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Energy Management Systems and Strategies in Buildings Sector: A Scoping Review

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ABSTRACT Energy management systems in buildings (EMSs-in-Bs) play key roles in energy saving and management to which an efficient energy management system in buildings (EMS-in-Bs) design contributes. Different scope-based designs of EMS-in-Bs are reviewed. The objective is to highlight different scope-based designs of EMS-in-Bs in which scopes of reviewed papers aim to implement a *function* of, for example, "monitor energy performance", "estimate energy-use", or "control energy-use". This paper aims to constitute a comprehensive conception of how efficient such an EMS-in-Bs to perform more than one scope (i.e., function). Meaning, is the proposed EMS-in-Bs able to perform several sequential functions? This paper's contribution is to give a function-focused EMS's review utilizing the scope of reviewed papers. That is, reviewed papers are classified based on the scope/function the selected EMS-in-Bs is designed for. This could help select an EMS-in-Bs to perform certain scope/function(s). Another contribution is that, numerous EMSs-in-Bs are reviewed in a classified way so that the most adequate EMS-in-Bs for a certain scenario considering the performed scopes/functions e.g., "monitor" are highlighted. Findings showed that "control-optimize"-functioned EMS-in-Bs achieved highest energy-saving rates ~30% compared to "estimate-predict" with 10%. Findings, insights given by reviewed studies, current problems faced, future directions, and remarks are drawn in conclusion. Analysis done on reviewed papers has found that the highest and lowest averaged-energy saving rates were obtained with papers whose their scopes are implementing "control"-with-"optimize" and "estimate"-with-"predict", respectively. Energy saving rates for these two classes of scopes have been equal to 22.57% and 10%, respectively. We recommend that there is a need to enhance the estimation- and prediction-related EMS-in-Bs to achieve a higher energy saving rate.

INDEX TERMS Building energy management systems, building management system, energy-use prediction, energy savings, energy consumption.

I. INTRODUCTION

Building management systems (BMSs) or Building Automation Systems (BASs) are those systems that concern management of such a control or an automation procedure of mechanical or electrical equipment connected to a building. BMSs or BASs, in addition to electrical equipment controlling and monitoring, can be implemented to large projects to monitor mechanical, heating, ventilation, and air conditioning (HVAC), access control doors, closed-circuit television (CCTV), or security systems [1], [2]. A BMS aims to effectively and efficiently perform a certain or pre-given task to the building's equipment either in a conventional, intelligent control, or automation way.

In the case with energy management systems in buildings (EMS-in-Bs), the main focus is how efficiently an EMS performs, for example, a "monitoring" function, implemented to electrical utility grids in terms of energy-use reduction and energy saving. In case with intelligent building energy management systems (iBEMS), the number of issues/

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factors being addressed is increased e.g., occupants' comfort with energy saving or energy consumption reduction using optimized solutions to perform several web-based information transferring [3] and processing [4]. Few simple differences between BMS, building energy management systems (BEMS), and iBEMS are briefly summarized in Table 1.

TABLE 1. Few Differences between BMS and BEMS.

BMS	BEMS	iBEMS
• Large scale systems	• Large scale and small systems	• Shifting to web /cloud-based technology, where their functionality will be delivered as services [3]
○ Mechanical, electrical, and HVAC equipment	○ Electric utility grids, HVAC, and lighting systems [5]	○ Hardware, software, and data transferring [6] thru an IP network
- Automation in an efficient way is the considerable issue	- Energy consumption and energy saving are the most considerable issue	- Energy saving, energy consumption reduction, occupants' comfort, and optimized solution are the considerable issue [7]

Energy consumption in buildings is a considerable issue and is needed to be efficiently manageable and reduced as well. There are several functions that can be performed out in a building to manage its energy-use e.g., control energy-use, analyze energy performance, monitor energy consumption, predict the energy demand, provide an optimal solution applied to a building. This variety has produced many types of BEMSs. The main aim of such a BEMS is to balance between two important considerations which are building energy efficiency (BEE) and occupants' comfort. By doing so, energy waste reduction, BEE, iBEMS occupants' comfort and other energy efficient systems related features can be gained. The performance of energy use mainly depends on BEMS. Meaning, the more optimal the BEMS is, the more the energy efficient of a system is and the less energy-use is.

From Table 1, it is briefly and simply found that differences between BMS and BEMS are the focus on large scale vs. small systems, mechanical vs. electrical systems, and automation vs. energy savings, for both BMS and BEMS respectively. Thus, in this paper, EMS-in-Bs considers a variety of this combination that BMS and BEMS have. Meaning, EMS-in-Bs considers the papers that consider small vs. large scale system; and automation vs. energy savings in several types of buildings. However, EMS-in-Bs considers optimization solution proposed to smart buildings offered by iBEMS, as highlighted in Table 1. Therefore, EMS-in-Bs differs from BEMS that, it reviews a wider range of systems and strategies applied to different scale of building implementing several purposes (i.e., functions).

There have been several BEMSs proposed since few past decades to address the problem of energy consumption in buildings e.g., [8]–[26]. Proposed research works have achieved high levels of energy savings depending on the technique used and its suitability with the design of building and surrounding conditions both external and internal ones. In this setting, numerous reviews are reviewed in term of their scopes.

For example, in [27], the way the data was applied to address challenges and difficulties faced by designers and researchers in regard to EMSs has been reviewed. It has considered data applications to do computational tasks. Examples of these tasks are briefly mentioned as follows: efficient operations for predicting energy demand and building operations, e.g., [28]–[32]; retrofitting analysis to achieve sustainable development of EMS, e.g., [33]–[35]; verification procedures to detect faults by monitoring building, e.g., [36]–[40]; economic analysis of energy-use by performing statistical operations to do classification, clustering, and pattern analysis to come up with a summary that understands how and when occupants/ customers need to use more energy, e.g., [41]–[46]; and falsified data injection detection and non-technical losses e.g., [47]–[53].

An interesting review paper [54] has addressed the factors by which the energy consumption and energy use performance in buildings can be affected. The review has mentioned that there are many impactful factors e.g., the interior design of building(s), external conditions, building operations caused by lighting, HVAC, switches . . . etc., occupants related activities, and other reasons causing the randomly energy-use operated. As a result, the energy consumption prediction for such a building will not be of an easiness task the related BEMS can do. The paper has collected and reviewed some other related proposed systems and designs dedicated to address this issue. It has focused on prediction methods to give readers a deep understanding on different types of prediction models and strategies e.g., statistical [55]–[61] and artificial intelligence [62]–[68] based. Other types' examples are to be discussed *herein*. One of these types reviewed in [54] is the example of using engineering methods to perform data collection of physical and thermal properties that can monitor energy behavior inside the selected building and can then measure the energy use accordingly. This type of methods [69] takes into account all other components installed in the building that can cause energy consumption. Another example is the use of statistical approaches that concern the previously collected data before a training dataset procedure is done. This type implements a number of gradually carried out cascade processes. It starts from a simplified process that uses one or more parameters continuing to carry out a complicated parameters-based process. Grey methods [70], [71] are another example in which there are little available information and details regarding the energy consumption inside the building. Based on this information, analysis and/or prediction task(s) can be done.

BEMS can exploit the capability of building environment and other factors to perform energy saving, optimize a minimum range of occupants' comfort, and demand response to interact with smart grids [72]. Another definition of a

BEMS is a method that can control and monitor energy related functions and tasks associated with a certain building. Such a method can contribute to come up with an efficient management of potential sustainable energy [73]. In [74], it is defined as an innovative technique that reduces and optimizes the energy use as well as saves more energy consumed by commercial and residential buildings. Also, it is used to control and monitor buildings' energy use [75]. It can initialize a safe and healthy building.

The BMS can simply be defined as a computer-aided controlling powerful tool for related components installed inside the building specifically mechanical elements [76]. BMS has an ability to perform further complex tasks with an intelligent level adequately designed for smart buildings [77].

Differences between BEMS, EMS and BMS can be simply summarized as that the BMS is a controlling focused system to perform usually real time tasks. BMS most of times concern a building's mechanical systems. The EMS can, generally, monitor and analyze the building's energy consumption utilizing visualized data [78]–[80]. It mainly focuses on energy savings and other energy related services and tasks.

On the other hand, an iBEMS [6] can be a developed system compared to BEMS. In addition to several functions run by a BEMS, further functions/tasks can be implemented by an iBEMS utilizing some other components to do smart services as energy transferring between buildings [3]. For example, an iBEMS can utilize hardware and/or software parts e.g., sensors, Internet-based platforms to do further intelligent tasks [81], [82]. Some of these tasks are to notify occupants of buildings, visualize monitored-data for analysis and prediction…etc. Furthermore, iBEMS allows for information sharing thru communication links using protocols and network connectivity so that different types of data can be transferred for different purposes related to energy performance enhancement [6]. Intelligent energy management systems for residential buildings can also efficiently contribute to energy reduction. There are many proposed strategies applied for iBEMS, for example [83]–[85]. Such a feature can contribute much to cloud services used with Internet of Things (IoT) based BEMSs [86].

In this paper, different proposed BEMSs have been reviewed in which different levels of performance in terms of energy saving and BEE [87]–[89]. Depending on the selected design of BEMS, obtained results can directly get affected. Although, many BEMSs have achieved acceptable levels of performance(s) of energy management and to preserve occupants' comfort and internal quality of lighting in a building, a number of challenges and difficulties is still faced. Sometimes, a BEMS is designed to do monitoring, but it fails to achieve a high level of energy efficient and/ or energy management to the building or scenario it is applied to. Different designs of BEMSs will produce different outputs if depending on their design and buildings being implemented to. In some cases, one BEMS can be applied to do one function (e.g., prediction) and applied to two buildings; but each building can produce a different result. That is because, the design needs to be carefully considered when it is applied to a building.

This review paper aims to present different BEMSs applied for a wide range of buildings' types since last few decades. Different purposes have required different designs for BEMSs. Varied levels of energy saving have been achieved depending on quality of the BEMS's design and other associated surrounding conditions e.g., internal design, type of building, and environment conditions. There are different types of BEMS designs each of which aims to achieve a certain function of energy management e.g., optimize, control, analyze, and predict in order to come up with an acceptable level of balancing between energy management and occupants' comfort. This paper attempts to classify collected papers into different categories based on the function each BEMS aims to implement.

EMS-in-Bs can implement several tasks related to energy efficiency, energy saving, energy-use, and smart management of energy sources. Thus, EMS-in-Bs can enhance performance of energy consumption, heat emission, and occupant comfort. This review paper considers EMS functions which have been implemented by other research studies. The term of "function" in this paper means that the proposed EMS in reviewed papers can perform a "control", "manage", "estimate", "predict" …etc. task or function. There are many papers have implemented more than one function in one EMS to perform several tasks. For example, in regard to papers which concern implementing the "estimate" function in their EMS-in-Bs, they also have performed further tasks in addition to "measure", "analyze", "monitor", and "predict". One of this review paper objectives is to investigate relationships between the main function and other related sub-functions as well as the percentages of how many times each sub-function has been used amongst a group of papers that concern the "estimate" function, for example. This paper also considers finding out more than a function that has been performed within one EMS by each reviewed paper. Also, it has included factors that each EMS-in-Bs focuses on to address the problem being stated in related papers.

The main contribution of this review paper is to classify the reviewed papers based on a paper's scope or function that each paper aims to achieve such as "monitor", "estimate", and/or "predict". Additionally, each paper's scope has a distinctive design made by the related paper, this review paper contributes by finding out those designs assigned to their corresponding scopes. This lets readers get the state-of-the-art in this matter for latest EMS-in-Bs.

Besides, one of the main objectives of this review is to highlight designs of reviewed papers that aim to implement a function or more of energy management systems related functions e.g., "monitor energy performance", "estimate energy-use", or "control energy-use".

This paper is organized as follows: Research Questions are mentioned in Section II. The Method applied to extract papers from literature is explained in Section III.

Literature Review will be presented in Section IV. Discussion is provided in Section V. Reported results obtained from the reviewed papers are analyzed in Section VI. In Section VII, findings, insights, problems faced by current research studies, future directions, and other remarks are drawn in Conclusion.

II. RESEARCH QUESTIONS

This paper attempts to answer two key questions related to strategies of EMSs applied to the buildings sector and possibility of potential relationship(s) amongst one building EMS. Research Questions are provided as follows:

- What are main energy management systems/ strategies applied to the buildings sector to perform energy saving with an optimal level?
- Is there a relationship between functions/ strategies implemented amongst one EMS-in-Bs?

III. METHOD

A. SCOPE-BASED CRITERIA (SBC) SELECTION PROCESS

In order to achieve the scope of the paper's title as a scope-based review, there are seven main scopes this review paper aims to achieve. These seven scopes as early mentioned are to: "*monitor*", "*estimate*", "*predict*", "*control*", "*manage*", "*analyze*", and "*optimize*". Thus, the extraction procedure of reviewed papers has mainly considered these seven scopes when the searching and extraction procedure is executed.

In this process, three search sub-processes have been implemented to retrieve building energy management systems related papers. Only those papers that their EMSs have performed two or more functions e.g., such *an EMS-in-Bs can monitor and predict the energy use*. During the period of July until March 2020, the search procedure was applied. Management and planning energy management systems are considered under the scope of "*manage*".

The SbC selection process contains three rounds each of which is implemented in sequence. These three rounds are discussed as follows:

1) FIRST ROUND

The search is applied to eight digital libraries, mentioned in a following sub-section. In this round, the following keywords have been applied: "*building energy management and planning system*" OR "*energy management system in buildings sector*" OR "*building management and planning system*" OR "*intelligent building energy management system*" OR "*energy management and planning system*" OR "energy use monitoring system in buildings" OR "estimation and prediction of energy use" OR "control and management of building energy management system's tasks and operations" OR "management and planning of building energy management system" OR "smart and intelligent building energy management systems" OR "analysis of energy consumption behaviors in buildings sector" OR "optimization solutions of building energy management systems".

Additionally, each extracted paper will be initially screened, if its scope has implemented more than one scope of the seven scopes mentioned in this paper, the related paper will be taken. In this round, there were 2055 papers obtained.

2) SECOND ROUND

It considered the occurrence of similarity in results and thus it has applied a removal process of redundant papers. Either, a similarity in titles has been found, it is considered duplicated papers and thus it will be removed. In this round, 712 papers have been obtained.

3) THIRD ROUND

Here, a further analysis is carried out by applying a certain structured formula (*sk*) of keywords denoted by F_{sk}. The F_{sk} includes seven SbC. These seven SbC are applied to the remaining paper one-by-one. Every criterion of SbC has been individually applied to whole 712 papers. With each SbC is applied, there are three phases carried out, which are as follows:

- Phase 1: A single keyword is applied first. One SbC out of seven SbC keywords is applied. In that case, $F_{sk(i);i=1to7}$ is applied.
- Phase 2: At least one SbC, otherwise the one applied in Phase 1, is included in the paper; i.e., $F_{sk(j);j=1to7}$. It is a must that: $F_{sk(j)} \neq F_{sk(i)}$ and $j \neq i$.
- Phase 3: The paper in the search queue will go thru the third phase with a must that the energy saving rate has to achieve the following condition: energy saving is greater than or equal to 5%.

The mechanism the above-mentioned procedure in the third round is applied is represented in Table 2.

To understanding how the $F_{sk(i)} \neq F_{sk(j)}$ analysis was applied using its three phases, a further clarification is provided in Table 3.

In Table 3, the operator denoted by "*op*" applied to whole search phrase including two operators "AND" and "OR". The operator AND is used between the three phases while the operator OR is only used within the Phase 2. That means it is a must to fulfil all three SbC in the three phases within a paper in order to be included in this research paper; otherwise, it will be excluded. However, the selected paper has fulfilled SbC for three phases it should have fulfilled one or more than an $F_{sk(j)}$ within Phase 2.

After the third round (with all three phases in a sequential order i.e., Phase 1 then Phase 2 after that Phase 3) has been applied, a new analysis result has been obtained. Only 43 papers have been selected. Statistics of this procedure based on pre-defined topics (functions/ keywords) are shown in Table 4.

In Table 4, each function represents a single topic to which each paper belongs. Each topic has implemented further sub-functions (based on multiple-keywords previously mentioned in Table 2).

TABLE 2. The 3[rd] Round Search Process Applied to Scope-based Criteria (SbC).

i	$F_{sk(i)}$	A single keyword	One or more than a keyword	ES* ≥ 5%?
1	$F_{sk(1)}$	monitor	estimate, predict, control, manage, analyze, optimize; $j \neq i$	True
2	$F_{sk(2)}$	estimate	monitor, predict, control, manage, analyze, optimize; $j \neq i$	True
3	$F_{sk(3)}$	predict	monitor, estimate, control, manage, analyze, optimize; $j \neq i$	True
4	$F_{sk(4)}$	control	monitor, estimate, predict, manage, analyze, optimize; $j \neq i$	True
5	$F_{sk(5)}$	manage	monitor, estimate, predict, control, analyze, optimize; $j \neq i$	True
6	$F_{sk(6)}$	analyze	monitor, estimate, predict, control, manage, optimize; $j \neq i$	True
7	$F_{sk(7)}$	optimize	monitor, estimate, predict, control, manage, analyze; $j \neq i$	True
* 'ES' denotes for energy saving.				

TABLE 3. The $F_{sk(i)} \neq F_{sk(j)}$ Analysis applied to remaining papers for final inclusion of papers.

Phase 1	Phase 2											Phase 3
$i = 1$	$F_{sk(j=2)}$	*op*	$F_{sk(j=3)}$	*op*	$F_{sk(j=4)}$	*op*	$F_{sk(j=5)}$	*op*	$F_{sk(j=6)}$	*op*	$F_{sk(j=7)}$	Energy saving
monitor	estimate	OR	predict	OR	control	OR	manage	OR	analyze	OR	optimize	≥ 5%
e.g., ("monitor") AND ("estimate" OR "predict" OR "control" OR "manage" OR "analyze" OR "optimize") AND (energy saving≥5%)												

TABLE 4. Statistics of papers per each SbC.

Paper related function based on SbC	No. of papers
monitor	8
estimate	3
predict	5
control	8
manage	4
analyze	9
optimize	6
Total	**43**

B. CURRENT REVIEW PAPERS' SCOPE AND FOCUS

The review paper presented in [27] has focused on data science to monitor and analyze building energy consumption utilizing data-processing technologies to enhance building energy management. This review mainly is limited by the scope of data science and algorithms applied to energy management for buildings' sectors. Similarly, data loss and data sharing thru Internet connection and networks utilized by Internet based building energy management systems have been the most focused scope for the review paper done by [73].

Another review is provided in [54] in which those factors by which the energy performance is being affected are the main scope and focus of this review paper. External weather conditions and lighting are some examples of those factors that have been considered by the review paper [54]. Related applications that can provide solutions are also reviewed.

Some review papers have focused on a single task e.g., [67] which has focused on prediction of the energy consumption and its related models. Another review paper presented in [74] has only focused on research studies which consider the controlling and monitoring functions related to buildings' energy consumption.

On the other hand, a recent review paper [90] concerning the reinforcement learning of BEMS and applications that contribute to develop autonomous BEMSs for better energy savings rate(s) has focused on such a scope.

Some reviewed systems and other research papers have whether focused on a single task and its relation to other BEMS or one function. Some others, for example a reviewed paper in [91], have concerned selected functions such as "optimization', "prediction", and/ or "control" functions achieving energy efficiency for residential and non-residential buildings. This paper concerns more than a factor or function that the BEMS can implement to perform more than a function/ task. In this review paper, several functions implemented by such a BEMS have been considered. Those research papers which their objectives are to monitor, control, manage, estimate, predict, analyze, optimize, and/ or to reduce energy-use and behavior performance of a building's energy have been considered and reviewed in this paper. The aim is to constitute a comprehensive conception of how efficient such a BEMS is designed to perform more than a task/ function is. Meaning, is the proposed BEMS able to perform two sequential tasks?

C. SELECTION CRITERIA

Two criteria have been applied in order to perform the selection process, which are as follows:

- energy saving rate $> 5\%$ is considered and
- those proposed EMSs-in-Bs that are designed to perform more than a function (i.e., reviewed paper's scope).

D. PROBLEM STATEMENT DEFINITION

An EMS-in-Bs contributes to energy saving in buildings and performs several related functions and operations to help achieve a better BEE and occupants' comfort. Energy monitoring, control, energy consumption analysis, and energy-use prediction are some examples of such functions applied to many types of buildings. This review paper attempts to achieve two criteria that can help solve such an issue.

Thus, there will be two considerations in this matter, which are as follows:

- This paper aims to discover what suitable strategies/techniques are applied for EMS-in-Bs to achieve high performance in term of energy-saving for a better energy management.
- It aims to find out what are relatively subsequent procedures and tasks that can be efficiently performed for optimization and performance enhancement. Meaning, this paper attempts to find out more adequate procedures that can get benefit from each function of an EMS-in-Bs when applied.

Both considerations are graphically illustrated in Fig. 1 in order to add a more explanation.

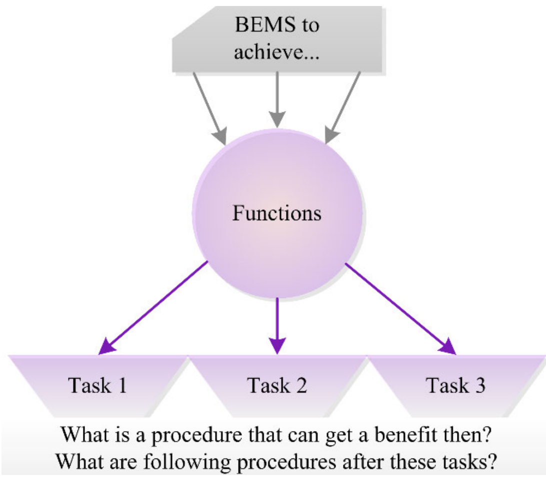

FIGURE 1. Problem statement definition based on a function-to-multitasks conception.

As can be seen in Fig. 1, in order to achieve an EMS-in-Bs, some approaches can achieve the goal of EMS-in-Bs better than other approaches when a certain function is aimed to be achieved or implemented. In addition, this paper reviews previous applied systems focusing on what tasks can be done after the main function has been performed. In other words, sometimes, if a selected EMS-in-Bs has been designed to perform a 'monitor' function, it is adequate to perform an 'analyze' task, when implemented to a 'residential' building; this is just an example. This paper reviews many different techniques and systems based on function's purpose.

E. PROBLEM STATEMENT-RETRIEVED KEYWORDS EXTRACTION

In this sub-section, the method applied to extract papers from literature has extracted keywords using problem statement's criteria will be applied. Therefore, the relationship between three parts, which are: technique, EMS-in-Bs function (i.e., monitoring), subsequent procedure (i.e., task) is graphically presented in Fig. 2.

There are numerous functions (i.e., category) where each EMS-in-Bs aims to achieve. Monitoring energy and occupants' related behaviors and profiles, measuring energy-use, estimation, measured reads analysis, estimation, prediction, controlling, classification, and optimization are extensively used by lots of EMS-in-Bs. Thus, this paper focuses on reviewing papers related to these main categories.

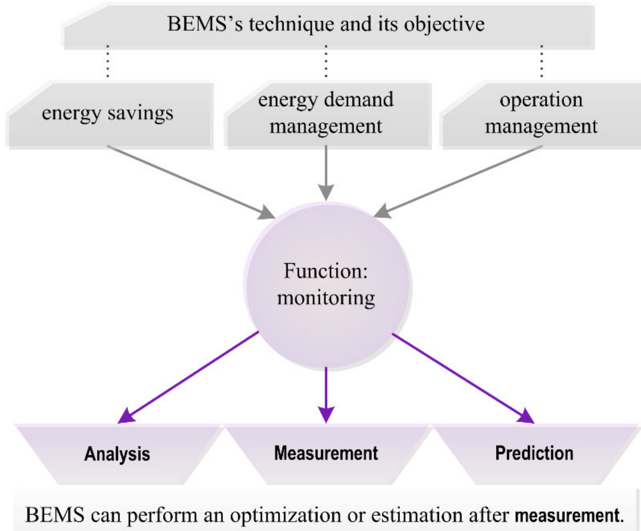

FIGURE 2. Keywords extraction method utilizing problem statement definition.

F. PAPERS COLLECTION STRATEGY

This review paper has selected top indexing services from which articles related journals are taken. Furthermore, eight publishers have been considered which are Elsevier, IEEE, Emerald, MDPI, ACM, Wiley, Taylor & Francis, and SAGE Publishing. Additional criteria which have been considered are provided in Table 5.

TABLE 5. Applied papers' collection criteria.

Indexing service	**Scopus OR WOS**
Publisher	Elsevier, IEEE, Emerald, MDPI, ACM, Wiley, Taylor & Francis, and SAGE
Digital library	IEEE Xplore, ScienceDirect, Emerald Insight, MDPI, ACM DL, Wiley Online Library, Taylor & Francis Online, and SAGE Publishing
Paper date	1982 to 2020
Type of papers collected	Conference proceedings & Journals
Scope of a candidate paper	Energy-use monitoring, energy management, measurement and analysis, and optimization
Selected system's main functions	Each system reviewed in a candidate paper must achieve more than or equal to an "*energy management related function*"
Energy management related functions	To monitor, estimate, predict, control, manage, notify occupants, optimize, analyze, classify, and reduce energy-use

IV. LITERATURE REVIEW

Different EMSs-in-Bs [92]–[98] have been proposed. Besides, there are many EMSs whose objectives are to increase BEE [99], reduce energy-use [100], optimize energy demand [101], [102], increase occupants' comfort [103], manage operations at buildings [104], [105], provide smart services for smart buildings [106]–[109] and many others have been reviewed and cited in this paper. Depending on each function performed by EMS-in-Bs, different types of systems designed and implemented to scenarios of buildings are reviewed in this paper. In this review paper, past related studies highlighting the performed function(s) of the EMS-in-Bs are presented.

A. MONITORING-ORIENTED EMS-in-Bs

The ''monitor'' function concerns performance behaviors of energy-use in the relative building. It is a very essential process to monitor energy-use performance inside buildings for an efficient EMS-in-Bs. Usually, energy-use monitoring process plays an important role for most of EMSs-in-Bs due to it affects other related processes/ functions e.g., analysis, estimation, prediction and optimization tasks in term of efficiency. Thus, BEE and energy-use performance will be affected as well. Reviewed research studies have included a wide range of EMSs-in-Bs applied to different types of buildings for monitoring purposes. Some of these examples have proposed a simulation model for energy use in buildings [110], some have focused to monitor energy-use performance using a quality control chart [111], and some others have utilized monitoring of a building energy-use performance to apply it to IoT applications [112]. However, a monitoring-oriented EMS-in-Bs sometimes can be utilized by other tasks in order to make a decision for energy-use reduction [113].

Similarly, in order to monitor, collect data, and perform analysis on energy-use of a building, an energy audit approach has been applied [112]. Energy audit is a useful tool for building energy management. This concept can be used with smart buildings using sensors. The proposed research work in [112] has simply adopted energy audit in order to achieve a high level of BEE as well as energy consumption reduction with a best occupants' comfort. In order to efficiently do so, energy consumption needs to be analyzed. Energy audit has been utilized prior to an analysis procedure to implement an energy management survey procedure by using energy audit. Usually, this procedure consumes a lot of time; therefore, IoT has taken a place in order to reduce the computation time by performing a data collection process of energy use consumed by whole electrical appliances pack. An embedded information system in which energy audit is implemented to analyze a building energy-use has been used. While this research work has been applied to a group of buildings, further sensors distributed in several places connected to each other using a wireless sensor network have been used. Energy-use can then be monitored and thus related data is in a real time collected utilizing IoT.

Sometimes, as proposed by a number of EMS-in-Bs, it is needed to perform a verification and validation of energy-use related data [110]. This procedure might be so useful for prediction purposes [114]. In [110], the proposed model has verified data obtained from monitoring a hospital building in term of energy consumption for a period of time. Then, it has applied a verification procedure. This model is good to verify collected and measured data from different measures e.g., building envelope, HVAC, lighting, and occupant profiles to predict the energy use. This model can be also used with a data-driven analysis for a monthly or annual basis. However, the method proposed in [114] has performed three main procedures, which are data collection, monitoring and prediction. It has monitored energy consumption after data is collected from a real scenario of a commercial building. Then, this data has been used to predict energy use for another building. It has applied a time-based series mechanism to monitor behavior of different building-related variables e.g., temperature and humidity that affect energy-use. Then, this mechanism has been re-used, after a verification procedure has been applied on, to predict energy-use for other similar buildings. It is useful to be applied on residential and commercial buildings.

B. ESTIMATION AND PREDICTION EMS-in-Bs

The ''estimate'' function concerns energy-use estimation made by behaviors of the building's occupants while the ''predict'' function concerns the building's occupants' needs of the energy based on their uses and behaviors.

As discussed above, there are several related procedures that can get benefit from a monitoring task; estimation-oriented EMS-in-Bs is one of the procedures that can be done once the monitoring-oriented EMS-in-Bs has been efficiently performed. In this sub-section of literature review, a number of proposed systems designed for energy-use estimation and prediction purposes [115], [116] are reviewed.

1) ESTIMATION-ORIENTED EMS-in-Bs

Few research studies focusing on energy-use estimation are discussed in [117]–[119]. An energy-use monitoring method was proposed in [117] to enable occupant save more energy and reduce cost. This method is suitable for commercial buildings and offices because it concerns a group of appliances. While this method monitors a group of appliances and their operations, it can be useful for a smart city. Similarly, another proposed EMS-in-Bs is reviewed in [118] and it can be used with large-scale buildings. In [118], an energy-use cost estimation technique is proposed to generate most recent estimates of demand to save energy. The proposed approach presented in this paper can be suitable to infrastructure equipped buildings and other high energy-use e.g., energy demand centers and big data analysis centers. In [119], a non-intrusive load monitoring method is proposed to monitor electrical devices to estimate correct energy-use for prediction purposes. This method is useful for estimation of energy consumed by known electrical devices. But for un-known devices, it may fail.

2) PREDICTION-ORIENTED EMS-in-Bs

Further examples for systems proposed to perform an energy-use related prediction procedure can be reviewed in [120]–[122]. Usually, these reviewed EMS-in-Bs aim to minimize energy-use [120], produce an efficient energy-use in a building [121], and/ or design an efficient energy management method [99].

In [120], a nonlinear dynamical programming control approach to analyze minimization of energy use taking into account thermally operational performance is reviewed. This approach has attempted to predict the energy-use. It is useful to predict energy demand for three types of buildings: heating-, cooling- dominated, and thermally balanced. The authors in [121] have proposed a model using controller parameters that affect the behavior of measures. It has used a logic controller method in which its parameters are adaptively adjusted. After 24 hours, a prediction process is proposed on how the energy-use for the next day will be. It looks somehow helpful to give semi-instantaneous predictions for real-time basis changing e.g., weather changing or other similar cases.

One study was implemented to predict energy savings for a campus building is presented in [122]. The proposed approach is applied on university campus micro-grid to perform a prediction-based energy savings plan. Once the monitoring process has done, an analysis procedure is carried out in order to do forecasting to ensure energy conservation. It has used informatics approach to collect data from smart meters and sensors at two-time intervals, which are: 15 minutes and 24 hours bases. It is useful with campus buildings to manage energy use and optimize daily operations and semester schedule energy-use.

In regard to energy consumption prediction during an energy operational management, an EMS-in-Bs has been reviewed in [123]. The proposed system has used a degree-day base temperature to predict energy consumption. BEM can use this method to control building performance by disaggregating energy-use between occupied and unoccupied periods. An adaptive energy consumption prediction applied to a building using multiple energy sources is reviewed in [99]. The proposed EMS-in-Bs in [123] differs from the one proposed in [99] whereas a single energy source is used. In [99], the paper proposes a system which monitors energy consumption produced by different sources e.g., renewable energy and grid power. It then predicts energy consumption using an adaptive algorithm to verify the energy efficiency. To verify the method, it is applied on actual buildings. This paper has proposed a prediction-based building energy management system. It has applied it on an actual building to verify the energy efficiency. Such a method can contribute to reduce the energy consumption and demand response for residential buildings. This method might be good for smart cities while different sources of power are being used.

Prediction and estimation could enhance operations of energy systems and enhance decision making of energy management. In [124], it is mentioned that a prediction based system has enhanced energy demand, system operations, and energy management. Also, it is mentioned in [125], that a prediction accuracy of a system has reached 88% using artificial intelligence based algorithm related to buildings' energy performance. The system has utilized information and analysis of metadata from a nation-wise level to obtain the prediction percentage. Thus, the related system has been used to help decision makers enhance spatial resources (including environmental and economic data) to improve the energy planning and also improve energy savings in clusters of buildings. Additionally, energy policy decisions have got impacts then.

C. CONTROL AND MANAGEMENT EMS-in-Bs

The "control" function concerns strategies and systems applied to control operations of appliances consuming energy in a building. The "management" of energy concerns different types of tasks applied to building in order to manage the energy-use of the building. The management term could refer to smart management as well.

1) CONTROL

In addition, one example that is dedicated for commercial buildings is reviewed in [126]. A predictive control strategy building energy management system is presented. This strategy has used a neural network rather than a scheduled on/off control. Such a strategy has contributed to reduce the energy use by about 20% compared to the on/off control strategy. This strategy has been applied on a commercial building to operate the boiler to heat the building. This has achieved good performance in term of optimization while the occupant's comfort is preserved.

One example reviewed in [75] has considered on the BEE and heat emission reduction by managing energy systems both hardware and software for a better energy management. In addition, operations related EMS-in-Bs have been considered in this matter. The reviewed study has utilized a simple design for EMS-in-Bs in term of configuration in which an open software platform has been used. The proposed research study can be a good tool for EMS-in-Bs in term of energy consumption reduction. This is therefore a supportive contributor to sustainable energy development achievement.

Similarly, in [99], the main focus and consideration of the proposed study has been the management of energy consumption reduction. Thus, authors in [99] have considered the management of power by designing a multiple power-based EMS-in-Bs aiming to enhance the BEE. The proposed design aims to propose a method that manages the energy distribution. In order for the energy consumption be adaptively controlled and managed, a consumption prediction-based method has been proposed. The proposed design has achieved about 5% of annual energy rate reduction.

The proposed design explained in [127] has focused on how to enhance the EMS-in-Bs with consideration of occupants' comfort and dynamical behaviors of occupants caused by energy related activities inside the selected building. Authors in [127] have defined the research problem in two different criteria. The first one is to consider the visually isolated zones and the second criterion is to consider the comfort goals. In the first criterion, halls, rooms, …etc.

have been studied and in the second one, visual comfort, air quality . . . etc. were also considered. The proposed design has taken into account conditional independence and thus this has enhanced the energy reduction with relation to computational complexity with minimal loss in optimality.

2) MANAGEMENT

The function of management of energy related sources and devices that has an impact on the performance of energy-use and/ or energy efficiency is very important to be efficiently and optimally considered. The management function also contributes a lot to many kinds of buildings e.g., smart buildings. Additionally, the effective energy management can be also useful for renewable energy. It is mentioned in a recently published study reviewed in [128] that renewable energy resources can be utilized to supply the load demand in buildings by using an efficient energy management strategy.

One considerable issue related to EMS-in-Bs has been discussed in [129]. The study has considered the building comfort management taking into account the dynamical behavior of occupant. Similarly, the behavior changes caused by the underlying logic of dynamic interactions between a building's occupants are a very important issue to be considered for a better energy management. It has been regarded as a very useful tool to contribute to energy savings as a sustainable method [129]. Additionally, a recently published paper [90] has mainly focused to collect past studies that consider intelligent methods and reinforcement learning applications which contribute to the energy management in smart buildings. Related algorithms that apply latest control and management technologies and systems for better optimization of energy utilization have been concerned. As for example, the paper [90] has reported that sensor technologies based EMSs-in-Bs, advanced algorithms designed to optimally control the energy use in smart buildings, or machine learning-based algorithms used for control tasks have been successfully implemented and they have contributed to EMSs in buildings with a rate of energy saving $\geq$ 20 %.

3) MANAGEMENT AND PLANNING

Management and planning strategies related to EMS-in-Bs have been paid much attention by many researchers due to the importance of their roles in decision making regarding the building. One of the considerable issues is the decision making regarding the retrofitting systems of buildings in order to enhance energy performance, reduce energy consumption, and improve indoor environmental quality [130].

D. ANALYSIS-ORIENTED EMS-in-Bs

The "analyze" function concerns systems applied to monitor and assess behaviors of energy use in order to help make a decision related to energy demand and management. The "analyze" function also contributes to support decisions for commercial and smart buildings. This procedure contributes significantly to the building energy management and can enhance the demand response especially if the load management is effectively analyzed. Analysis conception has been performed and implemented by many EMSs-in-Bs [131], [132]. For example, it has been performed to explore technical feasibility of the demand response to handle the load management in a commercial building as in detail discussed and reviewed in [133]. Also, it has been applied in order to study the energy performance of buildings [134], [135], optimization of multidimensional modeling for decision support [136], and with smart buildings [112], [134]. However, there is a number of techniques implemented to analyze and measure comfort of occupants in terms of indoor quality and operational management based to reduce the energy-use [137].

In [133], the proposed study was done to perform an analysis of load impact of demand response in commercial buildings implemented in Tokyo. This study is useful to work with the energy audit to manage and analyze effectively the load impacts that occur randomly and rapidly made by buildings' operations.

The paper reviewed in [134] has presented a validation model that evaluates the energy-use in order to be passed to energy management projects. The output of the proposed model depends on parameters taken from inputs that affect the energy consumption. This model could be used in order to help produce a prediction-based analysis that estimates the energy-use in a monthly-basis manner and therefore such an output is effective with smart buildings. However, the study reviewed in [135] has focused on the use of the solar energy for heating and cooling purposes. The proposed algorithm has been applied on different residential buildings for four climatic zones in Lebanon. It aims to find alternative solutions of energy demand. In order to do so, it analyzes and compares between the amount of energy-use with and without using the solar energy. It investigates whether the use of solar energy sources could contribute to the energy saving or not. This research work [135] aims to discover how good energy demand is in case of using the renewable energy. The scope of the work is limited.

To enhance the overall performance of building energy management systems, it is advisable to concern data organization to develop a reference data model [136]. This model is multidimensional based. This proposed model is useful for a wide range of buildings but it requires several dimension(s) and parameters to be included to design an optimal energy management system. Additionally, it requires a lot of computation time caused by a deep analysis to come up with a correct made-decision which might not be applicable for buildings that require a real-time response.

However, some other methods concern an analysis procedure applied to measure energy consumption for large scale buildings. As for example, the paper reviewed in [138] has concerned the energy consumption caused by lights in large buildings. It analyzes some other methodologies that measure and monitor the energy spent by the indoor lighting. This paper is useful for building automation and control systems because it helps much in term of monitoring-collected data.

E. OPTIMIZATION-ORIENTED EMS-in-Bs

The "optimize" function concerns strategies and systems applied to provide optimal scheduling of energy use and management inside the building to produce smart actions and events.

The optimization function associated with such an EMS-in-Bs is important due to it achieves better performance in terms of energy efficiency and energy-use reduction [139]. Additionally, optimization-oriented EMS-in-Bs is also considerable for smart buildings specifically [140], [141]. There are different types of optimization of EMS-in-Bs that focus to address different purposes e.g., optimal scheduling EMS-in-Bs of components of a local energy system [142] or to concern different types of buildings e.g., a smart home [143].

The proposed EMS-in-Bs in [142] has applied two-stage optimization method that determines the best scheduling of a number of energy system's components within a local energy management system so that can contribute to BEE. Another way to optimize the energy-use in buildings is by using a programmable and scheduling based tool [143] that enables users/ occupants to set their energy demand based on a pre-schedulable scheme. It uses particle swarm optimization to produce semi-optimal values that help achieve an optimized EMS-in-Bs for a smart home.

Sometimes, an optimization-oriented EMS-in-Bs uses a multi-objective based algorithm [139] and some other EMSs-in-Bs use a single objective optimization algorithm as represented in [144]. The multi-objective algorithm has been applied to a real scenario of public buildings in Italy while the one discussed in [144] containing a single objective design has been applied to a smart home (a single residential building). The multi-objective EMS-in-Bs [139] has focused on determining an optimal retrofit plan to come up with a decision on the votes-highest optimization in regard to the energy retrofitting plan for a group of buildings in terms of efficiency and comfort. Such a study has contributed to the city governance to make a decision for better BEE, as obtained results revealed.

F. ENERGY-USE REDUCTION-ORIENTED EMS-in-Bs

In this type of EMSs-in-Bs, the main objective is how to reduce the energy-use [75] while the occupant's comfort is considered. Some proposed EMSs-in-Bs have managed air conditions [145] and some others have considered HVAC control systems [146]. Energy management systems considering large loads such as HVAC have impacts on the energy use [147]. Such efficient EMS-in-Bs can improve the energy performance. In [145], the proposed system has concerned the energy management in term of demand response. It has proposed a multi-objective algorithm that quantifies the energy demand and in the same time it keeps the occupants' comfort. To do so, this study adopted 8 air-conditioners working in dependent and independent scenarios. This has come up with a comparison between these two scenarios. It concerns residential buildings in term of operations e.g., air conditioning. While in [146], it has dealt with HVAC placed in a university's libraries. It has analyzed the energy consumption and has stated that the frozen station is one of the largest energy components in air conditioning systems. Thus, it has designed an electronic logical circuit system for the water-cooling system in order to control and reduce the energy consumption caused by HVAC inside a library campus. Although, the energy-use has been reduced after the designed system has been used for cooling purposes, the applied system has not been tested in term of robustness. Generally, it is most important to manage energy-use and the aim is to design an energy demand related building management system.

Such an EMS-in-Bs can however consider optimization in order to balance between energy reduction and occupants' comfort using a fuzzy logic system. In [148], its aim is to reduce the energy consumption at airport terminal buildings. It used fuzzy controller strategies. It has managed to play operational functions e.g., illuminance and external temperature at terminals based on monitored time schedule of air-flights to perform an occupants-counted function upon arrival and departure. This paper has focused on optimization of terminal building energy-management. It has optimized to temperature, airflows, lighting for passengers (occupants). It can be useful with smart buildings.

V. DISCUSSION

A. ONE-TO-MANY RELATIONSHIPS OF MAIN AND SUB-FUNCTIONS OF EMSs-in-Bs

What are functions performed by an EMS-in-Bs proposed in the reviewed paper? How many functions are performed by an EMS-in-Bs? What is a percentage value of each function being performed in a relation to the other functions?

As discussed earlier, papers reviewed in this paper mainly perform more than a function. In this sub-section, an analysis procedure is applied on selected papers each of which performs two or more functions related to EMS-in-Bs.

In this type of analysis evaluation, there have been seven main functions/ keywords chosen, as per Literature Review section and sub-sections, which are as follows: "*monitor*", "*estimate*", "*predict*", "*control*", "*manage*", "*analyze*", and "*optimize*".

These seven terms (functions) consider the following matters, respectively, performance behaviors of energy-use, estimation of energy-use made by building's occupants' behaviors, prediction of building's occupants' needs from energy, control operations of appliances consuming energy in a building, energy management's tasks applied to building, assessment of energy use behaviors to help make a decision related to energy demand and management, optimal scheduling of energy use and management inside the building producing smart events.

Each paper usually performs at least one main function and a number of related sub-function(s) in order for such an EMS-in-Bs to be implemented to the selected building.

These seven keywords were selected to implement an analysis to find out how rate, in percentage, other related sub-functions have followed their main function is. Meaning, an EMS-in-Bs reviewed in a paper whose its objective is to perform a main function (say: to "monitor"); there will be at least one sub-function (say: to "measure" or "control") related to the main function and implemented after the main function has been performed. This is simplified in a graphical representation as shown in Fig. 3.

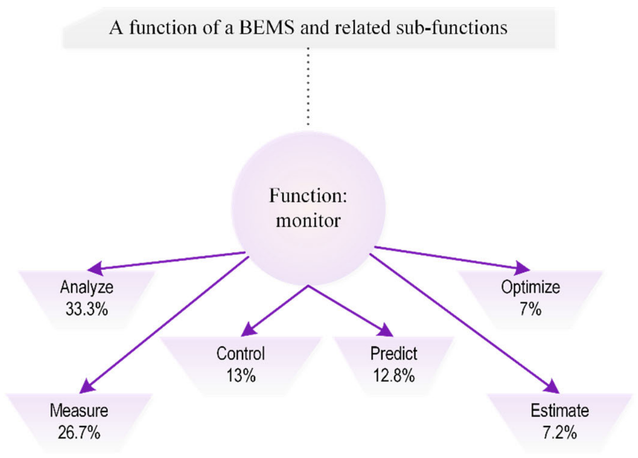

FIGURE 3. Percentages of sub-functions mentioned in the papers which aim to *monitor*. Percentages of usage of each sub-function amongst the selected group of reviewed papers used in this type of analysis. The selected keyword for the main function is: "*monitor*". Amongst this group of papers, 33.3% of papers have implemented the " *monitor*" function and then implemented the " *analyze*" function following the "*monitor*" function.

In Figure 3, a selected group of reviewed papers has been considered in this analysis. There are two criteria have been applied. Those papers achieving the two criteria are considered and thus rates in percentages shown in Fig. 3 are calculated only for them. Criteria have been applied are as follows: the first one is that the selected paper has considered the keyword "*monitor*" as the main function of the EMS-in-Bs presented in that paper. The second one is that the paper has to have another function following the main function and has been applied to the EMS-in-Bs by that paper. A list of keywords (i.e., main or sub- functions) is mentioned earlier (as can be seen in Table 2).

In Fig. 3, the EMS-in-Bs has been the focus for whole group of papers. All these papers have performed the "*monitor*" function and only 33.3% of these papers have performed the "*analyze*" as a sub-function. Subsequently, the percentage of papers that performed a "*measure*" sub-function following the "*monitor*" equals to 26.7%. A list of other related sub-functions is "*control*", "*predict*", "*estimate*", and "*optimize*" with percentages of 13, 12.8, 7.2, and 7%, respectively.

Similarly, the keyword "*estimate*" as a main function has been analyzed. In this analysis, selected papers in which the objective is to "estimate" have been gathered. Then, other sub functions have been extracted. A simple formula has been applied to obtain percentages of usage each function compared to all sub-function amongst that group of papers. Related results are shown in Fig. 4.

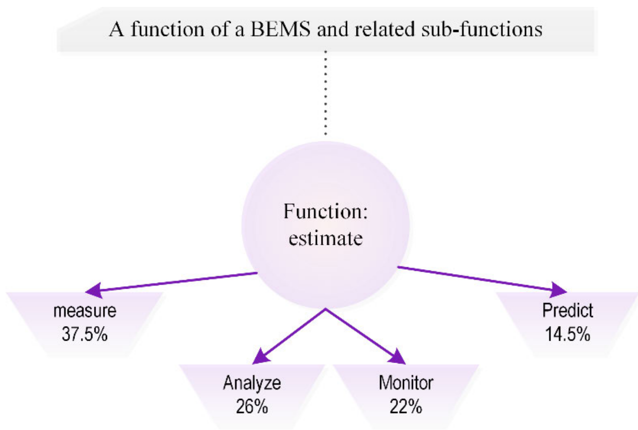

FIGURE 4. Percentages of sub-functions mentioned in the papers which aim to *estimate*.

In Fig. 4, the most frequently used keyword as a sub-function has been obtained amongst the group of papers that aim to *estimate* is the "measure"-ment with a percentage equals to 37.5%. Then, this list is followed by three keywords which are as follows: "analyze", "monitor", and "predict" with percentages equal to 26, 22, and 14.5%, respectively.

Following is the keyword "*predict*" as a main function and its related sub-functions with their percentages as shown in Fig. 5.

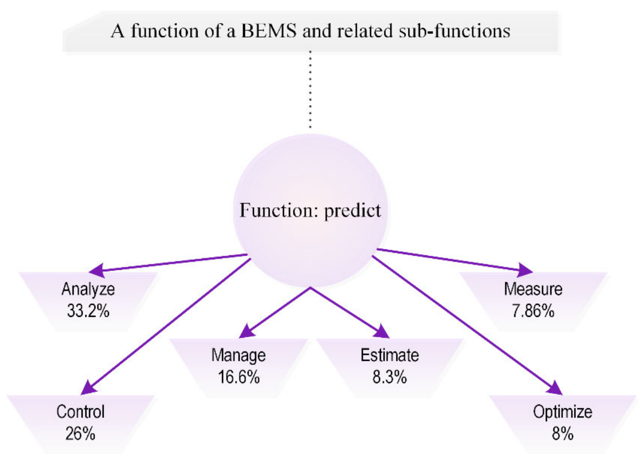

FIGURE 5. Percentages of sub-functions mentioned in the papers which aim to *predict*.

In Fig. 5, there are six sub-functions extracted from a group of papers that their aims are to "predict" which are as follows: "analyze", "control", "manage", "estimate", "optimize", and "measure". In this analysis, 33.2% of whole papers have considered "analyze" in their proposed EMS-in-Bs. The sub-function "control" comes after then with a percentage of 26%.

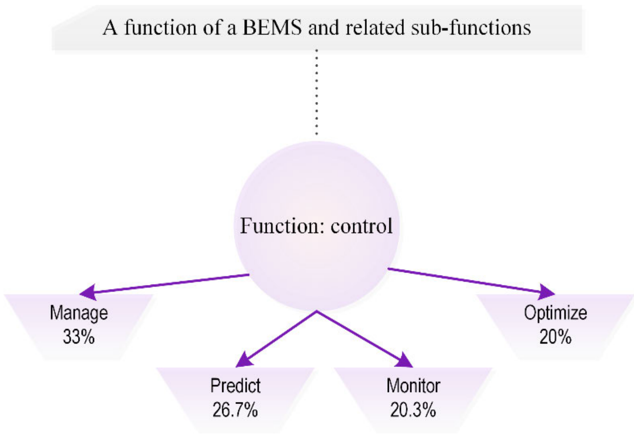

FIGURE 6. Percentages of sub-functions mentioned in the papers which aim to *control*.

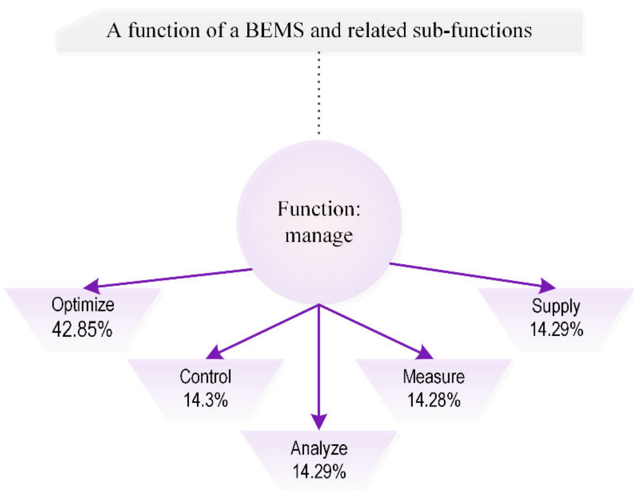

FIGURE 7. Percentages of sub-functions mentioned in the papers which aim to *manage*.

In the following figures, there are four main functions which are "control", "manage", "analyze", and "optimize" with their related sub-functions, shown in Fig. 6, Fig. 7, Fig. 8, and Fig. 9, respectively.

In this figure, it is clear that EMSs-in-Bs concern *to* "*control*" are also considering *to* "*manage*" with a percentage equals to 33% as per the selected papers. Then, the sub-function to "predict" has a 26.7%. The "monitor" and "optimize" sub-functions have 20.3% and 20%, respectively.

Some examples of cited papers that have been used in this analysis are provided in Table 6.

B. PERCENTAGE OF EACH FUNCTION IN RELATION TO WHOLE FUNCTIONS MENTIONED IN CITED PAPERS

This evaluation calculates how many times that each function has been considered by an EMS-in-Bs (i.e., each cited paper considers one proposed EMS-in-Bs) in relation to all EMSs-in-Bs mentioned in cited papers. Starting with the function/keyword "*monitor*", it has been considered by *i*'s papers in

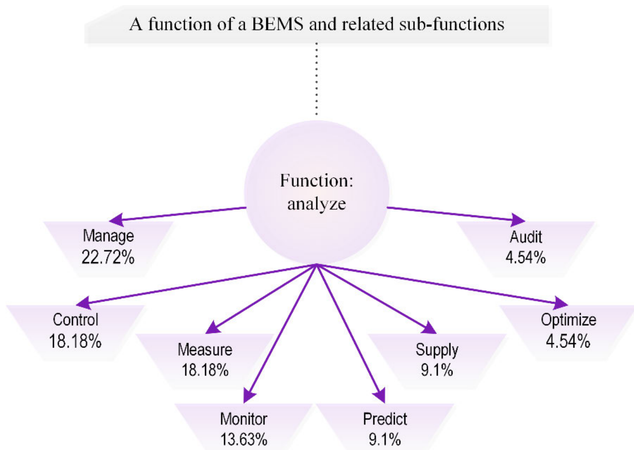

FIGURE 8. Percentages of sub-functions mentioned in the papers which aim to *analyze*.

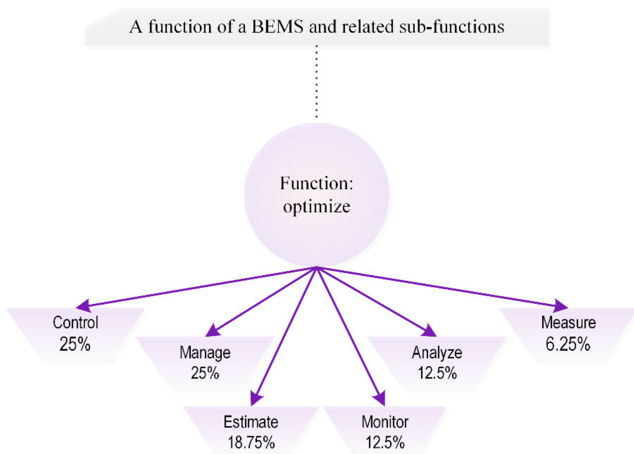

FIGURE 9. Percentages of sub-functions mentioned in the papers which aim to *optimize*.

TABLE 6. Various examples of cited papers used for the one-to-many relationship analysis.

Main Function - *keyword*	Examples of cited papers - *references*
to Monitor	[103, 108-114]
to Estimate	[117-119]
to Predict	[99, 120-123]
to Control	[75, 101, 102, 105, 106, 108, 126, 127]
to Manage	[90, 100, 128, 129]
to Analyze	[107, 112, 131-136, 138]
to Optimize	[139-144]

different EMSs-in-Bs. This is formulated in Eq. (1).

$$percentage_f = \frac{\sum monitor}{\sum all\_functions} \quad (1)$$

where,

- $percentage_f$ is the calculated averaged percentage for the selected function out of main functions mentioned in Table 6

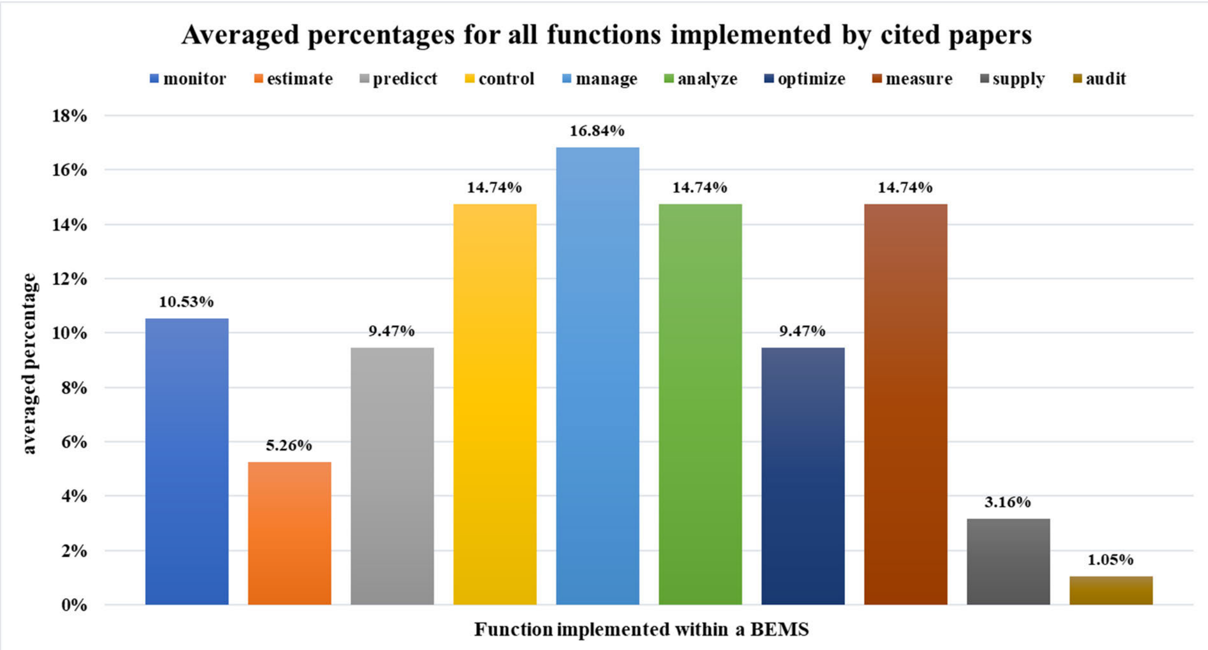

FIGURE 10. **Averaged percentages for functions used in BEMSs proposed by reviewed papers.**

- $\sum$ *monitor* is the total number that the function "*monitor*" is used and implemented by an EMS-in-Bs in a cited paper
- $\sum$ *all_functions* is the total number that all functions have been used in all cited papers.

The total number of whole functions of EMS-in-Bs considering all functions inclusive "*monitor*" also is equal to 95 references/ cited papers. Therefore, the percentage equals to $\approx \frac{10}{95}$10.53%. Averaged percentages obtained for all functions are shown in Fig. 10.

As can be seen in Fig. 10, the function "*manage*" is ranked at the first and the most frequently used in EMSs-in-Bs while the function "*audit*" is the least. Other functions are located amongst this list starting with "*control*", "*analyze*", and "*measure*" with the same value of averaged percentages.

C. CLASSIFICATION OF PAPERS BASED ON TWO CRITERIA: FUNCTIONS AND FACTORS BEING STUDIED

Here, it is overviewed the types of factors that each BEMS-function has focused on considered to be addressed, or has attempted to solve such a problem. Meaning, those papers that their BEMSs have implemented the function "*monitor*" have mainly concerned three factors as shown in Fig. 11.

As shown in Fig. 11, it is mentioned that those papers implementing the *monitor* function by EMSs-in-Bs have in general discussed three main factors to be addressed, which are as follows: energy use prediction, building operation, and occupants' comfort and behavior.

It is noticeable that proposed EMSs-in-Bs with a "*monitor*" function have implemented sub-functions to perform further tasks e.g., measurement and monitoring of energy use and building operation.

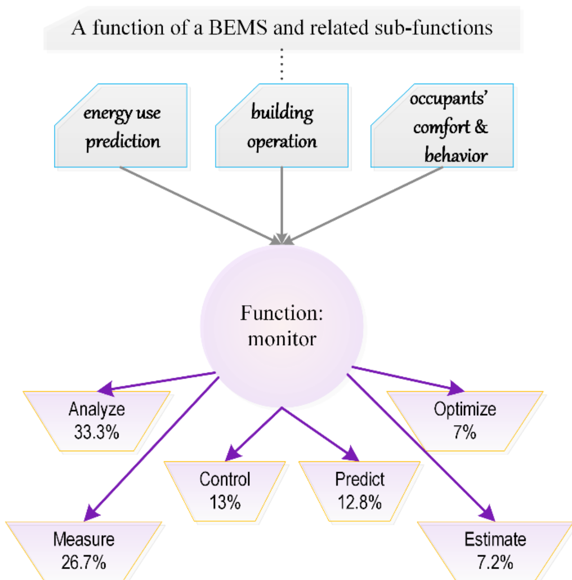

FIGURE 11. **Factors mentioned in reviewed papers that their main function is to "monitor".**

In regard to the function "*estimate*", there are, also, three main factors discussed which are: energy-use monitoring, energy efficiency, and devices behavior as shown in Fig. 12. This type of functions has concerned energy use monitoring for a better estimation of energy cost, for example. Also, estimation of energy consumed by certain electrical devices

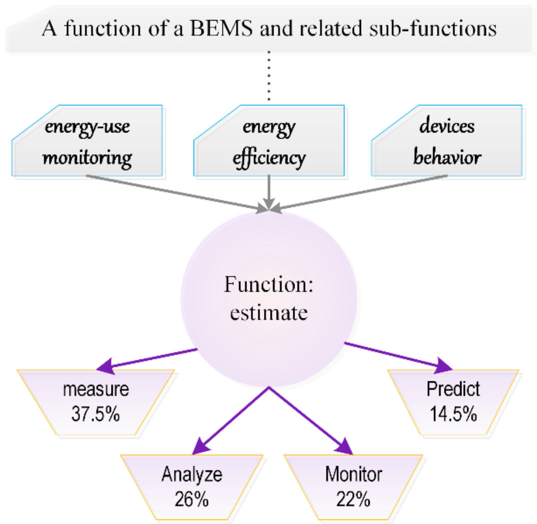

FIGURE 12. Factors mentioned in reviewed papers that their main function is to "estimate".

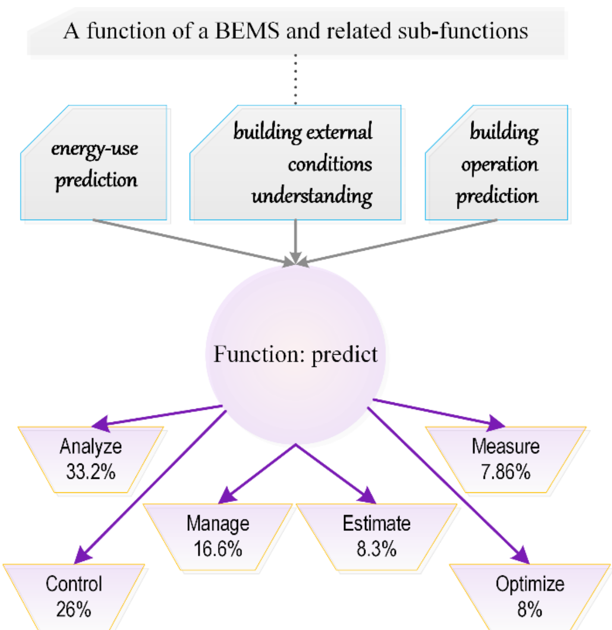

FIGURE 13. Factors mentioned in reviewed papers that their main function is to "predict".

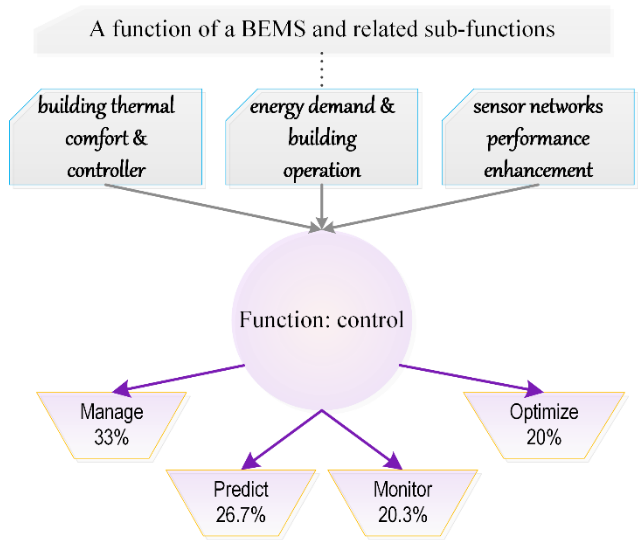

FIGURE 14. Factors mentioned in reviewed papers that their main function is to "control".

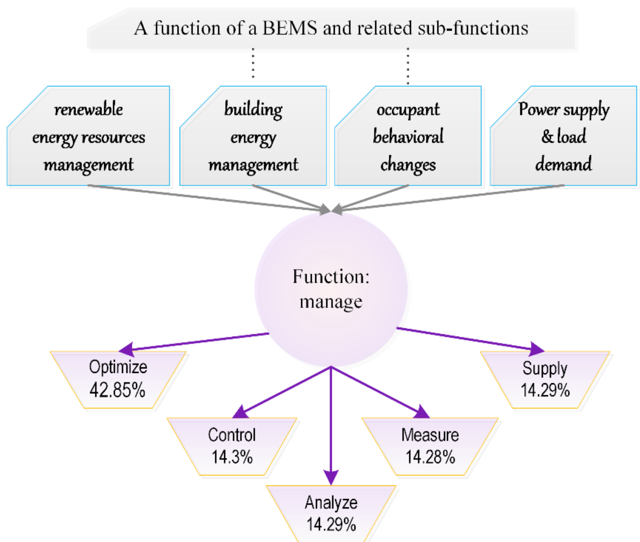

FIGURE 15. Factors mentioned in reviewed papers that their main function is to "manage".

has been studied for a better behavior understanding method in term of energy use caused by such cases.

Next, reviewed papers that performed the function "predict" have studied three factors which are: energy-use prediction, building operation prediction, and building external conditions understanding as shown in Fig. 13.

In this type, building operation conditions and parameters are being carefully studied and understood in order to perform energy-use prediction.

Subsequently, the function "*control*" mainly focuses on three factors, which are: building thermal comfort & controller, energy demand & building operation, and sensor networks performance enhancement, as shown in Fig. 14.

For the "manage" function, four factors have been the main focus for the related reviewed papers, as shown in Fig. 15, which are as follows: renewable energy resources management, building energy management, occupant behavior changes, and power supply & load demand.

The following function is the "analyze" in which five factors have been considered by related reviewed papers. In Fig. 16, these factors are highlighted.

Lastly, the function "*optimize*"-related papers reviewed in this paper have discussed many factors in their papers associated with the proposed and designed BEMSs. These factors are highlighted in Fig. 17.

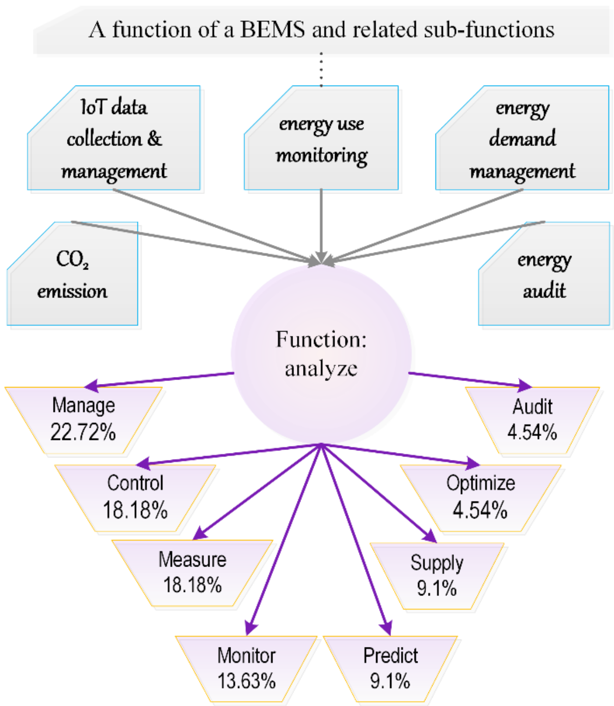

FIGURE 16. Factors mentioned in reviewed papers that their main function is to "analyze".

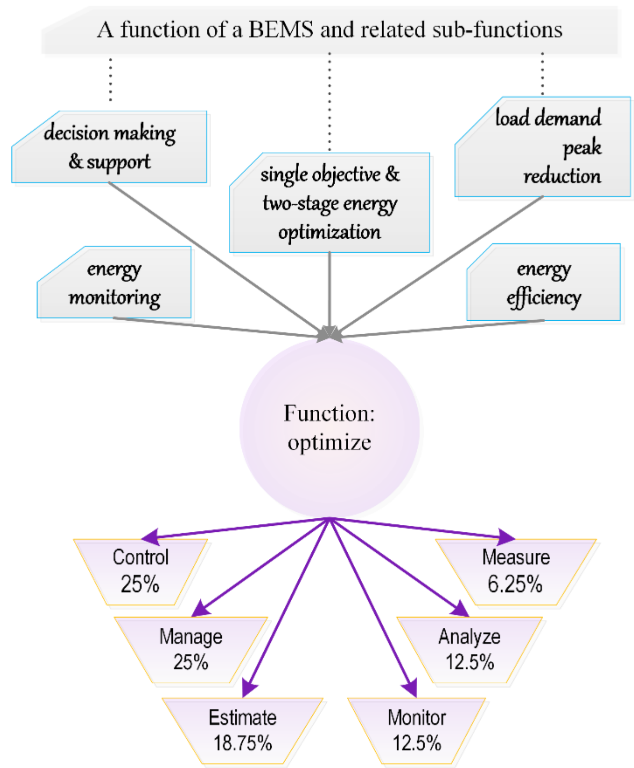

FIGURE 17. Factors mentioned in reviewed papers that their main function is to "optimize".

D. PAPERS VS. APPLICATIONS

In this type of analysis, a list of applications is highlighted. There are varied kinds of applications and/ or buildings for which each EMS-in-Bs can be suitable. Reviewed papers vs. applications are mentioned in this sub-section according to the main functions earlier discussed that include *monitor*, *estimate*, *predict* …etc. A related list is provided in Table 7.

As shown in Table 7, it is noticeable that there is a variety of suitability of BEMSs proposed by reviewed papers to be applied to different types of buildings. Also, such a function-aimed paper or function-implemented BEMS is suitable for more than an application. The essential difference is the purpose each function-implemented BEMS is designed for when there has been a further sub-function implemented. For example, with the "*estimate*"-implemented BEMS, the "*monitor*" *as a sub-function* can be used with "home appliances" in order to estimate the energy use needed once devices behavior has been *monitored* and tracked. Thus, the function "*estimate*" is suitable for the "home appliances monitoring" applications when such a factor like "devices behavior" is considered taking into account that such a modified scenario is used; please refer to Table 6, Fig. 4, and Fig. 12. Meaning, in order to read Fig. 12, the sub-function "*monitor*" is used to monitor "*devices behavior*" and in order to "*estimate*" the "*energy-use*". And thus, the related designed BEMS is applicable with "*home appliances monitoring*" applications.

Additionally, there is also an important and effective role of information systems as a tool for the prediction and estimation for the decision making. In this direction, collected information from a building will help information system to have better performance in regard to decision making related to energy management. For example, if information collected from such a building in which energy consumption is huge, the energy generation or distribution utility would make a decision to produce more energy as a supply to the related building. Such a procedure will contribute towards better performance of EMS-in-buildings.

VI. ANALYSIS OF REPORTED RESULTS IN REVIEWED PAPERS BASED ON THE FUNCTION-IMPLEMENTED BEMS CRITERIA

This section highlights the two research questions mentioned in this paper by analyzing their relationships in term of energy saving. It answers also the research questions.

A. WHAT ARE MAIN FUNCTIONS BEMSS IN REVIEWED PAPERS HAVE IMPLEMENTED?

There are seven main functions which are mentioned according to objective: to "monitor", to "estimate", to "predict", to "control", to "manage", to "analyze", and to "optimize". Per each function-implemented BEMS, there is a different energy saving rate achieved. Relationships between these functions, as discussed earlier, differ based on the purpose for which a BEMS is designed. Reported percentages of energy saving(s) for these BEMSs are to be mentioned in the following sub-section.

TABLE 7. Papers' scopes vs. applications and/ or buildings.

Paper' scope	Applications and/or buildings' types	Selected references
monitor	integrated building automation and management systems	[103, 108-114]
	industrial BEMS	
	hospital buildings	
	quality control and monitoring applications	
	smart and sustainable buildings	
	commercial buildings	
	historical buildings	
estimate	data centers	[117-119]
	information technology devices centers	
	home appliances monitoring	
predict	multi-power sources BEMS	[99, 120-123]
	heating-cooling demands' buildings	
	buildings with logic controllers	
	commercial daily occupied buildings	
	building energy-use patterns (management, optimization)	
control	optimized commercial BEMS	[75, 101, 102, 105, 106, 108, 126, 127]
	multi-zones' buildings	
	prosumer residential buildings	
	microgrids, smart grids	
	residential demand response BEMS	
	industrial buildings	
	smart BEMS	
	integrated building automation and management systems	
manage	hybrid storage systems	[90, 100, 128, 129, 149, 150]
	campus buildings	
	industrial BEMSs	
	smart homes	
	smart grids	
	information and data sharing and exchange between buildings, centers, and utilities	
analyze	smart grids; smart buildings	[107, 112, 131-136, 138]
	IoT and wireless sensors-based buildings	
	building automation	
	energy demand response and dynamic pricing purposes	
	home appliances management	
	heating and cooling purposes at buildings	
	heating and cooling management at residential buildings	
	real-time response buildings	
	building automation and control systems (BACS) for large buildings	
	smart metering	
optimize	building portfolio	[139-144]
	smart home energy management system	
	smart grids	
	smart metering	
	optimal scheduling for hotel buildings	
	optimal scheduling for residential buildings	
plan	planning for smart building	[151, 152]
	planning for decision making	
	planning and management for enhancing indoor environmental quality	
	planning for optimization of EMS-in-Bs	

B. REPORTED PERCENTAGES OF ENERGY SAVING (ES) IN REVIEWED PAPERS PER EACH FUNCTION

Energy saving (ES) percentages achieved per each BEMS in the reviewed papers have been reported. In this sub-section, the calculated values for each ES rate are provided. In order for those percentages to be easily read, only the minimum and maximum achieved percentages per each group i.e., per each function-implemented BEMS have been grabbed. Calculated values are shown in Fig. 18.

TABLE 8. A number of findings from reviewed research studies.

Function	Findings	Ref.
Monitoring	- Monitoring BEMS enhances analysis function of energy use. - Energy-use related data can be verified obtained from monitoring	-
Estimation	- Estimation BEMSs can correctly help for energy-use prediction.	-
Prediction	- Logical programming-based operations can be utilized for prediction purposes.	[120]
Control	- It has been applied to commercial buildings.	[126]
Management	- It has been found to be a very useful tool to contribute to energy saving as a sustainable method.	[129]
Analysis	- It can well perform with time-basis operations e.g., monthly-basis in smart buildings or four climatic zones in residential buildings.	[135] [134]
Optimization	- It is found that optimization-oriented BEMSs are amongst the top in energy saving achievement due to it select the best semi-optimal solution in energy management. This type of systems is useful	[139]

As can be seen in Fig. 18., percentages of ES are varied depending on many factors. Sometimes, suitability of using a BEMS within an application is achieving higher ES compared to some other alternative choices. In some other cases, using sub-functions with the main functions may come up with different results when the same main function is used with other sub-functions. Another example is that, a given order of main and sub-functions can produce higher results compared to the same order of functions if they have been applied to different types of applications or different types of buildings. Amongst this discussion, it is obviously noticeable that the function "*control*" with its related sub-functions have achieved the highest ES percentage compared to the "*optimize*"-implemented BEMS that has achieved 25.6% in term of ES-maximum. However, the "*optimize*" for ES-min is better than the "*control*" one. These calculations are given in regard to min- and max- ES percentages. But for the averaged percentages of ES for each function-based BEMS, calculations are implemented and related results are illustrated in Fig. 19.

As shown in Fig. 19, calculated values of averaged ESs for this purpose are done using Eq. (2):

$$ES_{avrg} = \frac{(ES - \min) + (ES - max)}{2} \tag{2}$$

where ES_{avrg} is the averaged energy saving percentage reported in reviewed papers.

Totally, the "*optimize*"-function has achieved the best level of ES with an averaged percentage equal to $ES_{avrg} = 22.55\%$.

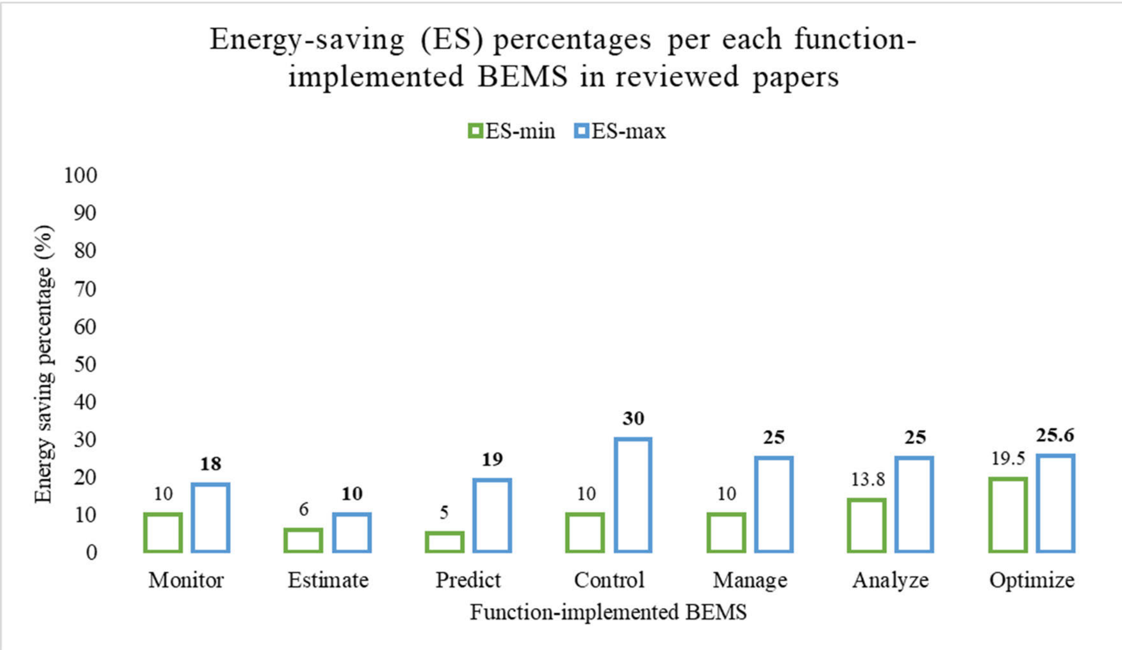

FIGURE 18. Percentages, reported in cited papers, of energy saving per each function-implemented BEMS.

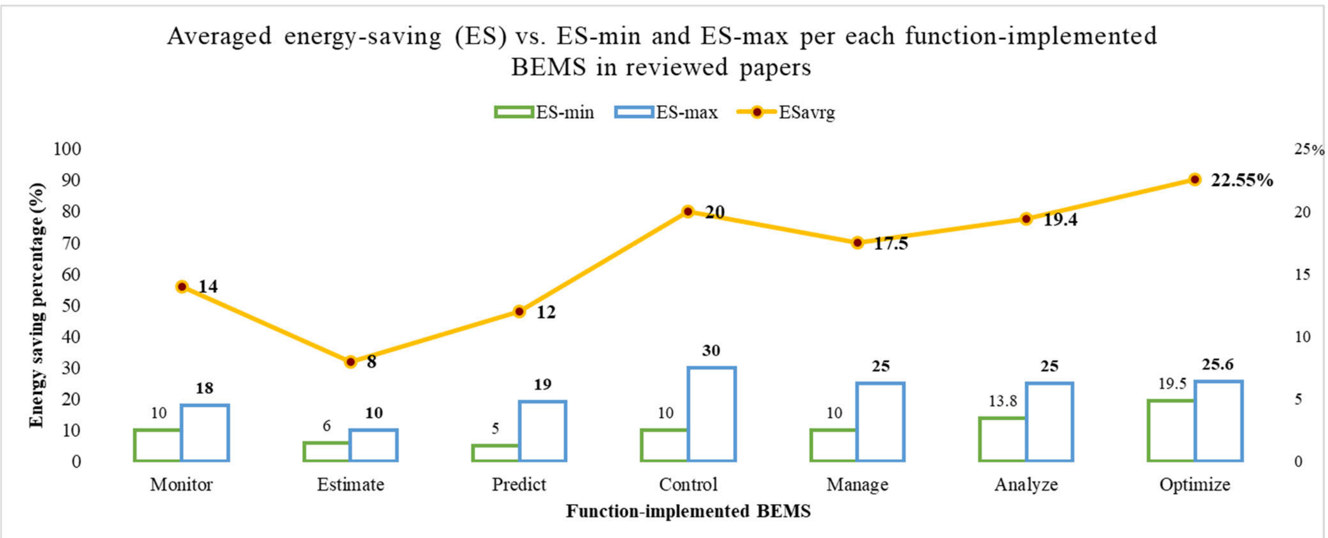

FIGURE 19. Averaged energy saving (ES) vs. minimum and maximum ES per each function-implemented BEMS in reviewed papers.

C. HIGHEST VS LEAST ES_{avrg} REPORTED IN REVIEWED PAPERS PER EACH FUNCTION

As can be seen in Fig. 19, the least percentages of ES_{avrg} are "Estimate"-based and "Predict"-based BEMSs with averaged ESs $ES_{avrg} = 8\%$ and 12%, respectively. It is also seen in Fig. 19, the highest ES_{avrg} percentages are "Control"-based and "Optimize"-based BEMSs with percentages equal to 20% and 22.55%, respectively. From the curve marked in an "orange" color displayed in Fig. 19, it can be noticed that, values of ES_{avrg} are divided into two groups based on *least* and *highest* terms. Hence, this can be graphically represented in Fig. 20.

As can be seen in Fig. 20, those papers focusing on either "estimate" or "predict" functions have achieved the least ES in average with a percentage equals to 10 %. As contrary, the highest ES_{avrg} achieved has been found with those papers implementing "control" and/ or "optimize" functions in EMS-in-Bs. These achieved percentages

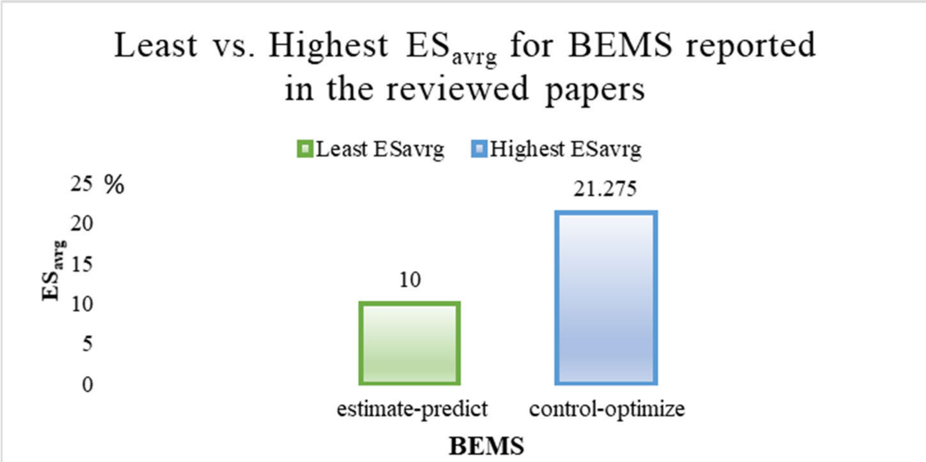

FIGURE 20. Least vs. Highest ESavrg calculated suing information from the reviewed papers.

might be caused because of that the estimation procedure for these systems is a difficult task to be accurately implemented. In addition, the per-defined conditions during design of estimation-related EMSs-in-Bs randomly change when implementing or those conditions are not well pre-designed. Unlike *estimation*- or *prediction*-related EMSs-in-Bs, such an *optimization* procedure might be easily done when real values exist and being compared to select the best value.

VII. CONCLUSION

EMSs-in-Bs are designed in order to come up with an efficient energy system, manage energy operations inside buildings, or increase occupants' comfort. This paper has reviewed a number of EMSs-in-Bs related designs applied to many types of buildings. It has reviewed research studies published within a wide period of time for about 40 years. That aims to find out what varied designs are that differ from time to time depending on several factors.

The conclusion of this paper can be discussed in several sub-sections, as follows: the first sub-section draws findings; then, the second sub-section briefly summarizes this review's insight; the third subsection mentions few problems faced by current research studies designed for EMSs-in-Bs; a number of future directions will be remarked in the fourth sub-section; and finally, few concluded remarks related to the scope-based definition are provided in the fifth sub-section.

A. FINDINGS VS. SCOPE-BASED FUNCTION

Numerous findings from the reviewed papers have been obtained. In Table 8, the findings vs. each scope-based function are listed.

B. INSIGHT VS. SCOPE-BASED FUNCTION

In Table 9, the insight is briefly summarized.

C. PROBLEMS FACED BY RESEARCHES

A number of current problems faced by research studies are provide in Table 10.

TABLE 9. Insight given by reviewed research studies.

Function	**Insight**	Ref.
Monitoring	- Monitoring BEMS can be used to design a simulation model for energy use in buildings. - Energy-use can then be monitored and thus related data is in a real time collected utilizing IoT. - It is useful to be applied on residential and commercial buildings.	[110]
Estimation	- Estimation BEMS can be suitable to high energy-use buildings e.g., energy demand centers and big data analysis centers.	[118]
Prediction	- This type of BEMS can be used for energy demand. - It can also be used with campus buildings to manage energy use and optimize daily operations and semester schedule energy-use.	[121] [122]
Control	- Different researches have mentioned that a good tool to effectively reduce energy consumption caused by heater and boiler that heat the temperature in buildings is to use a predictive-control BEMS.	[126], [75]
Management	- It is mentioned that renewable energy resources can be utilized to supply the load demand in buildings by using an efficient energy management.	[128]
Analysis	- This function is good for BEMS that tackles demand response. - Load impact can be analyzed to perform demand response in commercial buildings.	[134, 135] [133]
Optimization	- EMSs that consider optimization functions is more adequate for smart buildings than other systems.	[140, 141]

D. FUTURE DIRECTIONS IN EMS-in-Bs

There are several issues in regard to future directions on energy management systems in buildings sector and can be remarked as follows:

- For Monitoring-oriented EMS-in-Bs, systems can be used to make a decision to reduce energy consumption utilizing IoT [112], [113].

TABLE 10. Current problems faced by reviewed research studies.

Function	Problems	Ref.
Monitoring	- If a "monitoring" function is not properly considered, it can affect estimation and prediction in term of efficiency.	-
Estimation	- For un-known electrical devices, estimation BEMSs may fail.	[119]
Prediction	- For multiple energy sources, it can work but not as good as a single energy source is used.	[99]
Analysis	- For this type, it requires data organization to develop a reference data model. - It requires a lot of computation time caused by a deep analysis. - A correct decision might not be achieved for buildings that require a real-time response due to the computation time constrains.	[136] [138]
Optimization	- There is a challenge for smart buildings to select an optimal BMS to optimize different operations of energy management.	[139]

- The Prediction-oriented EMS-in-Bs can be helpful for semi-instantaneous prediction purposes for real-time basis changing e.g., weather changing. [121].
- The Control-implemented functions in EMS-in-BS are aimed to increase efficiency of energy reduction level of multiple power-based EMS by enhancing the related adaptive controlling strategy [99].
- Additionally, the energy use can be gradually managed in which intelligent methods and reinforcement learning applications can be utilized to contribute to energy management in smart buildings [90].
- One of the biggest challenges is to reduce energy consumption largely while a lot of devices and equipment is being gradually increased and involved by the buildings. Meaning, there is an obvious challenge to use new and additional electrical equipment and in the same time the energy consumption is being reduced. In this setting, BEMSs face difficulties to manage related energy equipment easily to achieve high energy saving. Additionally, due to the need to optimally and effectively perform BEMS-related functions for smart buildings utilizing big data collected from a number of smart devices, the design of such a BEMS needs to carefully consider a lot of criteria and conditions 153]. It is hence very essential to include computational intelligence, energy security, and occupants' comfort.

E. REMARKS RELATED TO THE SCOPE-BASED DEFINITION

- This paper has reviewed various types of BEMSs. As for example, monitoring focused BEMSs are one type. Monitoring BEMS can work efficiently when there is an input from sensors installed inside around the selected building being monitored and managed. Somehow, this type of systems might be costly if it has been applied to a building equipped with a huge number of physical sensors. Thus, it should be carefully chosen with more suitability buildings in order to design an efficient BEMS and low-cost one.
- Another example is estimation oriented BEMSs which can be useful for largescale buildings and offices. While there are numerous appliances within a building that might be operated for periodically scheduled times, an estimation design might be supportive and achieves energy savings.
- Analysis-oriented BEMSs are significant in term of energy saving and also can help design semi-optimal BEMSs in which their main functions are to optimize or predict energy-use.
- Prediction-oriented BEMSs can depend mainly sometimes on a deep analysis function that is efficient enough to perform very accurate analysis operations.
- Additionally, optimal BEMSs can achieve a high level of BEE when the related design has utilized a very accurate analysis of energy-use and occupants' activities associated with energy demand.
- To be concluded, when such a BEMS is designed for a real scenario, a number of considerations and factors needs to be carefully taken into account. For example, when a Prediction-oriented BEMS is designed there are two considerations in this case being taken, which are an analysis function of energy-use and type of building.
- Hence, energy saving levels can be accordingly gained. The best the BEMS design is, the highest the energy saving in a building is. Reported energy saving rate(s) in the reviewed papers have been discussed.
- Different relationships between the seven scope-based criteria have been mentioned and graphically represented.
- Analysis done in this paper has concluded that there is a need to enhance the *estimation*- and *prediction*- related BEMSs since they have achieved the least energy saving rates with about 10 %. When comparing this value to other BEMSs e.g., the "*control*" or "optimize" BEMSs, they are higher with more than two times.

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