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Building Energy Efficiency (BEE): Conventional and Unconventional Techniques

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Abstract

In this review paper, a number of research studies and technical methods have been reviewed. Recently published papers related to the Building Energy Efficiency (BEE) have been cited in order to give readers information about latest applied approaches and technologies implemented to real scenarios for different types of buildings under different conditions. In this paper, reviewed papers that consider BEE and energy-use are selected. For example, approaches that achieve high rate(s) of building energy efficiency and energy-use performance have been cited. However, methods applied to measure building energy efficiency and predict energy-use behavior for energy demand measurement purposes have been considered and reviewed. This paper aims to collect a number of papers whose their aims are to propose systems affecting the building energy efficiency and energy-use performance either in a direct or indirect way, thus retrofit systems significantly affect building energy efficiency therefore retrofit related papers have been reviewed. Also, light control systems related papers have been considered. On the other hand, solutions proposed by several studies e.g., adaptive lights and smart buildings used for smart services e.g., notifying occupants in regard to energy-use have been covered in this review. Collected papers have been retrieved from top-tier publishers e.g., IEEE, Elsevier, PLOS, MDPI, and Emerald.

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1. Introduction

Recently, there have been many research studies proposed in order to achieve a high level of Building Energy Efficiency (BEE). Also, a number of systems have been designed and implemented to real scenarios of different types of buildings in order to create an energy efficient environment in buildings. The building energy efficiency plays an important role in in Energy Informatics and affects the energy-use performance as well as occupants' comfort. In addition, there are a lot of issues and considerations being affected by the way the BEE behaves. For example, energy demand, Carbon dioxide (CO_2) emission, and global warming issue. Several research studies have been proposed in order to treat such issues and challenges. For example, a number of research studies have mentioned buildings emit a huge amount of CO_2 and consume about 30% to 40% of energy consumptions [1-7]. This is just one of the big hazards that an inefficient energy building or a system might cause.

Many reviewed papers have attempted to enhance BEE using different techniques [8, 9]. Some of these techniques have focused on energy-use prediction by utilizing the building energy efficiency measurement [10]. A number of reviewed techniques attempting to design light efficient systems with regard to building interior design are reviewed [11]. Different types of lighting systems' designs that aim to achieve high level(s) of energy savings are reviewed in [12]. Some proposed techniques have achieved a good level of building energy efficiency and some others need further improvement. For example, one of the big issues most of retrofit approaches face is the cost and time. Therefore, the building energy efficiency is getting enhanced under certain conditions and limitations.

This paper has reviewed various papers that propose systems and approaches related to building energy efficiency. As discussed earlier, there are a number of limitations and issues to which those proposed approaches have been continuously and efficiently attempting to solve. This paper has also reviewed and discussed many related approaches. In this review paper, there have been four issues considered, which are: papers related to building energy efficiency measurement and predictability, energy-use related papers, light control systems, and buildings retrofit in terms of interior design. All these four considerations have been taken while papers are collected and cited by this review paper. Other conditions and criteria are in detail explained later in Proposed Method section. This paper highlights recently published approaches implemented and applied to real scenarios. However, some papers which have proposed a simulation and modelling based techniques and approaches have been considered and reviewed in this review paper. The most focus amongst reviewed and cited papers is the building energy efficiency and energy use performance issues.

The organization of this review paper is briefly introduced. The proposed strategy of papers' collection process is presented in Section 2. Literature review is provided in Section 3. Past studies in term of methodology are reviewed in Section 4 while the Framework is discussed in Section 5 Past studies' results are reported in Section 6. Discussion is given in Section 7. A Recommendation on techniques used to enhance the building energy efficiency measurement summarized in Section 8. Finally, Conclusion is drawn in Section 9.

2. Strategy of Reviewed Papers' Collection

This paper has applied several criteria in order to extract a number of reviewed articles. One of these criteria is the age of the papers. The paper age has been set to five years. Some related papers have been considered with an age of 15 years in order to give a related discussion. Also, several additional issues [13] were considered in this paper. One of these is the keyword(s) selection. In this review paper, keywords are classified into four main classes which are: "building energy efficiency", "energy-use", "retrofitting methods", and "smart methods for building energy efficiency". This part has been enhanced compared to [14].

3. Literature Review

This literature review is designed based on the variety term that most proposed and reviewed papers include. Several designed and proposed approaches and techniques related to the energy efficiency and the energy-use have been reviewed. If their performance(s) can be an optimal or semi-optimal level for energy saving will be considered. Also, many limitations and disadvantages were mentioned.

3.1 Challenges Faced by Current Research Studies

In [3, 15], the research study discussed the energy consumption in China. The paper [15] has proposed a measurement method and calculation has reported that 20% of energy-use is consumed within residential buildings. As discussed, two reasons can cause such a huge amount of energy-use. The first reason is the way the thermal isolation is designed as. The second one is the heating system in which its efficiency is low [15].

Additionally, a similar scenario in UK has been reported in a paper [16] that discusses the issue of carbon dioxide emissions. It is 19% of energy consumption. It is mentioned that the energy use is affected by profiles of activities of occupants inside buildings.

Another example dedicated for commercial buildings and offices has mentioned that energy-use can be affected by internal design specifically in regard to the HVAC [7, 17, 18].

3.2 Energy use Reduction

There are many researches focused on the issue of energy use reduction for different of buildings. As for example, the paper reviewed in [19] has suggested that to reduce the energy consumption, it is advisable to efficiently consider the lighting designs and systems. Another proposed study [20] has suggested that a good and efficient decision can contribute much in energy savings for different types of buildings using several techniques.

3.3 Building Energy Efficiency (BEE)

The building energy efficiency has been considered by many research studies aiming to achieve good energy savings levels and performances. In [21], a method has been proposed to enhance building energy efficiency. It has used sensors for monitoring and performing control functions inside rooms and interior space(s) of the building. The energy efficiency has been then measured. In [22], there are two conditions have been addressed to find out relations between buildings and high energy-use. This study has only focused on a building with a fully-glass area and a 40 % glass windows. This design would enhance and contribute to energy consumption in buildings. In some different methods, in [23], for example, it is mentioned that occupant behaviors can be a key factor in enhancing energy use much.

4. Methodology

This paper concerns building energy efficiency and energy use whereas research studies are addressed.

4.1 BEE Measurement related Research Studies

Here, those papers which aim to deal with the issue of BEE are taken in this review paper. An example is presented in [23]. The designed method contains three sub-sequential steps: the first one is pre-processing, the second one is data collection, and the third one is normalization, clustering, classification, and building energy efficiency calculation.

4.2 Prediction based Methods for Energy use

An interesting article discussed in detail in [23] has concerned profiles of occupants where the related data has been collected during different times.

A research study discussed in [16] proposed a measurement method for the energy use. Firstly, data collection procedure has been applied utilizing activities of occupants. Then, the energy consumption, table data, has been created. Secondly, the averaged rate of the energy use for each day has been then calculated. This has been followed by an analysis procedure. The minimum value of energy use has been extracted. The ranged amount between 25 kWh and 35 kWh for working hours has been appointed. External conditions, e.g., changing in temperature has affected the internal performance of the energy use, as reported in the results of that paper.

4.3 Proposed Designs for Internal Environment of Commercial Buildings

There have been several types of designs proposed to enhance the performance of energy use for buildings from the design of internal environment perspectives. Some related papers are discussed. For example, in [19], it is designed for lighting systems purposes. A light-controlled design to measure the luminance of internal areas of spaces inside the building. The aim is to measure how much the light will be needed in order to come up with the optimal occupants satisfactory. The energy use also will be measured and should be as low as can. There have been many conditions and parameters considered during design and have been evaluated e.g., corridor areas, free spaces, small rooms, and walls to attempt achieve higher energy savings and the highest building energy efficiency.

There is also another paper presented in [20] that concerned the occupant's activities. Related features have been exploited. The aim of the paper is to have the energy use reduced compared to other competitive research works. The first step is to collect relative data from profiles of occupant. Also, the behaviors of occupants have been taken into an account. The proposed method aims to come up with a number of multi criteria-based optimization solution(s). It is then concluded that the resources of buildings being used can be evaluated to see either the energy use performance have been enhanced or it is needed for a further making decision strategy to be applied to the proposed system. There is another objective of this paper, that is to investigate either the governance sector can get benefits from such decision making solutions and strategies in regard to the building energy efficiency or not. The proposed design consists of two main parts, the first one is the decision design while the second one is the decision making. Each part consists of several steps. There have been retrofitting procedures that have been applied to the selected buildings in order to measure the energy use. Meaning, the energy use sometimes is reduced much with the help of retrofitting strategies. A list of examples of retrofitting measures can be found in [24].

5. Framework

This review paper is determined by some limitations and thus some discussed advantages and disadvantages of reviewed papers are discussed accordingly. In this sub-section, a brief overview on generalized scope that most papers follow in the field of building energy efficiency is provided. Then, this is followed by some discussion about their limitations. Finally, advantages and disadvantages of several papers will be discussed based on limitations mentioned.

5.1 Scope and Limitations

Most of papers have focused on using a simple mathematical procedure to measure the building energy efficiency whereas some others have considered the issue of energy predictability. On the other hand, some research studies have implemented practical designs for buildings to replace their current interior designs or most of interior designs parts in order to reduce the energy-use.

5.2 Interior Design Analysis

One of the effective techniques attempting to introduce enhanced portfolios for interior designs dedicated for connected buildings has been reviewed in [20]. It has produced somehow effective portfolios and solutions for semi-optimal decision making retrofit designs for a number of buildings. However, it is considered cost and requires an additional change for some building's interior design materials and parts in order to achieve an adequately integrated building technology. Despite some other methods e.g., [3] has considered using the existing interior design of building to reduce the energy-use, its results have been positively reported to produce efficient solutions in terms of energy saving and energy efficiency performance enhancement.

6. Results Reported in Previous Research Studies

Selected techniques have achieved higher rate than other competitive research studies in terms of energy savings and building energy efficiency. There are however many challenges and difficulties that many methods have concerned and addressed to overcome them. So, there will be an analysis discussion and related results of such research studies are reviewed and discussed here. Additionally, limitations of those methods that might affect the performance of energy use will be briefly mentioned.

6.1 BEE Measurement

The building energy efficiency issue has been discussed in many studies and related results have been reported. One retrofitting related study has been reviewed in [21]. It has concluded that the retrofitting technique of sensors in old buildings costs a lot. Compared to recent buildings, it is simpler and easier and therefore it reduces the energy use. Further challenges that may occur can be the internet connection [23]. Such an issue may increase the response time for energy reads associated with, for example, smart meter data. Also, random spikes at different times might be happening causing wrong obtained results and reads.

The energy use caused by lighting systems has been addressed by many research studies [25, 26]. Some papers have taken into account the occupant's preferences-based light's conditions to monitor the energy use however neural networks [27] have been considered by many others. In some cases, logic systems effects on illuminance [28, 29] have been studied. In [16], it is concluded that users' activities could obviously allow for an extra rate of the energy use. Thus, it is advisable that automatic derived controlling systems will be a good retrofitting technique to increase the building energy efficiency and reduce the energy use for a different variety of buildings. In case of large-scale buildings, this solution will be useful and can contribute much to energy savings utilizing retrofitting strategies.

6.2 Energy use

Many techniques have been exploited by a number of research studies related to the energy use. There are several criteria considered e.g., building energy consumption, building construction cost, and CO2 emission in order to design an effectively cost tool to help make a decision by which the building energy-use is getting reduced. For example, the authors in [30, 31] have considered a number of measurements based on the three criteria mentioned earlier in order to make a decision related to factors that mainly and effectively reduce the energy use. Other research studies e.g., [32-34], have proposed multi criteria-based decision-making tools in which certain measures have been considered. These researches have supported decisions to effectively design a system that addresses the energy use and building energy efficiency whereas some important considerations have been taken into account for example; environmental influence vs. renovation cost [35, 36], building interior design characters vs. sustainable energy savings [34], and which building(s) to choose for upgrading vs. how to establish an optimal portfolio of energy efficiency for connected buildings [37, 38]. All the considerations mentioned above have been addressed by several attempts with a limited and poor performance of results due to a number of drawbacks.

7. Discussion

7.1 Light control system design related studies

Many reviewed papers in literature have been found focusing on designing light control systems in order for energy use being reduced so that the building energy efficiency can be better for an optimal measurement performance and predictability. Obtained results from a number of recently discussed papers have confirmed that such a good design of light control system can significantly reduce the energy-use as reported in [19]. Another example is the light system proposed in [28, 39] which produces a very low energy-use for a room lighting system. Despite it is suitable for a single room, it could be efficiently re-used for a single building and/ or connected buildings since its results have confirmed the design comes with a low cost. Therefore, such a lighting system design is acceptable for building being constructed or small building inside commercial offices, complexes and/or factories.

7.2 IoT related studies

The Internet of Things (IoT) can be exploited by many energy efficiency systems to get benefits from such features. IoT-based functions can be extensively performed and done within a wide range of applications used by smart appliances [40].

In [41], it is suggested using an interactively IoT-based system with occupants in a real time scenario to measure the building energy efficiency. In this work, one of the smart home appliances has been selected to be the tested platform. This appliance (refrigerator) has been selected due to it consumes a part of building's energy. A smart plug in and data availability are the most challenges of this work. However, the findings have reported that occupants, i.e., they are defined as an IoT-based system's users, are interactive to share data with energy monitoring sector to measure the building energy efficiency and save more energy from being unnecessarily used. The term "smart services in building energy efficiency" has been studied recently by few numbers of concerning firms. This term has been slightly applied in small buildings to do smart services using IoT [42].

8. Recommendation

It is recommended that such light control system designs, for example, are of intelligence to automatically on/off room's switches to fast alter between two cases of working and nonworking od energy-use mentioned in [23]. This technique could be exploited by smart home and buildings. In [28], it has been shown how efficient and effective automatic switch of room's light could contribute to save energy and reduce the building energy for an optimal efficiency performance. Therefore, such smart systems could be implemented using IoT technique to send reports to energy sector distributor and suppliers. By using an IoT tool, such a building could be recognized for a low energy-use level. This technique can be applied for connected buildings and it could help predict the energy-use as well while data is sent easily and frequently with no human intervention. By using smart techniques, they can utilize IoT in order to produce enhanced building energy efficiency related tools to save much the energy-use from being unnecessarily used at several times. In this case, related sensors, however, will be required to be installed outside buildings to measure weather changes such as sunny days, cloudy days… etc. As concluded, a summary of methods applied on general problems and gaps found in research as well as advantages and disadvantages of suitability to apply proposed methods for certain cases is illustrated in Figure 1.

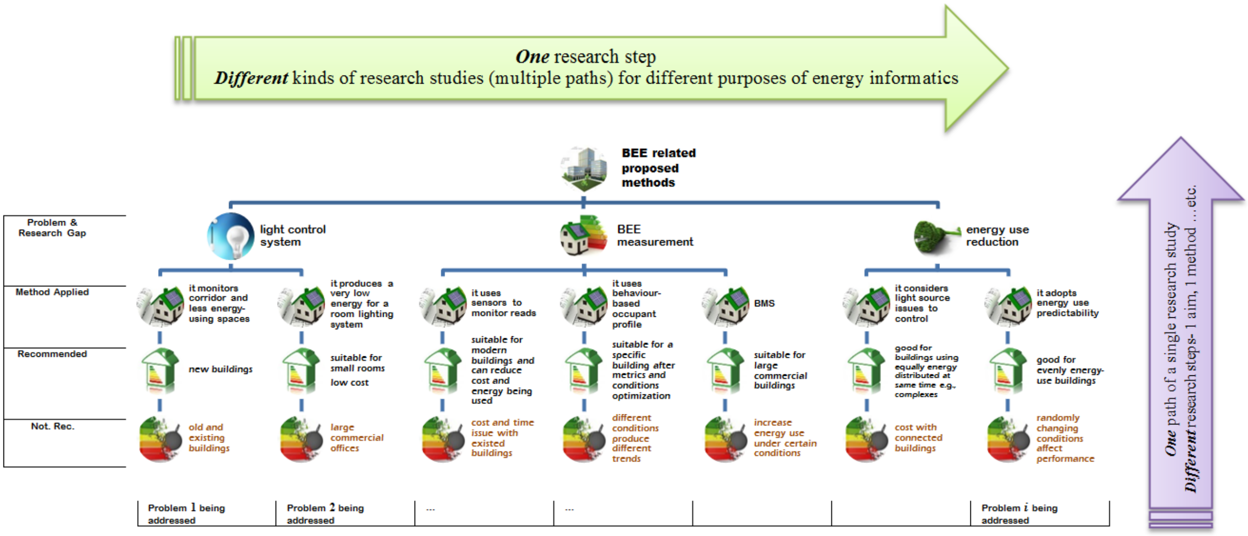

Figure 1: BEE Proposed Methods Suitability – A Recommended View

9. Conclusion

In this review, many research studies that concern the building energy efficiency have been reviewed. In this review paper, the papers that have been recently published within last five years have been cited. However, there are some related papers have been cited within about fifteen years of publishing date. Main keywords have been set to: "energy-use predictability", "light control systems", "retrofit the interior design", "occupants' profiles", and "smart techniques".

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