved energy at the municipal level,"

[30] S. Hammarsten, 1987"A critical appraisal of energy-signature models," Appl. Energy, vol. 26, no. 2, pp. 97–110.

[31] J. Arnell and F. Martinsson, "Miljöklassningssystem för fjärrvärmeuppvärmda byggnader," Stockholm, 2013.

[32] International Conference on Energy and Sustainable Environment IOP Conf. Series: Earth and Environmental Science 665 (2021) 012025 IOP Publishing doi: 101088/1755-1315/665/1/012025 13

[33] Amstalden, R. W., Kost, M., Nathani, C., & Imboden, D. M. (2007). Economic potential of energy-efficient retrofitting in the Swiss residential building sector: The effects of policy instruments and energy price expectations. Energy policy, 35(3), 1819-1829.

[34] Ardente, F., Beccali, M., Cellura, M., & Mistretta, M. (2011). Energy and environmental benefits in public buildings as a result of retrofit actions. Renewable and Sustainable Energy Reviews, 15(1), 460-470.