A Review on Building Energy Savings Strategies and Systems (BE3S)

Abbas M. Al-Ghaili*
Institute of Informatics and Computing in Energy (IICE)
Universiti Tenaga Nasional (UNITEN)
43000 Kajang, Selangor, Malaysia
*Corresponding author's e-mail:
abbasghaili@yahoo.com & abbas@uniten.edu.my

Hairoladenan Kasim
College of Computer Science and Information Technology (CSIT)
Universiti Tenaga Nasional (UNITEN)
43000 Kajang, Selangor, Malaysia
e-mail: hairol@uniten.edu.my

Marini Othman
Institute of Informatics and Computing in Energy (IICE)
Universiti Tenaga Nasional (UNITEN)
43000 Kajang, Selangor, Malaysia
e-mail: marini@uniten.edu.my

Bo Nørregaard Jørgensen
Center for Energy Informatics
University of Southern Denmark
Campusvej 55, 5230 Odense, Denmark
e-mail: bnj@mmmi.sdu.dk

Zainuddin Hassan
CSIT
Universiti Tenaga Nasional (UNITEN)
43000 Kajang, Selangor, Malaysia
e-mail: zainuddin@uniten.edu.my

***Abstract*—Energy savings in buildings as a goal in recently established buildings either residential or commercial has been nowadays paid much attention by many researchers, designers, and decision makers due to the need of reducing energy demand and global warming issues. This challenging goal is affected by several factors and roles which play important roles by which this goal is affected. Those factors in most cases are difficult to be treated by one method or design. Many proposed systems have been introduced for many years; their performance(s) have varied percentage(s) of achievement in terms of energy savings. In this setting, such a review paper could help much to draw a clear plan for researchers and buildings' designers to follow and get them directed to best and easiest systems. However, many review papers have been published which included many limitations, e.g., some review papers focused only on residential buildings. In general, there is a need to give an overview of reviewed papers with taking into account many factors and policies together with strategies applied. In this setting, it is understood that different designs have produced different levels of performance being achieved. In this review paper, Building Energy Savings Strategies and Systems (BE3S) are reviewed. Different points of views have been considered. For example, lighting control systems, buildings' retrofitting systems, and occupancy profiles related systems have been reviewed. This paper has also included different types of buildings on which strategies and systems have been applied. Reviewed papers are collected from top-tier journals published by very well-known publishers which are IEEE, Elsevier, Emerald, MDPI, and ACM. Indexing services adopted in this BE3S paper are Scopus and WOS. BE3S paper has only considered last 20 years providing a summary of recently designed strategies achieving semi-optimal performance(s) in terms of energy savings in buildings.**

Keywords-building energy saving; residential buildings; office buildings; lighting control systems; occupancy behavior; smart lighting systems; retrofit lighting systems in buildings

I. Introduction

Energy saving has been given a huge portion of attention due to its crucial role in energy demand and energy efficiency. Energy demand made by buildings sector is becoming bigger nowadays and is being massively increased in the future [1]. Energy consumptions in buildings either commercial or residential ones are considered one of the highest amongst other sources. In this regard, a recent study implemented in the US [2] has mentioned that small commercial buildings account for 90 % of total commercial buildings in terms of energy consumptions. Reviewed researches have shown varied percentages of energy consumptions. These variations are affected by several factors e.g., strategy proposed [3] (system(s) being designed for selected scenario(s)), building's types [4], and history of building [5].

There are also some considerations and correlations that play importantly in increasing or decreasing percentage of building's energy consumptions. This has led researchers to apply different types of methods depending on building type and history [5]. For example, an old existing construction requires a different designed system from a new building.

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In order to reduce energy demand, energy consumptions, or energy-use and in a same time enhance energy savings rate, the selected building needs to be investigated and carefully studied. In order to achieve semi-optimal energy savings performance, there are some factors each proposed system will carefully consider. For example, some research studies have focused on lighting systems to control energy-use, whereas some other systems have considered occupancy profiles [6] to manage energy-use in buildings. There exist some other proposed strategies/ systems reviewed thru Literature Review section.

Other than that, different strategies were applied on different buildings' types e.g., office [7], commercial [8], residential [9], non-residential buildings [10, 11]. By classifying these buildings' types-based strategies in terms of intelligence, they can be divided simply into conventional systems [12] and smart systems for intelligent buildings [13].

A number of previous review papers have been focusing on certain items that resemble in several properties. Some previous reviews, for example, consider only lighting control systems in energy savings [14]; some others focus on office buildings [15], some others review techniques proposed for building energy efficiency [16] and so on. This review paper, i.e., Building Energy Savings Strategies and Systems (BE3S) attempts to cover a wide range of similar and varied items which resemble in many properties and additionally are related to a main keyword which is, in this paper, "*building energy*". In detail, the BE3S review has considered several factors which play important roles in performance of *building energy*'s objective which is "energy savings". BE3S paper has also considered different energy controlling strategies as well as different types of buildings in order to come up with a wider overview to help a broad band of researchers, designers, decision makers from different fields. Thus, this paper could be suitable for researchers from many areas and fields. It aims by then to overcome a number of previously mentioned determinants and shortages exist in some other competitive papers.

Based on this, BE3S has adopted four main classes of which reviewed strategies and systems consist. The first class is lighting systems which is one of the most widely used strategies in building energy savings. Various researches have been using this strategy for many years [5, 17-25]. The second class is retrofit designed systems which have been exploited by many research studies [26-34]. The third strategy has focused on reviewing systems related to occupants' profiles and behaviors utilizing their activities retrieved data [6, 35-39]. The last one reviews a number of monitoring based systems for energy savings [1, 40-42].

The BE3S review has collected papers from five publishers thru their five related digital libraries. It is necessary for journal papers to fulfill two criteria which are: paper belongs to one of five publishers and related journal in which the selected paper is published must be cited by one of two indexing services either Scopus or WOS. The criterion of twenty-years of paper's age is a must.

The BE3S's objective is to find best solutions used with a certain type of buildings amongst other strategies.

This paper is organized as follows: Section II explains in details the proposed methodology of how papers have been collected. In Section III, Literature Review is discussed. Conclusion will be drawn in Section IV.

II. Proposed Papers' Collection Methodology

A. *Problem Definition*

There are some factors by which the *main pre-defined keyword (i.e., energy building savings in BE3S paper)* gets affected. Once these factors/ roles are efficiently treated, energy savings could be achieved. There have been many energy control systems proposed in order to come up with a best or semi-optimal energy savings rate. While different systems have been implemented and applied on various scenarios, different energy savings have been achieved. In this setting, there are many roles affecting the proposed system to achieve a high rate of energy savings. This is depicted in Fig. 1 in order to give a more clarified view. This paper reviews different proposed systems using different techniques applied on several building types.

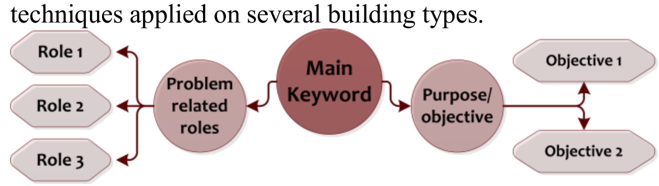

Figure 1. Keyword(s) Definition.

B. *Problem Statement-derived Keywords Selection*

To highlight how keyword(s) can be selected is mentioned. The mainly considered issue to be taken is that what the main keyword seed is. Once, it is selected, some other related issues need to be clearly defined. The first one is the objective the main keyword aims to achieve and the second one is what factors and roles affect those objectives. This is graphically shown in Fig. 2.

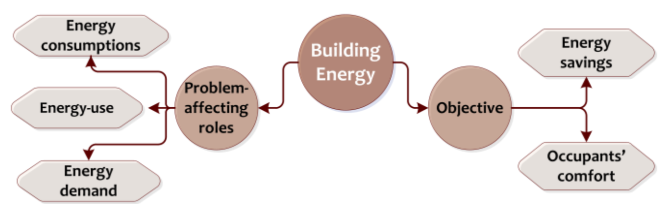

Figure 2. Keyword(s) selection.

The main selected keyword is "building energy" where it is surrounded by a problem that is needed to be solved. Thus, there might be more than an objective. Furthermore, there might be a factor or more affecting the performance of proposed solutions towards achieving objective(s).

This paper aims to discover a number of proposed systems that fit to the problem stated as: "*building energy savings control strategies/ systems*". Based on this, related objective(s) have been selected which are: "*energy savings*" and "*occupants' comfort*". But, there are a number of roles that play an important role that affect directly or indirectly on the performance of "energy savings control systems" to achieve a semi-optimal "energy savings" level or rate. Some of these roles are: "Energy consumptions", "Energy-use", and "Energy demand" each of which reduces "energy savings". With consideration of these five terms which are: "*energy consumptions*", "*energy-use*", "*energy demand*", "*energy savings*" and "*occupants' comfort*", there will be two scenarios resulted which are shown in Table I.

TABLE I. FACTORS-AFFECTED OBJECTIVES SCENARIOS

If		**Then**			
Factor/Role	=	Objective 1	=	Objective 2	=
energy consumptions, energy-use, and energy demand	high	energy savings	low	occupants' comfort	high
energy consumptions, energy-use, and energy demand	low	energy savings	high	occupants' comfort	low

There exists a challenge to achieve such a scenario that is shown in Table II:

TABLE II. OBJECTIVES-ACHIEVED REVIEWED PAPERS

If		**Then**			
Factor/Role	=	Objective 1	=	Objective 2	=
energy consumptions, energy-use, and energy demand	low	energy savings	high	occupants' comfort	high

Thus, BE3S focuses on reviewing papers which have proposed control systems by which a similar scenario mentioned in Table II could be achieved with a good level of performance.

C. *Strategy of Keywords Generation & Selection*

A simple strategy of keywords generation has been applied. Firstly, the main keyword will be definitely connected and affected by other items. Thus, the main keyword is affected by several factors. In the same time, it aims to achieve such an objective. There are three items existing which are: main keyword, factors (roles), and objectives. These three items are precisely taken into account. Secondly, in order to achieve a certain group of objectives, there surely will be a group of solutions applied. Solutions are then considered as well. Thirdly, solutions usually are applied on different types of buildings (scenarios) and their findings out differ based on solution being designed. Also, findings depend on buildings' types on which the selected solution (i.e., proposed system) is applied. By then, there are a group of core items which are: main keyword, sub-keywords (a mixture of affecting roles and objectives), solutions (proposed systems/ strategies), and types of buildings on which solutions are applied. These items are schematically represented in Fig. 3.

D. *Strategy of Collection of Journal and Conferences' Proceedings related Papers*

In BE3S paper, five publishers with five digital libraries are used. Papers cited are collected from both conference proceedings and journals published by the above mentioned publishers. Journals are indexed only by two indexing services which are Scopus and WOS within twenty years from 2000 to 2019 are taken. Further criteria applied to papers whether to be selected or not can be found in Table III.

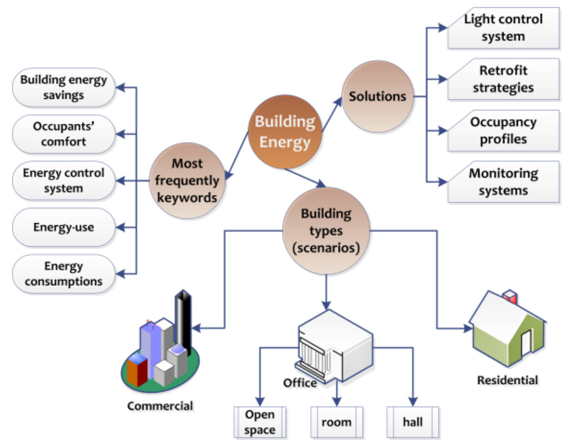

Figure 3. A Schematic Representation of Keywords Generation & Selection Strategy.

TABLE III. CRITERIA APPLIED TO PAPERS' COLLECTED FROM DIGITAL LIBRARIES

Publisher	IEEE, Elsevier, Emerald, MDPI, ACM
Digital library	IEEEXplore, ScienceDirect, Emerald Insight, MDPI, ACM DL
Indexing service	Scopus OR WOS
Paper date	2000 to 2019
Type of papers collected	Conference proceedings & Journals
Conditions and criteria to select a paper	Conference proceedings belong to 'Publisher' A journal is indexed by 'Indexing service'

Once criteria in Table III have been applied, related statistics are summarized in Table IV in which number of papers per a publication type is calculated as well as number of papers per year.

TABLE IV. NUMBER OF PAPERS/PUBLICATION'S TYPE & NUMBER OF PAPERS/YEAR

Paper per Publication	
Publication Type	**#no.**
Conference papers	3
Conference proceedings	15
Journal papers	43
Total	**61**

Paper per Year			
Year	**#no.**	**Year**	**#no.**
2000	4	2010	3
2001	2	2011	3
2002	1	2012	2
2003	1	2013	5
2004	0	2014	6
2005	2	2015	6
2006	0	2016	6
2007	0	2017	7
2008	3	2018	6
2009	2	2019	2

III. LITERATURE REVIEW

A. *Light Control Systems for Energy Savings*

There have been lots of energy control systems focusing on lights in buildings. Those systems have achieved varied energy savings rates. There are many roles affect performance of proposed systems e.g., building type the system is designed for. Energy savings in building by controlling lights can efficiently achieved. Thus, numerous methods and systems related to control lights have been proposed in order to contribute in energy demand reduction. Those systems have attempted to use different technical designs and inputs in order to enhance buildings' energy savings rate. One of these systems is proposed in [43] which aims to reduce energy consumptions by controlling lights inside building. The authors in [43] have proposed a LED lighting system in order to gain an energy efficient structure. The proposed structure detects movement of occupants by using motion sensors inside buildings. A noticeable percentage of energy consumption reduction has been reported. Thus, the proposed system discussed in this paper will efficiently enhance the BEE by about 16%.

Another example of light control systems is to use an intelligent lighting method. It can contribute to enhance in energy savings by about 19 % of total of building energy consumptions [15, 44]. This has encouraged researchers to work on enhancing this percentage by proposing various systems. In this regard, it is stated by [45] that the optimal distribution of light inside a building can significantly lead toward a semi-optimal energy management system for Building energy efficiency and energy-and-cost savings.

In In [44], a lighting control system is proposed in order to balance between reduction in energy-use and preserving occupants comfort by using an intelligent lighting system. This method firstly, has collected occupants' profiles from different Wi-Fi infrastructure distributed in different zonal locations inside building, in a non-intrusive way. Then, a central lighting control assigns a dimming function for each lamp based on both occupancy-driven adjustment of brightness and a local controller connected to each lamp. Finally, the proposed system dims light of a lamp by sending command of a function to a Wi-Fi gateway that executes the action. This system is customized, however, to give occupants more preferences options using their mobiles. Results have confirmed a high energy savings percentage can be achieved in similar scenarios. The achieved percentage was about 80.27 % of energy consumed in a multi-zonal office building in Singapore when compared to a static scheduling system using a PIR sensor.

B. *Retrofit Design for Energy Savings*

This is one of the desirable applied strategies specifically on existing buildings [46] due to it preserves buildings' structures and helps produce energy savings in a shorter time when compared to new buildings'. However, building retrofitting is considered in some cases cost and inefficient in terms of short and medium periods. Thus, there exist several challenges faced by proposed systems attempting to develop such strategies. In this setting, the core focus of such a retrofitting system is to how to propose a design of changing a conventional building to a smart one. Nevertheless, other scenarios of transforming and retrofitting are profusely considered. For example, a proposed study reviewed in [47] has considered a group of parameters and factors e.g., energy savings, energy fluxes optimization, and Smart Grid interactivity.

1) Lighting System Replacement and Retrofit: There are a wide variety of proposed strategies and systems applied on different types of buildings both commercial and residential. For example, a recent research study discussed in [48] has been applied on academic buildings aiming to contribute to energy savings by using a retrofitting system. This system has considered energy savings achieved by controlling light and air conditioners (A/C) systems in the building. It has implemented a series of steps; firstly, the central control unit has been connected to multiple zones and buildings by proposing a wired and wireless network(s), then, temperature was adjusted to a pre-defined value, after that, retrofitting of conventional lights with LED lights was applied. Results obtained in this study have confirmed a good percentage of energy savings can be achieved. This study has proposed a retrofit design for light energy system. The proposed retrofit design aims to preserve the quality of light inside the building and reduce the quantity of lamps. The authors in [49] have applied an audit and cost study to prove that their proposed retrofit design can contribute much in energy savings in terms of commercial and residential lighting wastefulness. It is concluded that replacement of lamps in commercial or residential buildings could achieve energy savings and BEE while the quantity is reduced and indoor lighting quality is preserved.

2) Building Envelope: Either a building contains an envelope design or not, the energy use is directly affected in terms of energy savings. Meaning, thermal properties of building envelopes lead to enhance or reduce energy savings of buildings. A very recently analysis based study applied in Japan [50] has stated that those buildings which contain reflective envelope materials are better in enhancing energy savings than those which do not have. Regardless only building envelope materials, a number of proposed systems sometimes consider building envelope alongside other interior building designs. A multifunctional retrofitting system, for example, proposed in [47] has implemented different stages for a group of operations and installations such as building envelope to reduce energy demand made by thermal load, retrofitting design for heat pump and power controller to reduce energy use, restructuring building components as a function to reduce installation time.

3) Computer –based Optimization: A simulation based optimization strategy to control energy consumption and enhance existing buildings is widely used [51-54]. In [54], the proposed computer-based optimization system has used multi value optimization to design a mixture of physical simulation of an office building. The authors have designed different retrofits depending on multiple variables producing suboptimal directions and hence the best optimal retrofit design is selected based on an evaluation in terms of energy consumptions. Some suboptimal solutions might be expensive and some others might be of a low energy savings rate.

C. Occupants Profiles for Energy Savings

It has been mentioned that some energy savings focused strategies and systems achieve good level(s) of efficiency in terms of energy-use. However, in some cases occupants' comfort might be not significantly considered [55]. Thus, there is a need to take into account both energy savings and occupant's comfort. Thus, in [55], in order to design such a system, space characteristics and patterns of occupant's behavior have been modeled for energy system's parameters. This proposed system with the help of an applied light retrofit on existing fluorescent has achieved a 43 % reduction in energy consumptions compared to the previously equipped light system.

An interesting simulation based research study [56] applied on a residential house located in Lithuania has aimed to find out the correlation between occupants behavior and energy demand. Hence, a predicted energy demand scheme can be efficiently produced. The proposed system has considered occupant's profiles for heating, ventilation, and lighting.

1) Commercial vs. Residential Building Occupants' Influences on Energy Demand: There have been several research studies and systems proposed aiming to understand the relation between occupancy behavior(s) and energy demand. Different types of buildings have come up with totally contrasting results even though input parameters are identical. One of the proposed studies [56] has concluded that occupants' behavior and characteristics directly affect energy demand and energy-use specifically in residential buildings. Whereas another study [57] has mentioned that occupants slightly have influence on energy consumptions. It has confirmed that energy demand in a building is still high whilst number of occupants is reduced. However, it has stated that when occupancy patterns are considered, a good level of energy savings can be achieved. The proposed study in [56] has found out that most affecting factors in occupancy profiles on energy-use and demand are age, behavior, and number of occupants. To balance between these two contrasting points of views, it is simply said when a commercial building or a non-residential one e.g., an academic building is considered, such occupants' profiles based energy control systems might be not highly suitable and cannot achieve efficient energy savings [57]. However, other strategies might be more efficient than occupancy based systems. On the other hand, occupancy based control systems [56] are adequate for residential buildings when different factors are taken into account.

2) Government Incentives based Occupants Behavior Influence on Energy Savings: A research study [58] has attempted to investigate occupants' motivations and incentives and their influences on energy demand in residential buildings. From this study, it has been found that governance incentives contribute much to reduction of energy consumptions and naturally achieve a high energy savings rate in residential buildings. Another governance incentive to encourage residential buildings occupants' in the UK be encouraged to contribute to the energy demand sector to achieve energy savings is proposed in [59].

D. Monitoring–Systems for Energy Savings

In this type of energy savings strategies, different designs and different strategies have been proposed in order to achieve energy savings rate by using smart designs that most depend on sensors and actuators by which a control function e.g., switch on/off can be made.

1) Energy Savings thru Intelligent Adaptive Control Systems: One of the reviewed papers has proposed a smart monitoring strategy [60]. Simply, this strategy has focused on monitoring light performance in a smart office and occupants comfort measure for a long-term monitoring scheme. It has installed a number of integral sensors and actuators to monitor lights as well as to adaptively modify lighting system in accordance to individual occupants comfort. With a similar scenario, i.e., an open space office building, this adaptive lighting installation strategy when compared to static light control systems can achieve between 42 % and 69 % in terms of energy savings. A recent proposed monitoring based energy control strategy is reviewed in [61, 62]. It has utilized Internet of Things (IoT) to monitor light consumptions by installing smart sensors that can respond to command sent via Internet. The energy use is computed and displayed on a webpage with which the occupant can access and have the authority to control; for example, the occupant can switch on/off. This intelligent design when applied to a real building, an energy savings rate was achieved.

IV. CONCLUSION

This review paper (BE3S) has reviewed a number of published papers within the last 20 years published by IEEE, Elsevier, Emerald, MDPI, and ACM and indexed by Scopus OR WOS. BE3S has focused on strategies proposed to enhance the performance of energy savings in buildings. It has reviewed 4 types of strategies which are lighting control systems, retrofit designed systems, occupants' profiles and behaviors based systems, and monitoring systems. Energy savings vary depending on the scenario (i.e., building) to which the proposed system is applied. Sometimes, a certain strategy e.g., will be so suitable for a specific type of building and then can achieve a high percentage of energy savings whereas this strategy fails to achieve similar percentage when applied to another scenario. In general, these simple findings out are concluded from the list of references reviewed above. Lighting control systems would be good for commercial systems that consider individual occupants profiles and behaviors. Time scheduling based light control systems sometime might be good for academic buildings e.g., university due to its dependence on specific period of the academic year. Retrofit strategy would be applicable with a high energy savings performance when it is applied to buildings newly constructed. Occupancy strategy sometime fails to achieve good rates of energy savings when it is applied to office buildings that consider sub-group behaviors. Therefore, the occupancy strategy would be useful for residential buildings that consider occupants behaviors and activities e.g., their ages. Monitoring systems would be adequate for smart buildings which include sensors installed to reduce cost as well as smart cities. As concluded, prior to a strategy is applied to a selected scenario, there is a need to consider different factors in order to find best systems that achieve high energy savings rate(s).

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