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Performance Strategies for Reducing Energy Consumption of Buildings and Related Greenhouse Gas Emissions: A Review

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Abstract
As population growth continues and economic growth rates increase in the world, global demand for primary energy will continue to grow by up to 50% by the middle of this century; at least 80% of this increase is expected to come from developing countries. As a part of the whole, Energy demand is also increasing for the construction and operation of the buildings, driven by improved access to energy in developing countries, greater ownership, and use of energy-consuming appliances, and rapid growth in global buildings floor area. Therefore reduction of energy consumption, and related greenhouse gas emissions (GHG), especially in the building sector has become global problems need to expend great efforts to develop applicable solutions. In this context, this review article aims to review and discuss the strategies performance of reducing the buildings energy consumption and related greenhouse gas emissions. This research concluded that the world currently depends on three strategies to achieve a significant reduction in energy consumption and greenhouse gas emissions related to the building sector activities. These strategies are the continuous improvement of the energy performance of the building envelope components, improving the performance of the buildings operation systems, as well as supply buildings with renewable energy sources. Finally, to achieve widespread success in the implementation of these strategies to reduce energy consumption and greenhouse gas emissions depend on improving the financial and technical abilities of all developing countries.

Keywords: Building envelope efficiency, Zero emission building, Renewable energy sources, Smart building technologies.

1. Introduction

Energy has a crucial role to play in the global development context (Ritchie & Roser, 2018), which appears in its ability to improve living standards, saving time, increasing productivity, improving public services (Ritchie & Roser, 2018). Over the time, types of consumed energy in the world are changing; the change is due to advances in technology, energy resources discoveries, energy prices, and environmental pressures. The only constant is that the amount of consumed energy has increased steadily over the time, as more people join the grid around the world, and the demand increases for energy-consuming appliances and means of transportation in general. As population growth continues, and economic growth rates increase in the world (Evan, M. et al. 2017), global demand for primary energy will continue to grow by up to 50% by the middle of this century; at least 80% of this increase is expected to come from developing countries. On the other hand, energy systems of fossil fuels (coal, oil, and natural gas) have critical environmental impacts (Ritchie & Roser, 2018), which are considered the fundamental driver of global climate change. Therefore there is a need for a secure transition to clean and sustainable energy sources, to balancing challenge between development and environment (Ritchie & Roser, 2018).

The building sector is an important sector that consumes about 40% of the world's energy and contributes to increasing GHG emissions (Ye & Song, 2017). Currently, significant international efforts are being made to reduce buildings energy consumption and consequently, greenhouse gas emissions. In this context, this review article aims to review and discuss the strategies performance of reducing buildings energy consumption and related greenhouse gas emissions.

1.1 Statement of the problem

- The world, particularly the developing nations are facing increased energy demand as a consequence of increasing population, urbanization, improved living standards (Evan, M. et al., 2017, p.2151), migration to cities, household size changes and lifestyle…etc., as shown in Figure 1(Dudley, 2017).

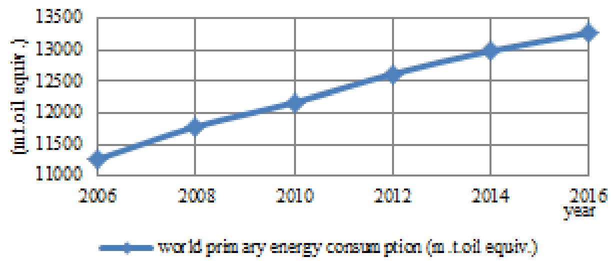

Fig. 1. The global increase of world primary energy consumption in recent decade (Dudley, 2017).

- The construction and operation of buildings contribute with about (11 Gt CO^2) 39% of energy-related CO^2 emissions in 2017, as shown in figure 2 (Global ABC, 2018), because the fossil fuels still constituting 64% of the currently global electricity generation mix, as shown in figure 3 (IEA, 2019a) which causes harm to the environment.

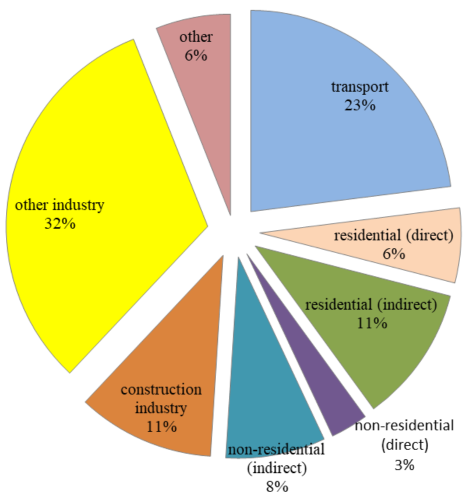

Fig. 2. The share of global energy-related CO2 emissions by sector, 2017,(Global ABC, 2018).

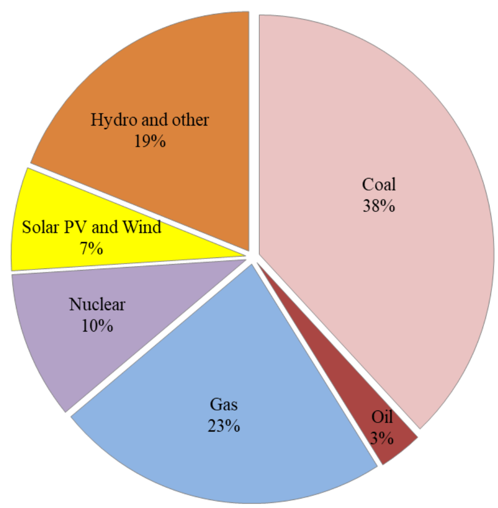

Fig. 3. Electricity generation mix 2018 (IEA, 2019a).

- The global consumption of the buildings sector represents 30% of total final energy use in 2017, as well as the construction of buildings including the manufacture of construction materials such as steel and cement consume about 6% of the total use of final energy, as shown in Figure 4(Global ABC, 2018).
- Neglecting the designers of most buildings especially in the developing countries the climate impact on the buildings led to lack of thermal comfort for users who rely only on natural techniques, but they are sometimes obliged to install cooling devices.
- Also, ignoring the application of the environmental design standards and the mandatory building energy codes, as shown in Figure 5. In addition to the inaccuracy of the buildings construction and users' behaviors contribute to increasing waste of large amounts of energy worldwide.

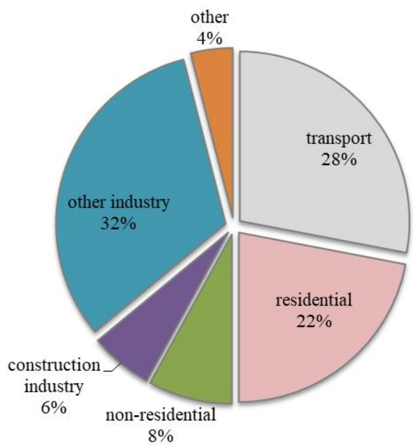

Fig. 4. The global share of energy consumption by sector 2017 (Global ABC, 2018)

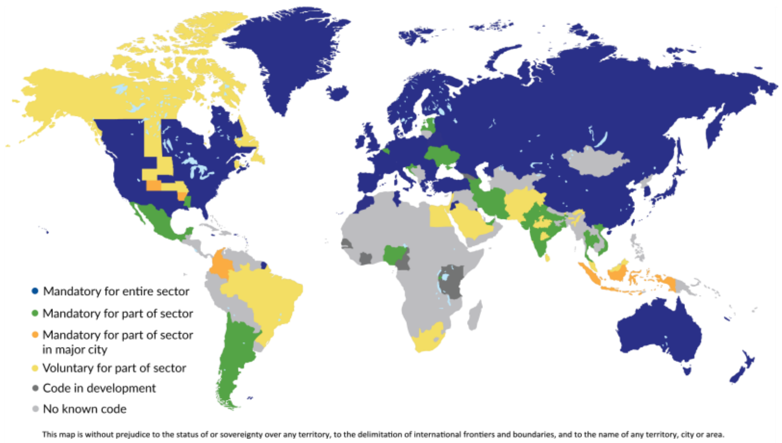

Fig. 5. Two-thirds of the countries around the world lacked mandatory building energy codes in 2018 (IEA, 2019b).

1.2 Aim of the Paper

This review article aims to discuss the strategies performance of reducing the buildings energy consumption and related greenhouse gas emissions.

1.3 Methodology

The researcher reviewed many scientific articles and reports related to the research theme, as well as reviewing many innovative technologies and methods to reduce buildings energy consumption and greenhouse gas emissions, and classified them into three strategies, which are considered currently as applied strategies that contribute to solving the research problems. Finally, the researcher has analyzed and discussed the efficiency of these strategies.

2. Terminologies

2.1 Zero Emission (energy) Building (ZEB)

Zero emission (energy) building means a building which can fulfill its annual energy demand from low-cost, locally available, nonpolluting, and renewable sources (Torcellini. et al. 2006). World green building council has defined the net zero emission building as a building which is highly energy efficient and fully powered from off-site or on-site renewable energy sources, (Torcellini, et al. 2006) as well as has an excellent indoor environment with respect to air quality, temperature, daylight, and acoustics, etc.

2.2 Energy Efficiency (EE)

Energy efficiency was defined by international energy agency (IEA) as using less energy to deliver the same or better levels of service as well as helps to decrease the use of the primary energy sources and acquire considerable savings in energy bills.

3. Building energy efficiency

Building energy consumption depends on many factors, which mainly include; thermal and physical properties of the building envelope elements, the accuracy of the building envelope construction details, building size, building age, building shape, climate characteristics of the building site, the energy efficiency of the building operation systems, and building users' behavior and their activities towards energy use (Delzendeh, et al. 2017). Also, international energy agency (IEA) has reported that the energy saving potential of buildings will remain largely untapped due to the continuous use of less efficient technologies, and weak investment in sustainable buildings in many countries (world energy council, 2016). In this context, to design and construct energy-efficient buildings which use minimal energy consumption and give the best levels of service, architects / buildings' owners should apply many efficient innovations in buildings components and buildings operation systems as much as possible. Currently, there are many methods to improve the energy efficiency of buildings as a result of considerable international efforts which are made to improve the building energy efficiency. These efforts can be summed up into the following three strategies, as illustrated in figure 6:

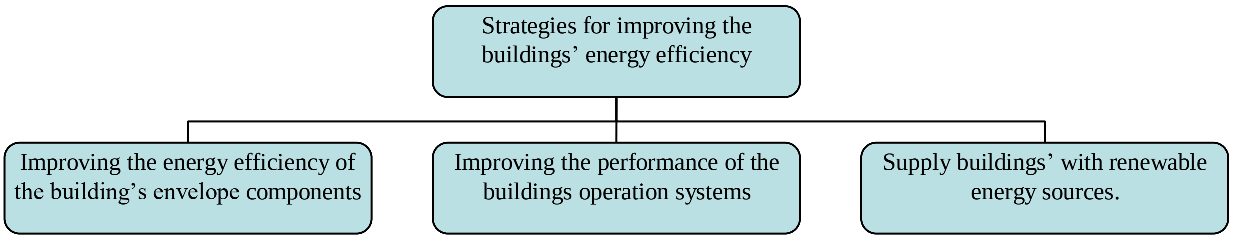

Fig. 6. Strategies for improving the buildings' energy efficiency

3.1 Improving the energy efficiency of the building's envelope components

The building envelope is a boundary between the indoors, and outdoors of the building, and it forms the outer skin of the building. It also performs many functions such as security, protection from the weather, fire safety, control of heat gain / heat loss, privacy, comfort, contact with surroundings, and aesthetic benefits. The building envelope consists of: "external solid components (walls, roofs, floors), and external void components (windows, doors, skylights, curtain walls). There is an urgent need to make the building envelope more airtight and energy-efficient because 20% to 60% of total consumed energy in the buildings affects the design and construction of the building envelope (Delzendeh, et al. 2017). Also, air sealing alone can decrease the need for heating by 20% to 30% (IEA, 2013). In addition, simulations on a large number of various buildings in widely varying climates have shown that reducing air leakage can save 5% to 40 % of heating, and cooling energy (Delzendeh, et al. 2017). In this context, architects, / buildings' owners should apply the below techniques to achieve a sealed building envelope regardless of climate (Delzendeh, et al. 2017):

- Using dynamic facades such as double skin facades (fixed / movable shading devices, etc) can provide great solar control, as shown in Figures 7 & 8 (Arup, 2019), this facade has a unique dynamic shading system and a modular Mashrabiya that opens and closes to provide self-shading as the sun moves around the building, the system reduces the solar energy entering the building.

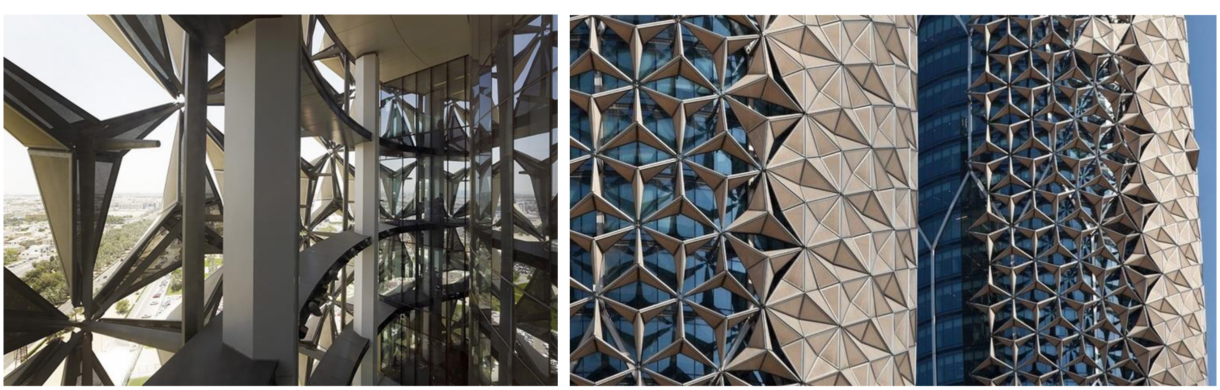

Fig. 7 & 8. An innovative dynamic façade of Al-Bahr towers in Abu-Dhabi (Arup, 2019)

- Well insulated transparent components (doors, windows, sky-light, and curtain walls), which characterize by highest quality sealing frames (Fenstertechnik-brand, 2019), and electro chromic glass which is smart, dynamic, electronically tint able, actively control daylight, glare, and solar heat, as well as it improves occupant comfort and significantly reducing energy consumption (Sage glass, 2019), as shown in figures 9 and 10.

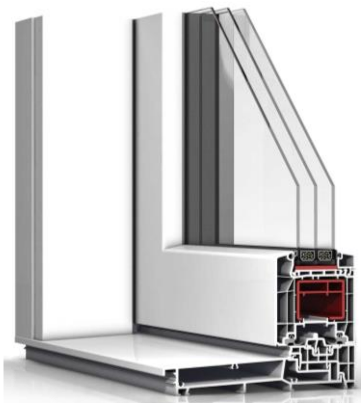

Fig. 9. Detail for highly insulating window, e.g. triple-glazed, low-e, and low-conductive frame (Fenstertechnik-brand, 2019)

Fig. 10. Skylights ceiling from electro chromic glass, which is smart, dynamic, electronically tint able, control the level of daylight, and heat gain, as well as it reduces energy consumption (Sage glass, 2019)

- Well insulated opaque components (walls, floors, and roofs), for example, applying advanced insulation materials with thermal conductivity of ≤ 0.015 W/m. k. (IEA, 2013), as shown in figure 11.
- Using natural cladding materials, and cooling techniques such as green roofs and facades, as shown in figure 12…etc.

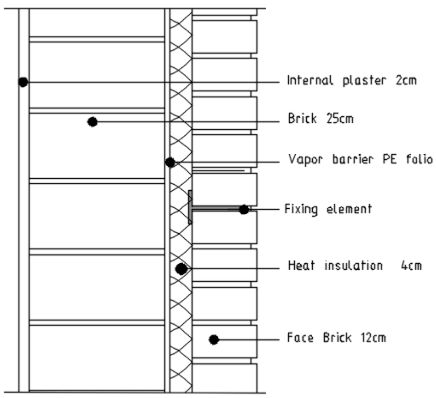

Fig. 11. Detail for advanced heat insulation of an external wall.

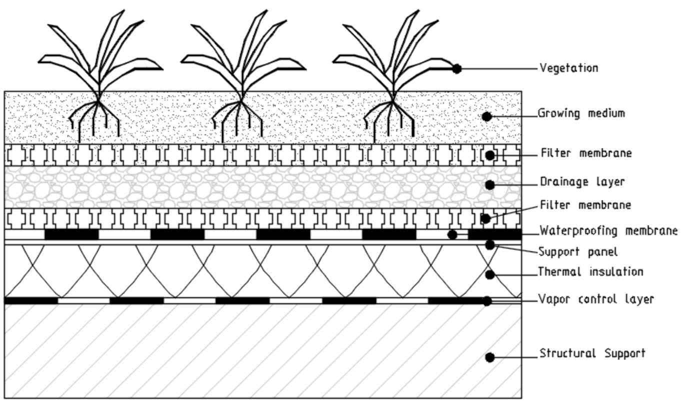

Fig. 12. Detail of an intensive green roof as a natural cladding technique to cool the building

- Using smart building materials that can be distinguished from traditional materials with some advantages such as immediacy, transiency, and selectivity (Fared, et al. 2015).
- Using Nano insulation materials such as vacuum insulated panels which characterize by maximum thermal insulation and minimum insulation thickness (2mm to 40 mm), as well as the thermal conductivity of these materials is ten times lesser than in traditional insulation materials (Elbellahy, 2017). Also, aerogel is a transparent insulation material that fills cavities between glass panels, which reduce the temperature equivalent to the thickness of 10 to 20 cm of normal glass (Elbellahy, 2017).

- Using energy efficient products such as doors, skylights, curtain walls, and windows, e. g. installation of energy efficient windows can reduce the household energy bill by 12%.
- Sealing air leaks through constructing airtight joints at the junction points of the building envelope components.
- Applying mandatory buildings energy codes (IPCC, 2014) for new constructions in developing countries. Currently, 69 countries having either voluntary or mandatory buildings energy codes either published or under development (Global ABC, 2018).

However, most of the previous technologies which are summarized in figure 13, and required to make building envelope more energy-efficient are commercially available but have not been widely deployed because of high upfront cost, and lack of information for many consumers (IEA, 2013).

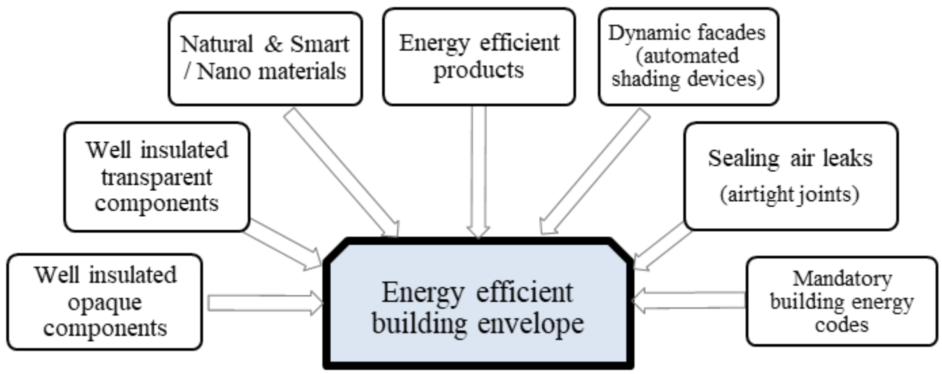

Fig. 13 Main required technologies to achieve an energy efficient building envelope.

The IEA market assessment shows clearly that Canada, the European Union, and the United States have made the most progress in deploying the previous technologies to achieve energy efficient buildings envelopes; Japan also has made some progress (IEA, 2013).

3.2 Improving performance of the buildings operation systems

3.2.1 *Improving the energy performance of the buildings operation systems:*

- Improving the energy performance of the lighting system: For example, energy efficient lamps use about 70 to 90% less energy than traditional incandescent lamps.
- Improving the energy performance of the cooling system: For example, energy efficient central air conditioners use 8 to 75 % less energy than conventional new models.
- As well as, the continuous improvements in the efficiency of the electrical and electronic appliances as illustrated in table 1 will save nearly three quarters of the global electricity demand, if the architects / buildings-owners apply them from now until 2030.

Table 1. Improvements in the efficiency of the electrical and electronic appliances (IPCC, 2014), (EPA &DOE, 2019)

Energy efficient appliance	Energy saving potential	Energy efficient appliance	Energy saving potential
Televisions	25 – 60 %	Washing machine	25 - 28 %
Telephones	40 %	Dishwashers	12 - 17 %
Refrigerators & freezer units	10 - 40 %	Air conditioners	50 – 75 %
Natural gas ovens	25 %	Ceiling fans	40 – 70 %
Electric ovens	45 %	Computers & monitors	40 – 70 %
Microwave ovens	75 %	Printers, scanners, copiers	30 %

3.2.2 *Application of smart building technologies*

The following smart building technologies could enhance the occupants' comfort and productivity while using less energy than the conventional building, as shown in table 2:

- Smart HVAC controls can limit consumed energy in unoccupied building zones, detect and diagnose faults, and reduce HVAC usage (King& Perry, 2017).
- Smart lighting includes advanced controls that incorporate daylighting and advanced occupancy and dimming functions (King& Perry, 2017).
- Smart plug load controls can automatically cut off power to equipment that is not in use.
- Smart window system manages the amount of solar heat and daylight that enters the building (King& Perry, 2017).
- Automated System Optimization (ASO) uses information and communication technologies (ICT) to collect and analyze the building operation systems and energy performance data and make anticipatory changes in operations based on external factors such as occupancy patterns, weather forecasts, and utility rates (King & Perry, 2017).
- Mobile apps could be used by the building occupants to control some workspace functions such as lighting, HVAC and kitchen appliances (King& Perry, 2017).

Table 2. Smart technologies give remarkable energy savings (King& Perry, 2017)

System	Technology	Energy savings
HVAC	variable frequency drive	15 – 50%
	Smart thermostat	5 – 10 %
Lighting	Advanced lighting controls	45%
	Web-based lighting management system	20 – 30%
Plug load	Smart plug	50 – 60%
	Advanced power strip	25 – 50%
Window shading	Automated shade system	21 – 38%
	Switchable film	32 – 43%
	Smart glass	20 – 30%
Building automation	BAS	10 – 25% whole building
Analytics	Cloud-based energy information system (EIS)	5 – 10 % whole building
Sources: Hydraulic Institute, Euro pump, and DOE 2004; DOE 2016b; Boss 2016; GSA 2012; BEEx 2015; Lutron 2014; InvisiShade 2016; Sage Glass 2016; Raven Window 2016; Gilliland 2016.		

3.3 Supply buildings with renewable energy sources

Currently, international efforts are working to increase the share of renewable energy in the global energy mix. These efforts include developing the buildings supply options with their renewable energy demands (Torcellini, et al. 2006) which include:

- On-Site Supply Options such as photovoltaic panels as shown in figure 14, solar thermal collectors, and wind turbines.
- Off-Site Supply Options such as hydroelectric power plants, wind power plants, solar power plants, and geothermal power plants, etc.

Because the buildings are responsible for a large part of the consumed energy worldwide and consequently GHG emissions, the scientific research has innovated new concepts of energy efficient buildings, such as zero emission buildings (for example: Eco-villa in Masdar city as shown in figure 15 consumes 100% renewable energy, less than one quarter energy than the traditional villa, and emission reductions 36 tons of CO_2 annually) (Masdar city, 2019).

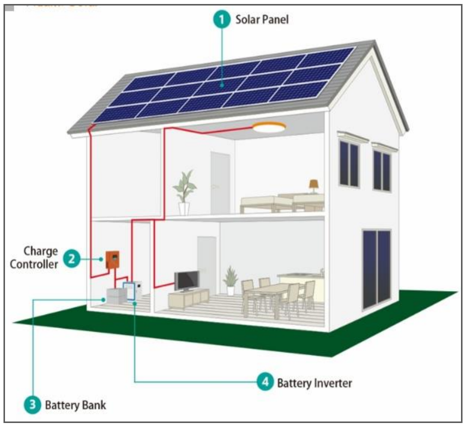

Fig. 14. Components of an on-site Supply solar power system (PV panels) (Solarhm, 2019)

Fig. 15. Eco-villa model in Masdar city which consumes 100% Renewable Energy, and less than one quarter energy than the traditional villa (Masdar city, 2019)

However, renewable energy supply options for buildings have advantages and disadvantages that can be summarized as follows in table 3.

Table 3: Advantages and disadvantages of renewable energy supply options for buildings.

Advantages of renewable energy supply options for buildings	Disadvantages of renewable energy supply options for buildings
▪ Environment-friendly. ▪ Low operating and maintenance costs. ▪ Promotes energy independence. ▪ Do not be affected by prices change of fossil fuels. ▪ Its fuel is free. ▪ Easy to install. ▪ Clean, available & sustainable. ▪ Cost effective. ▪ Electricity fixed price over a long period of time (e.g. 20: 25 year). ▪ Electricity production doesn't consume water.	▪ An on-Site Supply Options still need high upfront cost. ▪ Some supply options don't produce electricity during the night, slow wind speed, and bad weather conditions. ▪ Dirt, dust, and shading from adjacent buildings and landscapes may reduce the PV panels' efficiency (Kayal, 2009). ▪ Requires the ability to store backup power when the sun sets or at low wind speeds. ▪ On site wind turbines for ZEBs are limited, because of wind obstacles, wind pattern, and noise.

4. Discussion

Presence of renewable and non-renewable sources of energy varies from one country to another depending on the geological and climatic characteristics of each country, therefore the world countries depend on various energy sources. Also, Energy prices, the health, and environmental effects of energy production and consumption affect consumers' choice of energy sources (Ritchie & Roser, 2018). Achieving the goal of eliminating the harmful emissions associated with the consumption of fossil fuels will be at hand in the future through the continuous development of technologies of production and consumption of fossil energy sources to become more environmentally friendly, as well as the increasing rate of transition to renewable energy sources. In this context, since decades the international efforts have been working to develop guidelines and innovated systems, and technologies that contribute to reducing the energy consumption and harmful emissions in all sectors. The building sector is one of the major sectors, which consumes a considerable part of energy globally - as shown in the above figure 4 - therefore enormous efforts are currently doing to develop plans to achieve a significant reduction in the energy consumption of buildings. The researcher has summed up these efforts into three strategies:

- Improving the energy performance of the building envelope components to minimize the heat amount gained and lost, thereby reducing the consumed energy in building use but the modern technologies of the building's envelope components are not necessarily suitable for the financial ability of each building owner, also it is not easy to be available everywhere at the same time. As well as, the diversity of building materials, climatic characteristics, scientific standards and practices in the design and construction of buildings around the world have led to significant differences between energy performance of buildings in developing countries and those built in developed countries. In most countries except for developed countries, energy performance of buildings envelopes has been significantly neglected. Most of the constructed buildings are leaky, have no insulation or exterior shade control, and have single-glazed windows and solar absorbing roofs in hot climates.
- Improving performance of the buildings operation systems to minimize their energy consumption; numerous countries applied these technologies, and the application ratio varies from one country to another according to the economic abilities of the buildings-owners and the availability of those technologies in each country.
- Supply buildings with renewable energy sources: in recent years, this strategy has achieved success, and increased interest, until becoming part of both EU and US policies on energy efficiency in buildings. In recast of the EU directive on energy performance in buildings that by the end of 2020, all new buildings will be “nearly zero energy buildings” (Sartori. et al. 2010). For the building technologies program of the US Department of Energy (DOE), the strategic goal is to achieve a commercial zero energy buildings in 2025.

i. e. the previous strategies have achieved relative success, where they deployed in some developed countries. Finally, the rate of application of the three strategies to reduce energy consumption and greenhouse gas emissions in developing countries will continue to depend on improving the financial abilities of more buildings’ owners in developing countries and the availability of those technologies in each country.

5. Conclusions

- A significant reduction in energy consumption and greenhouse gas emissions in the building sector is currently achievable through the continuous improvement of the energy performance of the building envelope components, Using high energy efficient appliances in the building operation systems, as well as Supply buildings with renewable energy sources to fulfill its annual demand of energy without harmful emissions.
- Widespread success in the implementation of those strategies to reduce energy consumption and greenhouse gas emissions depends on reducing upfront costs of the advanced technologies and improving the financial abilities of buildings’ owners in developing countries.

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