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Research paper

A Review on Building Energy Efficiency Techniques

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Abstract

This paper highlights a number of recently published research studies during last five years in order to provide a summary related to latest trends of energy efficiency in the smart buildings technology. It reviews numerous technical methods applied to achieve a high level of Building Energy Efficiency (BEE). In this paper, methods applied to measure the BEE and to predict the energy-use have been considered and reviewed. Furthermore, some other methods discussed in articles which consider retrofitting of interior design of buildings have been taken. One of the most impacts that has been considered is the light control system because it directly affects the energy use. This paper has reviewed different types of techniques that save energy consumptions such as predictive techniques of energy use, Internet of Things (IoT) buildings, light control systems inside buildings, and Quick Response (QR) code based services used to notify occupants for energy-use. It has provided a simple comparison between different techniques used to retrofit the interior design of buildings due to its high importance in saving energy. The paper has also recommended suitability of methods taking into account the existing situation, design, limitations, and conditions of the building being studied.

Keywords: *energy-use; building energy efficiency; occupant behavior-based energy-use prediction.*

1. Introduction

The Building Energy Efficiency (BEE) topic has attracted many researches due to its importance in energy informatics. Thus, many attempts from both academia and governmental worlds have been driven into the BEE direction to enhance its related studies. The main aim of these studies is to reduce the energy-use and save more energy from being consumed unnecessarily.

One of the most important keys that many researchers have considered to address the BEE is that the building energy-use emits a huge amount of Carbon dioxide (CO_2) and consumes between 30% and 40% of all energy [1].

Many proposed methods have been reported and reviewed attempting to enhance the BEE using different techniques, some of which have focused on the energy-use prediction based on different methods used to measure the BEE. Some others have focused on proposing new designs of light systems. Also, recent studies have suggested retrofitting an interior design of the building.

Despite these studies have given good results, there are several challenges faced by recent techniques to reduce the energy-use, to measure BEE, and to enhance BEE-related techniques' performance.

In this paper, many BEE related techniques have been summarized. Different aspects have been included. Different limitations have been applied on many types of buildings. In regard to obtained results of reviewed articles and techniques, the paper has focused to highlight three issues which are the BEE measurement and predictability of energy-use, control light systems, and retrofit the interior design. Briefly, several proposed methods dealing with BEE measurement have produced an acceptable level of findings in terms of efficiency and energy-use prediction. Some interior design related techniques have been reportedly costly. However, their related technical results are discussed later.

This paper aims to give readers an overview on recent techniques which have been applied on a specific building or connected buildings to enhance BEE measurement and energy-use predictability. It also highlights the most suitable techniques for research cases being addressed.

In regard to the strategy of collection of reviewed studies in this paper, many conditions have been set which are discussed herewith. Mainly, recent papers within the period of last five years have been considered to be in detail reviewed and investigated. However, a deeper strategy of several older studies reviewed and cited by those recent studies has been considered to build an attractively complete idea to readers. Many considerations have been made. For example, the following keywords: "building energy consumptions", "building energy efficiency", "building management", "commercial building", "efficiency-based entropy", "energy awareness", "energy savings in buildings", "energy use predictability", "energy use reduction", "energy-use", "Internet of Things (IoT) building", "lighting control system design", "smart buildings", and "Quick Response code (QR-code) for smart buildings" have been selected and used while searching for recently published articles.

Besides the first condition, the date of published articles has been set to two classes which are: the first class has mainly determined within last five years. Articles of this class have been deeply reviewed. The other class however has gone so early and some old researches have been considered within the period of last fifteen years whereas smart home applications are associated extensively by that period.

As for publishers, IEEE, Elsevier, MDPI, Emerald are the main sources. Accordingly, the following digital libraries: IEEEXplore, ScienceDirect, MDPI, Emerald insight have been the only source.

Another condition is related to the types of articles: experimental published in top-tier journals and indexed by SCIE WOS and Scopus have been taken.

This paper is organized as follows. Section 2 gives a research background on a number of relatively proposed methods and techniques reported in previous works. In Section 3, Methodology of recently published articles to highlight their technical presentations is given. Analysis of BEE Techniques is summarized in Section 4. Section 5 suggests some recommended remarks on techniques used to enhance the BEE measurement. Finally, Section 6 depicts Conclusion.

2. Research Background

2.1. Introduction to Research Background

This section reviews a number of proposed methods used to measure the energy efficiency and enhance the energy-use for an optimal or semi-optimal for energy save and consumptions in either a specific building or connected buildings. Different methods have been investigated each of which has a specific design raised from the problem being studied. There have been several limitations and drawbacks reported in literature. That has made it difficult to implement or apply a specific designed methodology of building(s) on others due to the diversity of limitations associated with the problem being stated and solved. This section differentiates between varied research studies. It also reviews techniques based on purposes for which studies have been designed.

2.2. Challenges Faced by Current Research Studies

In a recently published study and its case study has been selected in China has discussed one of the energy-consumptions related issues which is the energy consumption by residential buildings [1, 2]. The paper reviewed in [2] has measured the energy-use in China whereas about 20% of energy-use has been consumed by residential buildings as shown in Fig. 1. Residential buildings use about, per [2] statistics, 200 billion kWh of energy. There are two main reasons causing this huge number of energy-use, a simple thermal isolation system installed in buildings and heating systems with low efficiency [2]. A likewise research has presented an analysis system to the BEE applied for Korean buildings. A big challenge reported in relative researches [1-3] has been extensively studied is that a huge number of civil buildings will continue to be built with inefficient energy-control systems every year which cause energy-use and the BEE faces new challenges which become costly when a retrofit new energy-saving technology is required.

Some other challenge reported by a recent research study [4] implemented in UK is that the emissions of CO_2. The study [4] has reported that nearly, 19% of the total CO_2 emissions in UK is caused by building energy-use. This study has derived the relation between the energy use profiles and users activities in a specific building in order to retrofit and design an optimal system that helps reduce the energy consumption.

Numerous studies have mentioned another challenge that has a relation to CO_2 emission which can be happened in non-residential building as well as residential buildings which is the Heating, Ventilation and Air Conditioning (HVAC). The researchers have reported that CO_2 emissions can be caused by this problem, i.e., HVAC. One of the researches has mentioned that a huge portion of energy use can mainly be caused by the poor interior design of HVAC specifically in non-residential buildings, offices and shopping complexes are two examples [5-7].

2.3. Energy-Use

This issue is so crucial and important for the field of energy efficiency; because it affects the efficiency and also controls the amount being measured. Once this issue has been efficiently manipulated and controlled, the whole BEE should have been enhanced. There have been several researches investigating the energy-use reduction problem. One of these research studies is reviewed in [8] whereas this study has considered the lighting source issue. It has considered that the lighting is one of the most sources consuming more energy. The energy-use of lighting sources is more than other sources. Thus, BEE is getting lower in the case of using high-consumption light. Based, this method has designed a system to save light-sourced energy. The authors have proposed a light-controlled system that helps to reduce the energy-use leading to increase the BEE in terms of light cost and its consumptions. This proposed method is mainly dedicated for lighting control in buildings and has used the occupant's profile data and behaviors in order to design a light system that reduces the energy-use during days' hours.

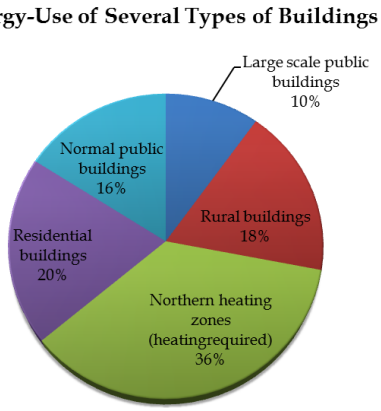

Fig. 1: Types of buildings in accordance with energy-use in China

On the other hand, there have been several methods [9] proposed in order to make efficient decisions on how to reduce building energy consumptions. But their performances are limited to alternative development aspects such as for management and automation of current buildings. Furthermore, the difficulty found is because of that current buildings being developed in terms of energy-use have a form of construction that makes such a BEE struggles much more in order to reach an acceptable level of performance in terms of energy efficiency. However, to benefit from decision-based occupant-profile analysis, it is useful to design an effective tool [9] that helps to retrofit and create an optimal occupant profile for decision making on what criteria are to reduce the energy-use to enhance the BEE.

2.4. Building Energy Efficiency (BEE)

Some proposed methods have been dedicated to measure the BEE while some others have attempted to enhance the BEE efficiency each of which has achieved a different level of performance.

2.4.1. Studies on BEE Measurement

The authors in [10] have proposed a method to enhance the building energy efficiency. It has used sensors to monitor and control the electric lighting fixtures of different office spaces and rooms to measure the energy efficiency. Another study reviewed in [11] has explored and investigated the relation between high energy consumption in modern buildings caused by some factors for example, HVAC and the use of supportive materials for green buildings that helps reduce the energy consumption for a better BEE. It has introduced a study to analyze the BEE in two different environments and under different conditions; the first environment is a glass area building while the second one is a 40% glass-window designed building. In this analysis study, the HVAC has been mainly considered in order to come up with a conclusion of analyzing fire and energy efficiency considering the green-building standards.

Some other methods have attempted different ways and techniques of measuring the BEE. For instance, both behavior-based technique and occupant-focused profile way have been exploited to enhance the BEE measurement. In previous studies, one of these

examples has been reviewed. In [12], behavior-based BEE measurement methods have been widely proposed and applied independently but with a limited quantitatively-performed classification of building occupants of their energy-use behaviors. Furthermore, other measurement methods such as Building Management Systems (BMS) associated with sensor networks do much slightly engage building occupants and do not effectively perform adequate measurement scores in terms of energy-use and data based occupants' behaviors. However, behavior-based measurement methods can be alternatively and someway be used with a quantitatively designed metrics method used for both behavior-based BEE and sensing techniques after a specific modification in terms of design and BMS optimization. The authors in [12] have exploited the feature of behavior-based BEE measurement method and re-designed a new set of metrics to efficiently analyze data collected from building occupants' behaviors and then measure and improve energy efficiency.

3. Methodology

3.1. Introduction to Method's Strategy Applied

This paper concerns building energy efficiency and energy-use related researches. Furthermore, this paper reviews some research studies which have designed new commercial methods by which building energy is being controlled and saved. Thru methodology's discussion, the strategy the reviewed articles have been collected is included and considered. Mainly, the reviewed articles are recently published within last five years and some related articles beyond that period are taken then.

3.2. BEE Measurement related Research Studies

This sub-section will summarize some techniques proposed to measure the BEE reviewed in literature review in order to give the reader a comprehensive picture about recently published works. One of the useful techniques dedicated for this purpose has been reviewed in [12]. The authors have designed their method in three steps which are: preprocessing and data collection and normalization, clustering and classification, and BEE calculation. After data was collected, a preprocessing is proposed to correct some corruptions occurred at different times for example, network connection loss and also to normalize collected data to avoid wrongly classified BEE measurement scores using Equation (1):

$$mat_B(i,d) = \frac{mat_A(i,d)}{max_e(d)} \quad (1)$$

The matrix $mat_B(i,d)$ is proposed in order to normalize non-normalized $mat_A(i,d)$ energy-use indexed by a time interval of *i* of a day *d*, by performing a subdivision operation with the maximum energy-use $max_e(d)$ of a day *d*. In this design, a time interval was set to 1 hour to guarantee 24 intervals per a day *d*. The second step has adopted to separate days into working days (WD) and non-working days (NWD) as well as work hours and non-work hours to have 24 clusters designed thru the first step. WD and NWD expressions define the day an occupant comes and doesn't come to the building, respectively, in order to efficiently measure the clustered measures, WD and NWD are classified into 0-24 h producing 25 points to be measured and defined by Euclidian distances to produce 25-D for vectored-measures for energy-use for a single day *d=1*. This accumulative process helps produce separated hours (i.e., work hours and non-work hours) indicating energy-use density; whereas for working hours the energy-use density is higher than in non-working hours as shown in Fig. 2.
These reads in green color will be used for measuring the BEE after a special threshold-based cluster procedure with the help of Euclidian distance has been applied on reads' values provided. The resulted threshold-based clusters are: high, medium, and low energy-use. For each occupant, the energy-use score will be used to mark a label mentioning, for example, *a 'high' energy-use* during work hours if a certain pre-defined criterion range (suppose: 10 W/h) within which the related occupant's energy-use is located has been fulfilled. The last step is to measure BEE by proposing a special equation performing a division operation of non-work hours of all days (WD and NWD) to all hours of all days. Once the calculated result is low, the BEE is low.

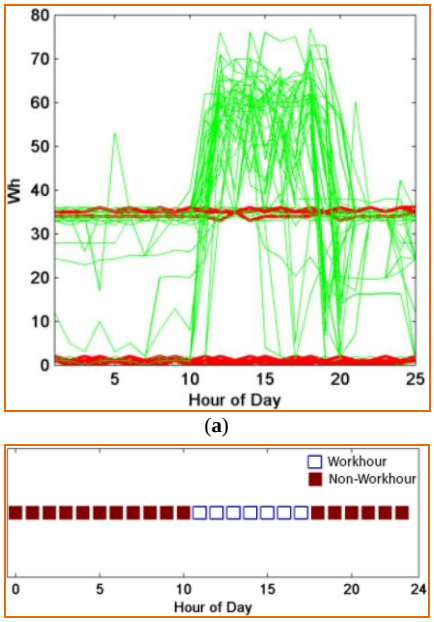

Fig. 2: The process of detection of working-days and working hours; (**a**) detection of WD (in green) and separation (NWD red) in a non-normalized phase and (**b**) its work hour range separation (Dark red); source [12]

3.3. Energy-use Predictability and Evaluation Methods

The authors in [12] have proposed a new measurement method for BEE and energy-use predictability based on quantitative data collected from building occupant profiles in different conditions such as working- nonworking days and working- nonworking hours.
In this matter and in order to deeply understand what the benefit of energy-use reduction in connected buildings is, the relation between energy-use and its consumption affected by occupants needs to be addressed. A study [4] has proposed, for a specific building, that a half-hourly basis profile is processed in which the energy-use is measured in order to come up with changing in energy-use profiles made by different occupants and activities. Firstly, data during a certain period of time is collected whereas users' activities are used to constitute an energy consumption focused profile. Then, average energy-use per each working day is calculated and then analyzed. The minimum energy-use amount that has been set for analysis and evaluation of the BEE measurement is selected to be between 25 kW and 35 kW during work hours. Statistics showed that about 35 kW to 58 kW of energy is consumed due to several reasons such as weather changing in noon times which require air-conditions turning on, activities that require more energy-use, and other activities that require more light use.

3.4. New Techniques for Interior Designs of Commercial Building(s)

This sub-section has presented a number of recently published research studies to discover techniques dedicated to propose new designs that control the energy consumption in a single building or connected buildings. However, some studies that have proposed solutions and new designs for interior design of buildings will be discussed here.

One of these proposed method reviewed in [8] has addressed an essential step in designing a light-controlled system which is to measure the illuminance of surrounding environments to detect the amount of light needed for the best satisfaction of occupants and the best of lowest energy-use. In order to consider every characteristic of light conditions for all building spaces and rooms for example, wide, small, and corridor type spaces, the proposed method has included a number of light-conditioned control parameters. These parameters take into account the occupant's movement to adaptively change the light illuminance (L) from maximum to minimum within a suitable period of time (T) that makes the occupant comfortable with light changing.

Other method has considered occupant's profile feature to propose a method in order to reduce the energy-use. A method discussed in [9] has collected certain data from occupant profiles and behavior in order to make a multi-criteria based decision that helps reduce the energy-use to propose an optimal solution for the available financial resources to be used at the relative building being evaluated. The second aim of this study is to propose further solutions provided to the city governance sector helping make an optimal management decision in regard to the BEE. Technically**,** it [9] consists of two phases which are decision design and decision making. In the first phase, parameters understanding for a best model simulation performance whereas these parameters are applied on a buildings scenario will be carried out. There are several steps of which the first step consists; one of these steps takes into account predefined criteria such as interior environment characteristics and ideal energy consumption. Another step ensures that the criteria fit to the respective status of building based on evaluated functionalities related to energy consumptions and interior environment characteristics. This step suggests a plan to which every criterion has to reach in order to retrofit multi-criteria plan for a portfolio of several buildings. Next, further measures are then applied on each building; attempting to produce a list that helps to reduce the energy-use based on retrofitting existing buildings' conditions. The aim of this step is to retrofit the current energy-use to a reduced one with relation to other buildings characteristics. This step might propose to replace a number of currently used energy equipment for example, HVAC. The proposed plan [9] in this step is one example of retrofit measures, however a list of examples of retrofit measures can be found in [13]. The second phase suggests solutions based on alternative options obtained from other buildings conditions and characteristics in order to produce an optimized strategy and plan by which the best BEE should be achieved. In case this method is proposed to connected grid, each building can accept certain options taking into account its interior design, environmentally surrounding area, technical needs of structure being considered, and so on.

4. Analysis of BEE Techniques

Some proposed techniques have achieved efficient performance in terms of BEE measurement and energy-use. However, some other reviewed articles have face challenge and difficulties once they have been applied due to a broad variety of reasons discussed earlier. This section will summarize some reported findings in order to analyze their performance based on limitations that have caused some challenges to achieve a high level of performance.

4.1. BEE Measurement

When a proposed technique is applied on a selective building or connected of buildings, some big impact factors are so close to decline the behavior of applied technique's performance. The design of building, age of a building in terms of modern or old history, and are some examples of these challenges affecting obtained results. This issue is explained and illustrated in Fig. 3.

In one of the reviewed articles [10], it has been found that it is of difficulty of installation procedure of new sensors equipment that monitors and helps reduce the energy consumption of old buildings is existent. But, with modern buildings the difficulty and cost are of simplicity.

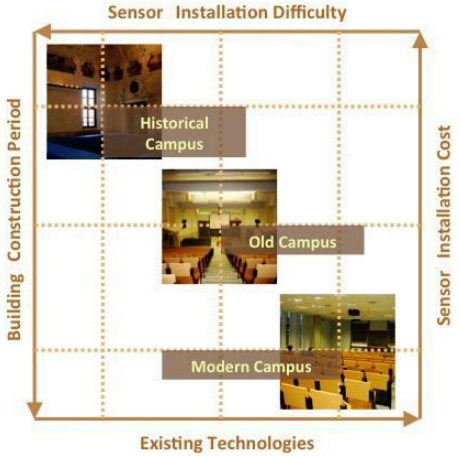

Fig. 3: Sensors' techniques installation on old and modern buildings [10]

Some reported challenges that might happen are with internet connections as discussed in [12]. This challenge will produce delayed reads and sharp spikes at non-accurate time causing false reading and scores for energy-use for a time interval *h*.

Some other competitive methods which have been proposed in order to reduce the energy-use caused by light have shown good performance in terms of BEE. For example, [14, 15] have adopted to select some occupant's preferences-based light's conditions in order to control the energy-use. And some others have used neural network [16]; others have used a logic-based system considering daylights to control the amount of illuminance [17, 18]. However, other reviewed study [4] has shown that when additional activities made by users and occupants the energy-use increases accordingly and the BEE becomes less. The authors have suggested a simple automatic solution to operate the energy for the building being used for their study in order to retrofit a semi-optimal BEE.

4.2. Entropy-based BEE Predictability

In [12], the proposed method for energy-use predictability based on the entropy efficiency should have enhanced the prediction of dynamical behavior of energy-use. As shown in Fig. 4, at *x-axis* between values 0.4 and 0.8, the entropy has the highest value of frequency among other values for 1 day, however it could be for a number of days, indicating a higher level of energy-use during this period which means the number of non-working hours of both WD and NWD is reduced; therefore, that means the BEE is going to be reduced.

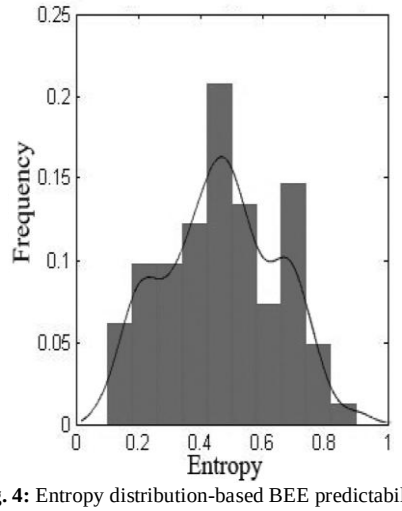

Fig. 4: Entropy distribution-based BEE predictability

4.3. Energy-Use

There have been several proposed methods considered a number of criteria for example, building energy consumption, building construction cost, and CO_2 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 [19, 20] have considered a number of measurements based on the three abovementioned criteria in order to make a decision related to factors that mainly and effectively reduce the energy use. Other research studies for example, [21-23], 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 BEE whereas some important considerations have been taken into account for example; environmental influence vs. renovation cost [24, 25], building interior design characters vs. sustainable energy savings [23], and which building(s) to choose for upgrading vs. how to establish an optimal portfolio of energy efficiency for connected buildings [26, 27]. All the above mentioned considerations have been addressed by several attempts with a limited and poor performance of results due to a number of drawbacks.

4.4. Evaluation of IoT and QR-Code Related Studies

Such IoT-based services implemented and applied on smart home appliances are of importance because they affect the performance of building smart services [28]. Energy-use and BEE are examples of services that can be efficiently studied using the artificial intelligence and IoT thru shared information by buildings' occupants.
The work proposed in [29] has suggested using an interactively IoT-based system with users/occupants in a real time scenario to measure the 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 plugin 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 BEE and save more energy from being unnecessarily used.
The term "smart services in building energy efficiency" has been studied recently by a few number of concerning firms. This term has been slightly applied in small buildings to do smart services using IoT [30]. In order for IoT be applied efficiently, some proposed ideas have used the QR-code technique to perform several tasks, for example, read energy-use from the building smart meters Advanced Metering Infrastructure (AMI), and inform occupants with energy notification. However, there have been some IoT-based projects proposed for example, [30], in order to perform tasks that contribute to save much more energy for smart building using AMI [31]. A sample of AMI used in is shown in Fig. 5.

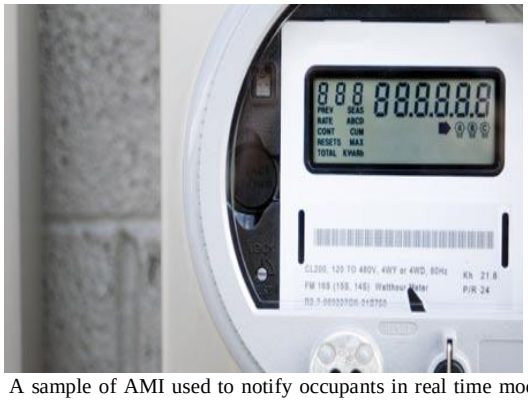

Fig. 5: A sample of AMI used to notify occupants in real time mode and calculate energy cost [31]

4.5. Advantages and Disadvantages

In this subsection, a comparative summary is given in order to compare between different types of methods proposed to enhance the BEE and also save the energy consumption using different techniques as shown in Table 1.

Table 1: Advantages and disadvantages of some reviewed techniques

Ref.	Study Purpose	Advantages	Disadvantages
[1]	Energy-use and BEE measurement in connected residential buildings	·Low-cost designed method compared to other techniques which require replacement of some interior design's parts	▪ Not fully and sufficiently been tested and applied on different buildings' design(s)
[8]	Light control system design	·Adaptive design of illuminance control	▪ Frequently-used light system ▪ Complicated hardware system for example, sensors
[9]	Occupant profile for decision making for energy-use	·Effective portfolios for interior designs ·Suitable for connected buildings	▪ Cost
[12]	behavior-based BEE measurement methods	·Enhanced a prediction level of dynamical behavior of energy-use	▪ Fixed energy-use parameters ▪ Internet connectivity issues
[29]	IoT for smart buildings	·Interactive application with users/occupants using smart phones ·Able to contribute to save energy when data is shared thru this system between occupants and energy monitoring sector	▪ Smart plugin enabled use ▪ Appliance data availability

5. Recommendations

From the above mentioned discussion regarding the BEE measurement and energy-use prediction, it is clear that there are many techniques suitable for a certain range of buildings and under certain conditions in order to produce a good level of efficiency. There is no one technique that can be optimal for a lot of building and as well there is difficulty to use one technique for different conditions and limitations. However, it is good to use the entropy measurement to predict the energy-use as concluded from reviewed articles. In regard to the interior design and retrofit electrical construction of a building, it is useful and can save much energy. However, these methods are costly and take much time to redesign. Therefore, it is an essential step to study the situation of such a building based on the existing condition to produce a semi-optimal solution whether it is a retrofit design or install a system to predict the energy-use for a better measured BEE. Smart services can be provided to occupants via smart phones' notifications. It is however a useful idea to receive news and updates from users regarding any technical issues by scanning given QR codes which are associated with AMIs.

6. Conclusion

This paper has reviewed several recent articles that focus on the BEE. It has suggested selecting recently published articles within the last five years to give readers with the latest technology used to study the BEE measurement. However, some other considerations such as energy-use predictability methods, light control systems design inside buildings, retrofit the interior design of building based on occupants' profiles, and smart techniques for example; IoT and smart buildings using QR-code have been considered and discussed whereas their advantages and disadvantages have been provided. It has highlighted a number of recent methods applied for researchers gaps and challenges faces to propose best solutions attempting to enhance the BEE and save more energy.

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