Utilization and Integration of Renewable Energy in the Construction of Buildings

Y. OLOTU[1], F. A. AIGBODIOH[2], A. I. OMOAKHALEN[3], A. S. OSOSOMI[3],

[1]Department of Agricultural & Bio-Environmental Engineering.
Federal Polytechnic, Auchi
Auchi, Nigeria
[2]Department of Electrical/Electronic Engineering
Federal Polytechnic, Auchi
Auchi, Nigeria
[3]Department of Mechanical Engineering
Federal Polytechnic, Auchi
Auchi, Nigeria

E-mail: realyahaya@yahoo.com

Abstract - The world's rising demand for construction energy is a result of rising living standards, technological advancements, and population growth. At the moment, a larger percentage of energy use has significant negative effects on the environment and human health because of excessive carbon emissions. This means that switching to clean, ecologically friendly energy for daily building needs like cooking, heating, cooling, and lighting will help greatly cut CO_2 emissions. Energy-related building issues can be successfully addressed, and the effects of climate change can be considerably reduced, by combining energy-efficient technologies with renewable energy resources (RES). Thus, in order to control building energy consumption and guarantee sustainable energy use, this article assesses the integration of renewable energy sources (solar power, wind turbines, and biomass) in building construction. In conclusion, the inclusion of renewable energy sources (RES) in building designs and constructions must be a fundamental component of any country's energy policy, and the Energy Regulation Body (ERB) should be responsible for ensuring that the policy is adequately implemented.

Keywords - Building energy demand, RES, energy efficiency technologies, energy policy, carbon emission.

I. INTRODUCTION

Building construction implies physical activities carried out on a parcel of land or water with the sole intention of erecting a structure for human habitation, warehousing, animal keeping, and others. However, operation inside the building is high energy-dependent [1-6] reported that a building's energy consumption is about 40% of global energy demand, which translates to 43% of greenhouse gas emissions globally. [17] concluded that energy consumption in building increased to about 30% across the world. Based on this, alternative sources of energy of low carbon emission mix to supplement high energy demand in the building is important. Renewable energy is environmentally friendly, and in some cases transportable. It has been reported that many researchers had worked and currently working on the application of renewable energy mix to either reduce the capital cost of energy or increase energy generation and distribution. Also, it is important to address the energy use in buildings. [16] showed that a reduction in building energy consumption could be achieved by the implementation of energy efficiency strategies and creating a renewable energy mix

It is clear that CO_2 emissions in buildings can significantly be reduced by improving energy efficiency.

The total energy consumption and CO_2 emissions could drastically be lowered by increasing the energy efficiency of the building sector [7]. The holistic design approach of energy-efficient in the building is shown in figure 1. Optimization of energy consumption is significant to achieve global sustainable energy demand in building [6, 8]. The design approach towards energy efficient building is depitched in Figure 1.

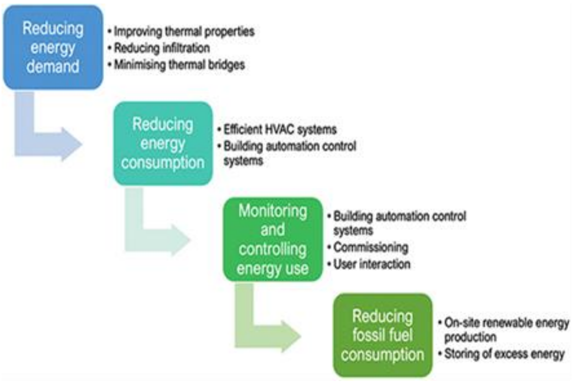

Fig. 1. Design approach towards energy efficient buildings [8].

However, energy efficiency is being incorporated into new building construction and some old buildings to reduce energy consumption. The statistic from [3, 4] showed the prospect of reducing the building sector's contribution to energy consumption. Currently, the field of environmental studies (architecture, building, quantity surveying, and others) have come to terms with the reality of designing building structures with low energy demanding and CO_2 emission. [10, 11] reported that with this approach in mind, that energy is a very important issue, not only with respect to natural energy sources but also in the integration of these concepts into buildings.

II. ENERGY DEMAND REDUCTION

The prime reason for the reduction in energy demand and application of energy efficiency could be explained in multi-dimensional ways such as mean to mitigate climate change, low carbon emission, and saving excess in expended on energy. Based on this, the International Energy Agency (IEA) and other agencies are engaging increasingly in reducing energy demand [19]. Conversely, the European Commission (EC) has developed long-term targets for global energy demand reduction using some policy formulations [19]. Energy supply in Nigeria is mainly from gas plants with more than installation 80% installation capacity and about 20% hydropower installation strength. However, the supplies from these sources are highly inadequate, erratic, and with fluctuating voltages. Again, meeting energy demand for the growing population has become a serious challenge to the socio-economic integration of the country.

The Nigerian Electricity Regulation Commission indicated that 80% of total energy generation comes from gas flaring, while 16% was produced from hydropower [7, 13]. Despite the fact that the energy needs cannot be achieved by the combined sources. Energy from the gas plants has contributed largely to carbon emissions in Nigeria. [12] showed that the estimated peak energy demand was 12,800 MW when the Nation's population was estimated at 170 million in 2012. The country's current population is over 200 million people with a peak energy demand of 19500 MW. Conversely, building energy demand (BED) is about 7800 MW based on the average BED of 40% of total global energy demand as reported by several studies [1, 5, 8]. The findings from [16] showed that energy reduction could be achieved through the adoption of energy efficiency strategies, and offsetting building's energy through the application of renewable energy resources.

Since there exists no replacement to energy demand, different groups of energy users source alternatives for their energy needs. However, the major alternative in Nigeria is the use of generating sets, while the companies, industries, and large establishments depend solely on generators of varying capacities. Thus, a large volume of fuel (fossil fuel) is being used on daily basis with resulting consequences on the economy, human health, environment, increase in carbon emission, ozone layer, and global warming. [9] reported that Nigeria leads in the world as a generator importing nation to the tune of 112 million USD. Again, the population using renewable energy (solar power/photovoltaic cell) is small compared to the generating plant due to its initial high installation, maintenance, and technical know-how.

Having accepted the constraint of meeting energy demand for building consumption, industrial, and infrastructural from the combined energy sources, it is important to rather reduce the BED and adopt energy-efficient technologies. Energy efficiency (EF) implies the optimization use of energy without unnecessary wastage using integrated and efficient devices. [14] indicated that EF does not translate to no usage of energy, but applies in an effective manner to reduce wastage. Projected energy demand in Nigeria is shown in Fig. 2.

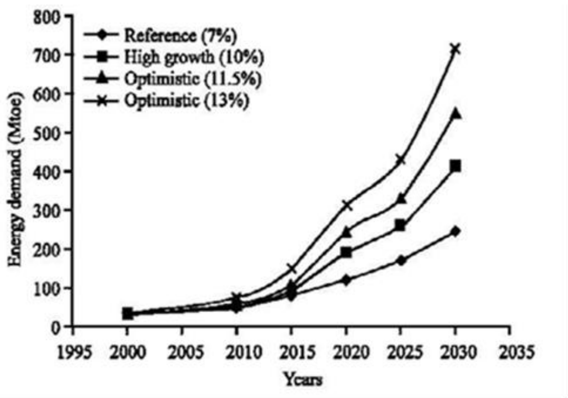

Fig. 2. Projected electricity demand between (2005 – 2030) [14].

III. RENEWABLE ENERGY IN BUILDING

Several studies have indicated that building is high consuming energy with about 40% of total global energy consumption [1, 12, 18]. However, a larger portion of the energy required is majorly provided through the building of fossil fuel non-clean energy.

The negative impacts of continuous dependence on non-clean energy could be catastrophic to the ecosystem and general human well-being. Since it is important to minimize energy in the building by lowering our dependence on fossil fuel and encouraging the incorporation of renewable energy resources-RES (solar energy, biomass, wind energy e.t.c); it is, therefore, necessary to design the installation of RES with the building plan from the inception of the building construction.

Application of RES in building is fast becoming a demonstrating leadership in resource conservation, environmental sustainability, and other related benefits [16].

A) Solar energy in building

Solar energy is a highly essential source of RES due to its abundance, sustainability, and transportability. The solar system is usually installed as photovoltaic systems (PS) and solar thermal collectors.

Electricity can be supplied to the building or transmitted to the grid through photovoltaic system whereas hot water in a building, cooling, and space heating can be delivered through a solar thermal system [18]. Sunlight intensity is the source of energy for solar energy which is converted to electricity using an array of photovoltaic cells [15]. In the design of a building with solar energy, thermal energy is used. However, the warm-up and cooling in the building are achieved through the natural processes of conduction, convection, and radiation [20]. Solar energy resources can be grouped as passive solar design (PSD), solar photovoltaics, and solar thermal. PSD is an exceptional form of solar energy which is mostly about window arrangement and placement. It is very cheap to construct with little or no maintenance cost and higher resistance in disasters and power outages [15].

Fig. 3. Arrays of photovoltaic panel (a), installation of photovoltaic in building (b), and installation of three forms of solar energy in building (c) [15].

B) Installation requirements for solar energy in building

The most important requirement and consideration in solar design and installation in buildings are to evaluate the potential of solar energy within the building's environment. Some of the installation considerations and questions are as follows :

- Is the installation building or site free from obstructions such as shed from trees, buildings, etc...?
- Is the roof space of the building convenient to accommodate the array of PV cells?
- The orientation of the photovoltaic panel
- The condition of the building roof and the kind of the roof plan that should be considered [13].

Installing a rooftop solar system involves solar panels with an array of photovoltaic cells (solar cells), AC/DC switches, an electrical conduit, and an inverter. All these arrangements can easily be mounted on the rooftop of a building to harness solar radiation. It is generally important to estimate and analyze the total power requirements for a building before the installation of photovoltaics (PV) cells. It is estimated that a solar panel consists of between 36 to 72 PV cells and each cell to supply power of 0.5 V.

C) Biomass in building

Biomass is mainly used in electric power generation for facilities heating and other applications. However, it includes materials such as woods, agricultural residues, human and animal wastes [2]. However, biomass has the advantage of dispatchability (it can be controlled and available when needed), and its downside is the production of emission which requires serious monitoring and controlling within the acceptable minimum standards [2].

Turbine generator produces electricity from the output of the burnt biomass because most biopower plants apply direct-fired combustion system. The overall energy efficiency could be increased to about 80 % from the standard biomass electricity using a combined power and heat systems.

A biomass electric generation system comprises many components as boiler, pump, steam turbine, pump, condenser, generator, cooling tower, emission controls, and system controls.

Figure 4 shows the steam turbine system. Globally, biomass is widely used in most of the developing world. Electricity can be produced from various processes from biomass technology [3].

The most commonly used approaches are i.. Combustion process ii. Gasification process. iii. Co-firing process [10]. However, the most important consideration in constructing a bio-plant in a building is to first analyze the building's utilities and appliances and their power requirements.

Fig. 4. In a direct combustion system [2, 10, 11].

D) Wind turbine integration to building

Micro wind turbines are usually developed for large-scale power generation such as for industrial farm and household uses, whereas local electricity is generated from micro wind turbines [12;14]. Horizontal axis wind turbine is the most common of the three groups of existing energy in building [12]. The major component parts of Vertical Axis Turbines (VAWTs) are rotor, blade, gearbox, and generator. It becomes significantly installed in building to reduce aesthetics and a for a high tower. With a reasonable installation height from 2 to 10 metres, the turbine could be installed on the rooftop building relative flow of wind can generate energy. Wind turbines are always installed on the rooftop because wind speed increases with height. Also, it can be installed with the building construction in which the building mounts the turbine [4]. Some requirements of wind turbines are: good performance in complex winds, low noise level, safe environmental operation, low maintenance, rugged design, and simple [4]. Generally, the main idea of installing a wind turbine is first to reduce the energy demand in building, secondly, to reduce carbon emission, and reduce dependence on fossil fuel. This perhaps would enhance the capacity of building to generate their electricity and improve environmental quality and health. Some of the first buildings with turbine installations are shown in Fig. 5a and b.

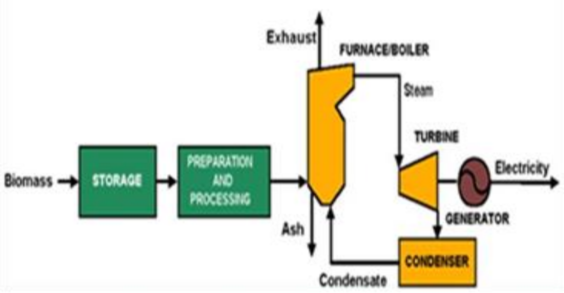

Fig. 5. Bahram world trade center (a) and Lincoln financial field, Philadelphia (b) [4].

E) Renewable energy sources: advantages and possible drawbacks

Numerous worldwide crises, including depressing climate scenarios, surging fossil fuel prices, macroeconomic instability, and most importantly, an urgent energy crisis, have spurred a move towards renewable energy sources. With its largest-ever increase of 348 gigawatts (GW) in installed power capacity, renewable energy saw yet another record-breaking year in 2022 [3]. Our reliance on renewable energy sources for electricity is currently 30%, and this number is steadily rising. Higher levels of renewable energy integration have been made possible by the growing proportion of electricity in end-use sectors' overall final energy consumption [5, 7].

There are substantial emissions of greenhouse gases into the atmosphere when fossil fuels are burned for energy, which exacerbates global warming. Even when taking into account the entire life cycle of the technologies, the majority of renewable energy sources produce little to no emissions [1, 3]. Wind energy needs to contend with other inexpensive energy sources. These days, wind and solar projects are more economically competitive than gas, geothermal, coal, or nuclear facilities when comparing the cost of energy associated with new power plants.

However, in some places with insufficient wind, wind projects might not be financially viable. Further cost reductions may be achieved with the aid of advanced technology, enhanced manufacturing processes, and a deeper comprehension of the physics of wind turbines.

Turbines change the aesthetics of the landscape and make noise. While the effects of wind farms on the environment differ from those of conventional power plants, concerns about the noise generated by the turbine blades and their visual impact on the landscape are common. It can be challenging to forecast precisely how much electricity a wind turbine will produce over time because of the weather's influence on a wind turbine's efficiency.

The turbine's rotor won't turn if the wind speed is too low on any given day. Accordingly, during periods of peak electricity demand, wind energy is not always dispatchable. Wind turbines require some kind of energy storage technology in order to operate solely on wind energy. Utilising the elevation differential created by a diversion structure, such as a dam, the hydroelectric technology generates electricity by having water flow in one direction and out the other. The elevation change and water flow volume determine how much energy is released by the water. From one place to another, this is referred to as the "head." Hydropower offers flood control, clean drinking water, and irrigation support in addition to electricity generation, which is just one of its many economic advantages. The weather and patterns in precipitation are ultimately what govern hydropower, a dependable energy source.

However, since river water is the primary source of hydropower energy, droughts will affect overall electricity production, which may have an effect on hydroelectricity's capacity [7, 8]. Electric production is unpredictable because the amount of water needed to produce hydroelectric power varies based on the weather. Biomass is a plentiful resource; organic matter is all around us, in waste dumps, croplands, and forests. In contrast to fossil fuel resources, which take hundreds of millions of years to replenish, biomass resources grow back rather quickly [8, 9].

All biomass initially obtains its energy from the sun through photosynthesis. Since biomass energy plants are frequently dispatchable, turning them on or off is simple. This permits the use of electricity from these plants by electricity grid operators at periods of high demand. By utilising already-existing natural resources and technoeconomic strategies, the development and utilisation of renewable energy promotes the sustainable development of buildings in the energy sector and even globally, helping to reduce emissions and increase building energy efficiency [4, 6]. Climate scientists believe that one of the most affordable ways to reduce greenhouse gas emissions is through energy-efficient construction.

The comparison between energy consumption and output is known as energy efficiency. This refers to the built environment, where it means utilising the least amount of energy (natural gas, electricity, etc.) necessary to run a facility properly. Making sure there are no air leaks, using timers or sensors to make sure the building isn't used when it's empty, and utilising energy-efficient equipment are some actions that can make a building operate more efficiently [3, 5, 7].

IV. Renewable Energy Installation Cost

There is a great comparison of cost relationship between the price of renewable energy (RE) and fossil energy. The initial cost of establishing RE is huge and is location-dependent. Domonic [5] indicated that electricity from fossil energy is about $ 0.05 to 0.15 /kWh whereas geothermal, solar voltaic, onshore wind, and biomass are less than $0.10kWh. Conversely, hydropower is estimated at an average of $ 0.05/kWh. The reduction in the initial construction cost for the bioenergy plant could be considered as one of the vital reasons for the effective competition of RE with fossil energy.

In 2018, worldwide average electricity cost for solar energy fell by 14%, wind by 13%, and hydropower reduced by 11%. However, these costs were achieved due to a significant decline in construction costs for bioenergy plants [5]. Thus, the decline trends are projected for the next decades most especially for wind and solar technologies [11]. Discounted cash flow is theoretically used to evaluate a solar system. Installation costs at the beginning of the project are the outflow, whereas the offsetting of electricity cost is the inflow cost. Electricity is generated freely using solar energy. However, there are some costs associated with the initial installation, and the cost is a function of capacity, location, and efficiency. The cost of installation in an average American house ranges from $11,144 to $14,696 [12] and $3000 to $5000 in Nigeria. Other costs that go along with installation apart from the procurement of PV panels are labour costs, inverter cost, and operational cost.

V. Conclusion

Global buildings' energy consumption is increasing and this has a significant share in worldwide energy consumption. A large portion of the energy sources to meet the growing demand is from fossil fuel, whereas the usage of the energy mix from renewable energy is low. Conversely, these further compromises health and environmental issues due to increasing carbon emission. With the increasing global population, the need for shelter and accommodation increases, and the pressure in building energy doubles, and the rate of carbon emission is elevated.

Therefore, it is important to reduce building energy consumption by adopting energy efficiency strategies (using energy-efficient lighting devices). Again, moving towards clean and environmentally friendly renewable energy sources in the building design and construction. This will not only reduce carbon emission but is cheaper after the initial plant installation costs.

VI. Acknowledgments

The authors gratefully acknowledge Miss Rabiat Deborah OLOTU and Muhammad-Jamiu OLOTU for their editorial reviews. In addition, the Department of Electrical and Electronic Engineering at Auchi Polytechnic in Auchi is also acknowledged for the release of datasets on photovoltaic temperature. Also, I acknowledge Engr. Gbenga Santos Okereji for his support. Finally, the holistic participation of all authors is well acknowledged.

VII. References

[1] M.H., Ahmadi, M., Ghazvini, M., Sadeghzadeh, M., Alhuyi, M., Kumar and R., Naeimi, Solar power

technology for electricity generation: a critical review. Energy Sci. Eng. 6,(2018), 340–361.

[2] BEG, Biomass For Electricity Generation by U. S. Department of Energy Federal Energy Management (2016)

[3] BEG, (2014). Biomass For Electricity Generation by U.S. Department of Energy Federal Energy Management (2014).

[4] M.,Bošnjaković, Wind power buildings integration**,** The Technical Department, University of Applied Science of Slavonski Brod, 1(5), 2013, pp7-9.

[5] D., Dominic, renewable energy costs take another tumble, making fossil fuels look more expensive than ever.a critical review. Energy Sci. Eng. 6, 2018.pp.23-40.

[6] S., Esbati, M.A., Amooie, M., Sadeghzadeh, M.H., Ahmadi, F., Pourfayaz, and T., Ming, Investigating the effect of using PCM in building materials for energy saving: case study of Sharif Energy Research Institute. Energy Sci. Eng. 8, 2018, 959–972.

[7] European Commission Energy performance of buildings.Availablefrom:https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/overview, 2019.

[8] L., Felius, F., Dessen and B., Hrynyszyn, Retrofitting towards energy efficient homes in European cold climates—a review Energy Effic.2 (13), 2019 101–25

[9] GIZ-NESP. The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy,Energy Efficiency and Rural Electrification, 2nd ed. June 2015. Available online: https://www.giz.de/en/downloads/giz2015-en-nigerian-energy-sector.pdf; Energy Platform.

[10] R., Hafezur, M.D., Rayhan, R., Sharif, and N., Tamzid N., Designing of Biomass Based Power Plant for Residential Building Energy System 2nd Int'lConf. on Electrical Engineering and Information & Communication Technology (ICEEICT) 2015 Jahangirnagar University, Dhaka-1342, Bangladesh, 21-23 May 2015

[11] IRENA, Kandt, Walker, Hotchkiss. Implementing Solar PV Projects on Historic Buildings and in Historic Districts. NREL. Draft Technical Report, 2020, NREL/TP-7A40-51297.

[12] K., Katlury, Consumer Affairs is not a government agency. Companies displayed may pay us to be Authorized or when you click a link, call a number or fill a form on our site, 2021.

[13] NSC, “Useful Tools” for links to PVWatts, SMA Sizing and the NW Solar Center Load Calculator for sizing photovoltaic systems, 2009.

[14] S.O.,Oyedepo, Energy Efficiency and Conservation Measures: Tools for Sustainable Energy Development in Nigeria. International Journal of Energy Engineering, 2, 2012, 86-98

[15] D., Raji, and B., Agarwal, Integrating of renewable energy in building. Journal of Civil Engineering and Environmental Technology,1 (3), 2014, pp, 6-8

[16] J. H., Sheila, and K., Alicen, Renewable energy application for existing building. Paper presented at the 48th AiCARR International Baveno-Lago Maggiore, Italy, September 22-23, 2011, pp 1-17.

[17] B., Si, Z., Tian, W., Chen, X., Jin, X., Zhou, and X., Shi, X, Performance assessment of algorithms for building energy optimization problems with different properties. Sustainability, 2 (1), 2018, 11:18.

[18] A. K., Soteris, Building integration of solar thermal systems Springtime-Builders, 2014: Springtime Builders builds *custom homes in Asheville NC* and specializes in cost-effective energy efficiency, building science and indoor-air quality, 3 (1), 2018, pp 3-7.

[19] S., Steve, Reducing energy demand: A review of issues, challenges and approaches Steve Sorrelln Centre on Innovation and Energy Demand and Sussex Energy Group, Science Policy Research Unit, University of Sussex, Falmer, Brighton BN1 9QE, UK: Renewable and Sustainable Energy Review 47(2015) 78-82

[20] I.,Yukser, and I, Karadag, Use of Renewable Energy in Buildings‘*Sectoral Trends in Global Energy Use* and *Greenhouse Gas Emissions’,* Berkeley, CA: Lawrence Berkeley National Laboratory (LBNL-56144)., 2006.