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Decision Making Approaches and Energy-Saving Retrofit Technologies for Existing Residential Buildings in Egypt

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الملخص:

مع استهلاك الطاقة المفرط في جميع أنحاء العالم حيث يتم استهلاك معظم الطاقة من قبل المباني القائمة في حين أن معدل استبدال المباني القائمة من قبل بناء جديد ليست سوى حوالي 1.0-3.0 ٪ سنويا، أصبح ترميم المباني اتجاها عالميا كاستراتيجية لخفض مستوى الطلب الكبير من شبكة الكهرباء. ولهذا السبب، اجتذبت كفاءة الطاقة في المباني ومفاهيم المباني الخضراء اهتمامًا مكثفًا من العديد من الحكومات والباحثين و المعماريين والمهندسين. تهدف هذه الدراسة إلى اقتراح إطار واحد يتكون من قائمة التقنيات التحديثية الموفرة للطاقة التي يستخدمها الباحثون لتحسين كفاءة الطاقة في المباني السكنية المصرية الحالية ومناهج صنع القرار المختلفة المستخدمة، والتي يمكن أن تساعد الباحثين في المستقبل على الربط بين استراتيجيات مختلفة لتوفير الطاقة.

Abstract:

With the excessive energy consumption worldwide where most energy is consumed by existing buildings while the replacement rate of existing buildings by the new-build is only around 1.0-3.0% per year, Building renovation has become an international trend as a strategy for reducing the level of peak demand from the electricity grid. Therefore, energy efficiency in buildings and green building concepts has attracted intense attention from many governments, researchers, architects, and engineers. This study aims to propose a single framework that consists of a list of energy-saving retrofit technologies used by the researchers to improve energy efficiency in the Egyptian existing residential buildings and different decision making approaches used, which can help future researchers to make a link between different energy-saving strategies.

Keywords

Energy Consumption, Existing Buildings, Energy Efficiency, Green Building, Retrofit Technologies

Introduction

Environmentally sustainable building construction has experienced significant growth during the past two decades. It became one of the leading hot topics worldwide, which is a way of enhancing community, environment, and economy. Given the numerous number of existing buildings worldwide and relatively low rates of replacement of existing buildings by new buildings, retrofitting the existing building stock has been identified, as having greater potential to improve energy efficiency and reduce GHG emissions than improving standards of new buildings. Since the building sector is one of the largest sources of greenhouse gas emissions and energy consumption around the globe which represent about 20.1% of the total delivered energy consumed worldwide (EIA, 2015). Therefore, the building sector should be a high priority in local, regional, and global climate change mitigation strategies.

Increasing energy consumption rates and the accompanied greenhouse gas emissions are considered of the world's greatest concerns. Globally building sector contributes around 40% of total energy consumption and one third of total greenhouse gas emissions (ELBadry, 2016). In Egypt, the total energy sold has reached 155 terra watt hour for year 2016 with an annual average growth rate of 5.25%, where the residential sector consumed more than 47% of the total nationally generated electricity, occupying the first place followed by industry and commercial sectors as shown in Figure (1) (EEHC, 2015-2016). The average growth rate of sold energy for the residential purposes increased at a rate of 2.8% yearly, while the average growth rate of sold energy for the industrial purposes decreased at a rate of 5.8% yearly for the period from 2011/2012 till 2015/2016 as shown in Figure (2). Therefore building sector in general and the residential sector in particular involved with a significant share in the current energy problem facing the Egyptian society. Therefore immediate action in the Egyptian existing residential sector toward sustainability is essential if we are to avoid more deterioration.

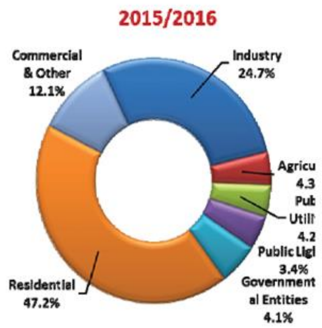

Figure (1): Percentage of energy sold according to purpose of usage (EEHC, 2015-2016).

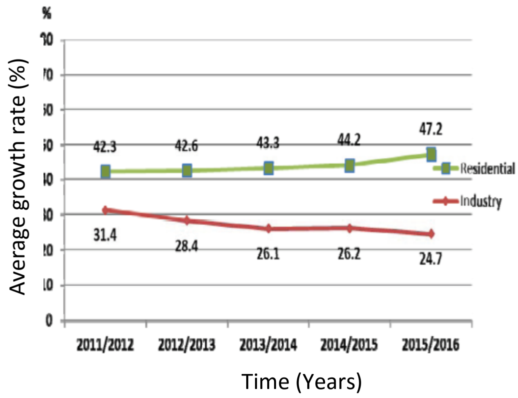

Figure (2): The average growth rate for the residential and industrial purposes (EEHC, 2015-2016).

The performance of existing buildings can be improved using a range of retrofit options, including green retrofit measures and sustainable technologies. Green retrofit measures can include, building envelope improvement, window enhancement to minimize heat gains, efficient lighting and lighting technologies. Other measures, such as enhancing natural ventilation and daylight, can further reduce energy consumption. Sustainable technologies can include solar systems, wind turbines, biomass boilers and combined heat and power systems, which have lower GHG emissions than conventional energy supply systems. (Jin Sia, et al., 2016).

Perspectives on the Concept of Sustainability and Sustainable Construction

Concern for sustainability arose in the early seventies as growing numbers of people realized that the degradation of the environment would seriously undermine our ability to ensure expanding prosperity and economic justice. Definitions and approaches to sustainability vary depending on everyone's perspective, but each emphasizes that activities are ecologically sound, socially just, economically viable and humane, and that they will continue to be so for future generations (Clugston & Calder, 1999).

Sustainability and Sustainable Development Concept

Sustainability is derived from the Latin word sustinere (*sus* means up and *tinere* means to hold). In general, sustainability means using of natural resources in such an equilibrium condition that do not reach decay, depletion and unrenewable point (Yilmaz & Bakis, 2015). "Sustainability" and "Sustainable" mean "to create and maintain conditions under which humans and nature can exist in productive harmony, which permits fulfilling the social, economic, and other requirements of present and future generations" (Clugston & Calder, 1999). Sustainability can better be called as responsible and accountable management of the resource usage where Sustainability is multi-dimensional term as shown in Figure (3) which maintaining a long term responsibility in economic, social and environmental dimensions (Rogers, et al., 2007).

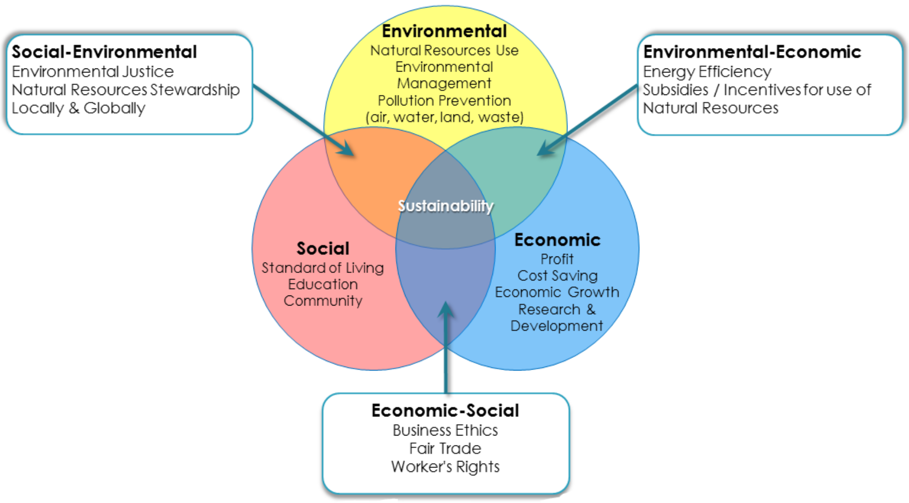

Figure (3): The multi-dimensional term of sustainability (Shaffie, 2014).

Recent Initiatives for Promoting Sustainability in Existing Buildings

The construction of buildings and their operation contribute to a large proportion of total energy end-use worldwide (Asadi, et al., 2012). In the building sector, most energy is consumed by existing buildings while the replacement rate of existing buildings by the new-build is only around 1.0-3.0% per year (Zhenjun, et al., 2012). Therefore, rapid enhancement of energy efficiency in existing buildings is essential for a timely reduction in global energy use and promotion of environmental sustainability.

At the same time, a significant amount of research has been carried out to develop and investigate different energy efficiency opportunities in order to improve energy performance of existing buildings (Asadi, et al., 2012). The results have showed that energy use in existing buildings can be reduced significantly through proper retrofitting or refurbishment Xing et al. (2011) as a holistic process which aims to sustain harmony between the nature and constructed environment by creating settlements which suit human and support economic equality. Building retrofitting or refurbishment is being considered as one of main approaches to realistically achieving reduced building energy consumption and greenhouse gas emissions as an application of sustainable development principles.

Review on the Energy-Saving Retrofit Technologies

Retrofit technologies are energy conservation measures (ECMs) used to promote building energy efficiency and sustainability. The retrofit technologies can be categorized into three categories which are as follows:

1. Supply side management.
2. Energy consumption patterns.
3. Demand side management.

The retrofit technologies for the first category supply side management include building electrical system retrofits and the use of renewable energy, such as solar hot water, solar photovoltaics (PV), wind energy, geothermal energy, etc., as alternative energy supply systems to provide electricity and/or thermal energy for buildings. In the last five years, there has been an increasing interest in the use of renewable energy technologies as building retrofit solutions due to the increased awareness of environmental issues. The use of renewable energy technologies may bring more benefits for commercial office buildings where a utility rate structure includes time-of-use differentiated electricity prices and demand charge is applied, on the other hand, the second category energy consumption pattern was denoted as human factors because the consumption level is basically determined by the users' behavior.

Finally in the third category the retrofit technologies for demand side management consist of the strategies to reduce building heating and cooling demand, and the use of energy efficient equipment and low energy technologies. The heating and cooling demand of a building can be reduced through retrofitting building fabric and the use of other advanced technologies such as air tightness, windows shading, etc. Low energy technologies may include advance control schemes, natural ventilation, heat recovery, thermal storage systems, etc (Zhenjun, et al., 2012).

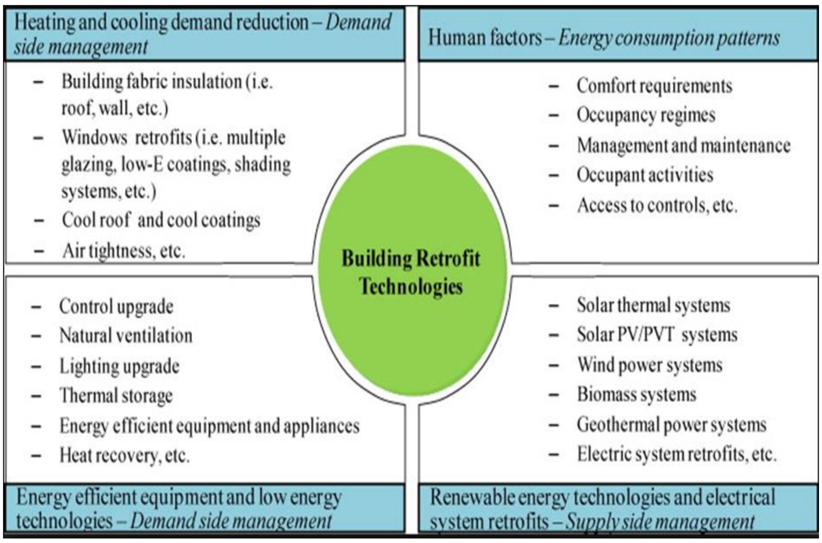

Figure (4): Building Retrofit Technologies (Zhenjun, et al., 2012)

International Application of Energy-Saving Retrofit Technologies

The use of energy-saving retrofit technologies has increased in recent years to reduce the consumption and depletion rate of non-renewable sources of energy and to protect the environment from their negative impacts. The use of these green techniques aims at improving energy efficiency, reducing energy consumption, promoting the use of renewable sources of energy, reducing greenhouse gases, and improving comfort and quality of life.

Several studies have been conducted to address the need for improving building sustainability by improving environmental and economic performances. Therefore, a number of research studies have been conducted to investigate the implementation of energy-saving retrofit technologies in existing buildings.

Von Neidaa, et al. (2001) conducted a research study on various commercial building types in a total of 24 states to analyze the potential of energy and cost savings of motion-activated lighting in commercial buildings. They found that motion-activated lighting can achieve energy savings that range from 6% to 13% of the total building energy consumption, depending on the type of application and which time-out settings were used.

Another study developed a computer modeling tool to calculate photovoltaic power generation for commercial buildings, this tool was able to calculate photovoltaic power based on hourly weather data and the tilt angle of a solar collector. The developed tool was also able to provide economic analysis for incorporating PV systems in commercial buildings. Furthermore, the developed tool was to calculate the most efficient angle of solar collectors that can provide the maximum power output (Pruitt, 2001).

Another research study analyzed the performance of LED Street lighting test project in downtown Raleigh over a period of six months. The LED lighting test project was found to produce 43% reduction in environmental impacts and 42% reduction in energy consumption (Abdallah, 2014).

According to Chiasson life-cycle cost study to compare the performance of green technology geothermal heat pumps with conventional HVAC system for a new office building in northeastern Nebraska. This study analyzed the performance of three HVAC systems including (i) gas heating and direct expansion cooling; (ii) air-source heat pumps; and (iii) geothermal heat pumps. The life cycle cost carried out for 30 years and showed that geothermal heat pumps had approximately 18% lower net present value as compared to the other conventional methods. This study also reported that the payback period of the geothermal system based on the annual energy savings ranges from 4.1 to 6.6 years based on the utilized system (Chiasson, 2006).

National Application of Energy-Saving Retrofit Technologies

In Egypt, a number of research studies have been conducted to investigate the implementation of energy-saving retrofit technologies in existing buildings. Attia and De-Herde conducted a study, addressing the impacts and potentials of community scale low-energy retrofit on a middle-income urban residential area in Cairo. It was found that by envelope retrofit, efficient solar protection, high thermal inertia, and hybrid ventilation strategies; in addition to domestic water heating, photovoltaic panels and solar thermal air conditioning (A combined strategy of retrofit) achieved up to 83% total reduction in electric energy demand (Attia & De Herde, 2009). According to ELBadry (2016) study which addressed to convert existing residential building to a net zero-energy building through applying energy modeling, it was found that by building envelope retrofit; in addition to the renewable energy strategies that suit the Egyptian context and potential, achieved the goal of a net zero energy building.

Another study was performed using a computer modeling tool to compare the baseline energy performance of three educational buildings located in Egypt with their retrofit energy performance.it was found that the retrofit enhancement methods have strong impact on energy consumption through some of the building envelope parameters such as, solar shading, glazing type and air tightness which achieved sequentially energy reduction by average of 23%, 8%, 2% (El-Darwish & Gomaa, 2017).

Similar study concerning higher educational buildings was conducted by Aboulnaga and Moustafa on a retrofitting approach to improve energy performance and mitigate CO_2 emission in hot climates, it was found that with some retrofitting approaches in glazing, insulation and green roof application could reduce 15% electrical energy consumption from the baseline energy use (Aboulnaga & Moustafa, 2016).

Another study conducted by Reda, et al. (2015) provides two building scenarios: Low investment scenario (LIS) and High investment scenario (HIS) where the first scenario includes some envelope solutions and system technologies but does not include renewable energy applications as it considered a low investment option. The energy savings for this scenario reached half the consumption of the reference case-study. On the other hand, the second scenario is more costly as it considered a high investment option, it beholds a combination of the first scenario with Photovoltaic system as an application of renewable energy technologies. The energy savings for this scenario reached the full consumption of the reference case-study.

A study and design of a complete photovoltaic system for providing the electrical loads in an existing family house according to their energy requirement was conducted by El-Menchawy et al. (2011) it is found that providing electricity to a family house in a rural zone using photovoltaic systems are very beneficial and competitive with the other types of conventional energy sources.

Finally a study accomplished by Elsayed (2017) in order to evaluate the impacts of "Feed-in tariffs Vs. Net metering" in deploying solar market in Egypt, this study included only a specific residential tier- above 1000 kWh. The mathematical outcomes showed that NEM is the best option for investment and offsetting/eliminating electricity bills for residential sector, without burdening the electricity grid. According to the results of this study the optimum approach for Egypt is "Net metering" scheme, as it offers the fairest program as it isn't limited on specific time, plus it provides the current market price for both user and electricity provider.

As discussed significant amount of research has been carried out to develop and investigate different energy efficiency opportunities in order to improve energy performance of existing buildings. The results have showed that energy use in existing buildings can be reduced significantly through proper retrofitting or refurbishment. Building retrofitting or refurbishment is being considered as one of main approaches to realistically achieving reduced building energy consumption and greenhouse gas emissions.

Decision Making Techniques for Selecting Building Upgrade Energy-Saving Retrofit Technologies

Decision making can be defined as the process of identifying and choosing alternatives based on the preferences of the decision maker. The process of making decision includes identifying objectives and goals of the decision problem, identifying possible alternatives and constrains, and selecting the best alternative that most fits the problem under consideration. Several techniques have been introduced in computer science and mathematics that aids decision makers in (1) identifying alternatives with the highest probability of success and effectiveness. (2) Identifying the alternative that best fits the decision making goals, objectives, and constrains.

Computer simulation software (modeling) and Economic analysis are a division of decision making where computer simulation software aims is to perform building modeling and provide a simulated prediction of building consumption rates and economic analysis methods are used to evaluate the economic viability of building retrofit technologies.

Building Energy Simulation

Reliable estimation and quantification of energy benefits are essential in a sustainable building retrofit decision-support system for prioritisation of retrofit measures. The performance of different retrofit measures is commonly evaluated through energy simulation and modelling. Building energy simulation tools have developed rapidly, hundreds of different tools have been developed. There are a number of building energy simulation packages, such as EnergyPlus, e-QUEST, DOE-2, ESP-r, BLAST, HVACSIM+, TRNSYS, etc., that can be used to simulate the thermodynamic characteristics and energy performance of different retrofit technologies.

Economic Evaluation

The selection of retrofit measures is a trade-off between capital investment and benefits that can be achieved due to implementation of the retrofit measures. Economic evaluation analysis, which facilitates the comparison among alternative retrofit measures, can provide an indication of whether the retrofit alternatives are energy efficient and cost-effective.

A variety of economic analysis methods can be used to evaluate the economic viability of building retrofit measures. Some of them, such as net present value (NPV), internal rate of return (IRR), overall rate of return (ORR), benefit-cost ratio (BCR), discounted payback period (DPP), and simple payback period (SPP), can be used to assess the economic feasibility of a single retrofit measure. Alternatively, the life cycle cost method and other advanced analysis methods can be used to evaluate the cost effectiveness of multiple retrofit alternatives (Verbeeck & Hens, 2005).

Discussion

The results from the analysis of the aforementioned studies have demonstrated that the energy-saving retrofit technologies commonly used in Egypt which compensate for the inefficiencies of the existing buildings are categorized as follows:

Category 1: Renewable Solar Systems (Photovoltaic systems - Solar water heaters)

Category 2: Energy efficient measures and lighting technologies (LED Lighting - Daylight level sensors - Energy efficient appliances)

Category 3: Building envelope retrofit technologies (Thermal insulation - Window enhancement - Solar Shading)

Conclusion

The present research study proposed a list of energy-saving retrofit technologies used by the researchers to improve energy efficiency in the Egyptian existing residential buildings and different decision making approaches used, which will help future researchers to make a link between different energy-saving strategies.

Existing building green retrofit initiatives in Egypt still have many uncertainties to overcome the challenges and the needed energy savings with respect to the allocated budget. Many retrofit approaches have long payback periods and is difficult to quantify the benefits of the green retrofit. The shortage of original existing-building design data and operational information is a major obstacle.

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