Building Energy Management Systems for Sports Facilities in the Gulf Region: A Focus on Impacts and Considerations

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Abstract
Sports tourism in the Gulf region started to flourish where several international sports events were secured for the next decade. This reflects on the number of sports facilities, their energy consumption, and CO2 emissions mainly due to the indoor and outdoor air conditioning requirements. This paper aims to emphasize the significance of energy management in sports facilities especially for hot climatic regions. It presents a review of the works for optimizing building management systems' (BMSs) operation, anomaly diagnosis, and mitigation. It indicates their application scarcity for sports facilities compared to other types of buildings, and for the regions with hot and humid weather conditions compared to amiable and cold ones, in addition to the considerations for optimizing BMSs of sports facilities based on their type and regional location. An overview is presented of the impacts related to the security and the reliable operation of the BMSs of sports facilities given the advancements in the deployed technologies.

Keywords: Energy saving, energy management, energy optimization, sports facility, building management systems

1 Introduction

The Gulf region has witnessed an increased interest in sports tourism in the past years proven by the several hosted and secured mega international sport events such as the 2019 World Athletics Championships, 2019 AFC Asian Cup, Expo 2020, 2019 and 2020 FIFA Club World Cup, FIFA World Cup 2022, 2030 Asian Game, and many others. This will result in increasing the number of sports-related buildings, and the total incurred costs during operation due to the indoor and outdoor air conditioning given the round the year hot climate of the Gulf region. In Qatar, where the 2022 FIFA World Cup, which is known as the largest global sports event, will take place, the number of sports facilities has increased by 25% in the past decade, with more than a quarter of these facilities being football stadiums (Planning and statistics authority 2016), and many of them are equipped with outdoor air conditioning systems (Ghani et al 2017). Moreover, sports facilities are known for their exceptional energy demand profile because they encompass spaces involving different types of activities (i.e., offices, indoor/outdoor arenas, football stadiums, swimming pools, etc.), extensive lighting and broadcasting requirements, and they operate at high-occupancy seasonal rates. For instance, the capacity of football stadiums is at least 30,000 spectators on average during events, while it is estimated that the energy used in a 90-minute game is equivalent to a year worth of energy consumption of residential buildings (Badia 2020). Nevertheless, this results in increased levels of CO2 emissions since the energy source in the Gulf region is crude oil (Triantafyllidis 2018).

This is a literature review paper aiming at highlighting the significance of energy management and optimization systems in sports facilities located in hot climatic zones such as the Gulf region. The analysis is focused on the building management system (BMS) operation and the air-conditioning requirements for sports facilities. The focal points of this paper are:

- demonstrating the necessity of energy management and optimization in sports facilities given the increased global energy demand/usage and the global warming dilemma,
- assisting to grasp the energy use considerations in sports facilities in hot regions towards developing and deploying smart and user-friendly solutions for energy saving and optimized management,
- addressing the impacts and considerations related to the reliable operation and security of the BMSs of sports facilities given the advancements in their deployed technologies.

This review paper is organized as follows. In Section 2, the background information about the different types of sports facilities and the description of their building management systems are provided. Section 3 presents a literature review about research works about BMSs management and optimization in the buildings sector overly in terms of energy use and operation, system health monitoring, and security. The section also presents the conducted works for sports facilities and highlights the limitations and shortcomings. The discussion and analysis are provided in Section 4 and finally conclusions are presented in Section 5.

2 Background

2.1 Building management systems of sports facilities

The building management system is a computer-based system for control and monitoring of the building operation. As demonstrated in Figure 1, it consists of sensing devices for process measurements, actuating devices, control systems for operation regulation, database and cloud servers, application servers, and human-machine-interfaces (HMIs) for monitoring and manual control. Those elements are linked by communication networks in a hieratical manner where communication protocols such as BACnet, KNX, and LONworks are deployed. Additionally, the BMS is comprised of several sub-systems that vary for the different types of buildings, which include heating, ventilation, and air conditioning (HVAC) system, lighting system, surveillance system, broadcasting system, and many others. Some of the sub-systems may or may not exist based on the scale, sophistication, and type of sports facility. For instance, basic sports facilities may not be equipped with renewable energy systems (RESs), and others may have simple control system for its major elements, i.e., HVAC systems. The proper control and regulation of those sub-systems are crucial because the BMS operation is associated with social and environmental repercussions that are reflected on the health and safety of users (i.e., spectators, fans, athletes, etc.), the water and energy usage, greenhouse gas emissions, etc. It is worth noting that the diagram of the BMS shown in Figure 1 does not represent a comprehensive structure of the BMS of sports facilities which may include additional field equipment, sensors and meters, and additional control and monitoring elements.

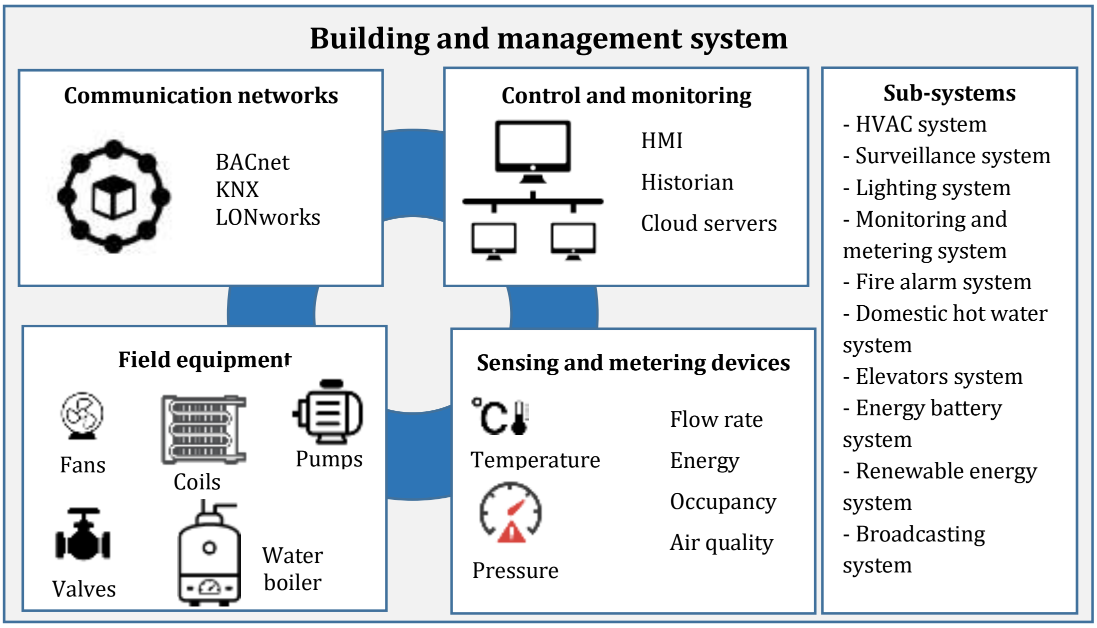

Figure 1. Overview of a typical building automation and management system.

2.2 Types of sports facilities

The understanding of the types of sports facilities and their requirements is the first step towards proper management and optimization of their BMSs. They have their distinctive features in terms of the activity type, occupancy and use profiles, energy demand, and others. For instance, stadiums are one of the most sophisticated types of sports buildings because they are large and have high energy demand profile and occupancy flow. Even though they are infrequently used, when operated, stadiums require extensive lighting requirements in addition to air conditioning and broadcasting services. Aquatic centers are the second most popular type of sports facilities. They host different water events and tournaments, and they are characterized by their high energy usage for water and air conditioning to maintain acceptable users comfort levels and air quality. Sport arenas and training halls are other types of sports-related buildings that include tennis courts, squash courts, gymnasiums, and others. Similarly, they have special air conditioning and lighting requirements, but their energy demand is comparatively lower than stadiums and swimming pools given their lower user flow.

3 Management and optimization of BMSs in sports facilities

With the increasing size of the BMS, its management becomes a complex task consisting of security management, fault diagnosis and mitigation, and performance monitoring and optimization. Energy management of buildings and the optimization of their operation have been addressed and handled extensivity by many researchers and scholars as presented in the following sub-sections. It was found that for sports facilities, the research focus was the energy usage and operation optimization while the subject of their BMSs health monitoring and security was rarely studied. The sub-sections below present an overview of the state-of-the art works covering the subject of BMSs management and optimization for conventional buildings versus sports facilities in terms of energy and operation optimization, and abnormality diagnosis and mitigation.

3.1 Energy use and system operation optimization

The proper management of the BMS operation towards performance optimization and energy saving is becoming the main goal for administrators and buildings managers. This is directly linked to the global awareness of the climate change challenge and buildings sustainability vision. This subject was investigated thoroughly for common types of buildings such as commercial buildings and residential buildings. Researchers and scholars carried out several literature reviews about the subject such as in (Hashempour et al 2020) for energy performance optimization of built environment and in (De Boeck et al 2015) for energy performance improvements in residential buildings. More particularly, given that the HVAC system is considered the most energy demanding and extensively operated equipment, researchers in (Ahmad et al 2016) conducted a literature review for the use of computational intelligence techniques for HVAC systems management and optimization, and in (Vakiloroaya et al 2014) for HVAC systems energy saving strategies. The diagram in Figure 2 lists the most commonly used approaches for this application.

Various approaches were utilized for the different types of sports facilities based on their greatest energy consumers of their BMSs. For example, using TRNSYS-based computational simulation, optimal heating applications were investigated in (Natali et al 2020) towards achieving energy savings and maintaining acceptable thermal comfort levels in swimming pools, while in (Oró et al 2018), an investigation was carried out for the potentials of heat reuse in liquid cooled data centers in swimming pools in which a TRNSYS dynamic energy model was developed for finding the best cooling configuration for liquid cooled servers in order to use their excess heat for swimming pool water heating. In addition, a cluster of passive and active measures for energy saving in a sports facility was investigated in (Katsaprakakis et al 2019) using TRNSYS software. In (Ciuman & Kaczmarczyk 2021), a simulation-based study was conducted to investigate the energy consumption of ventilation processes in swimming pools to identify energy saving potentials by examining the effect of the supply air volume flow rate on the annual energy consumption using IDA ICE software. In (Katsaprakakis 2020), the deployment of solar-combi systems in swimming pools was investigated by means of computational simulation while in (Manni et al 2018), the utilization of renewable energy systems in stadiums to achieve energy savings was investigated by carrying out a series of dynamic simulations using Design Builder. In (Nord et al 2015), energy models of an air supported indoor sports hall were used to analyze the energy optimization possibilities to achieve efficient and proper regulation of the indoor temperature in sports centers using Energy Plus.

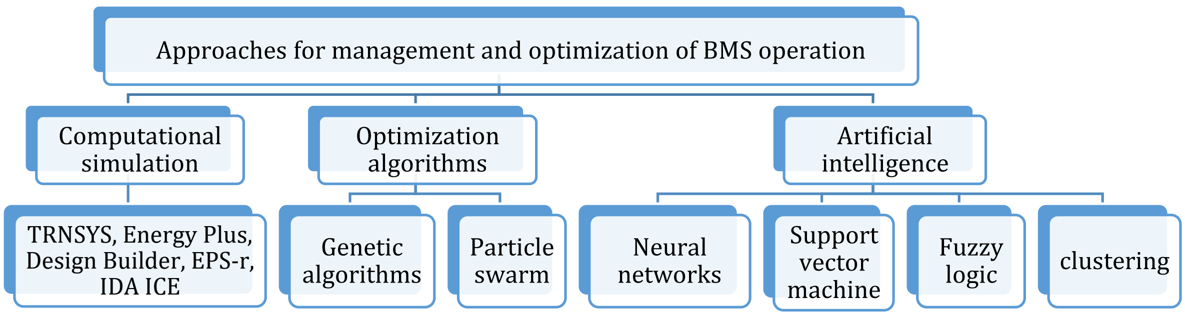

Figure 2. Approaches used for management and optimization of BMS operation.

Particle swarm optimization algorithm was utilized for a heat pump system design optimization in (Lee & Kung 2008) in a swimming pool to achieve energy use reduction. While in (Petri et al 2017), a multi-objective genetic optimization algorithm was combined with the building information model (BIM) to optimize the electricity consumption of the HVAC system in swimming pools. In (Petranović 2015), the genetic optimization algorithm was utilized for an outdoor football stadium lighting system design to achieve energy savings compared to the conventional approach, while in (Arnesano et al 2016), an optimization solver was used to determine the best sensor placement combinations in stadiums as accurate measurement of the indoor thermal conditions is essential for dependable operation of the BMS. In (Xiao-wei 2020), a smart sports center management system was developed utilizing a support vector machine-back propagation (SVM-BP) neural network for the prediction of the passenger flow in the center that was then used to better manage the facility. In (Yin et al 2020), k-means clustering algorithm was used for design optimization of a smart management system in stadiums in terms of the internet of things (IoT) technology to achieve integration of automation, digitalization, and information management towards overall energy, water, and cost savings. In (Yuce et al 2014), an artificial neural network was used for the prediction of energy consumption and thermal comfort level towards the management and control of an indoor swimming pool. In (Saleem et al 2021), fuzzy logic was used to assess the sustainability of swimming pools in terms of energy management, indoor environment conditioning, thermal comfort, service quality, and others.

3.2 Anomaly diagnosis and mitigation

Anomalies are activities or observations that are unacceptable or represent a bad behavior (Sachowski 2019). Anomaly detection is the first step towards the diagnosis and then the mitigation of their effects. It is defined as the establishment of a baseline to identify the scope of the acceptable behavior by observing process activity. As defined in (Sachowski 2019), the development of the anomaly detection framework follows the steps of:

1. deducing the acceptable behavior of the system outside which the observations are regarded anomalies,
2. formulating the baseline into an interpreted model,
3. profiling non-conforming observations as anomalies when deviating from the pre-defined acceptable behavior according to the baseline model.

Once an anomaly is identified, anomaly diagnosis is concerned with identifying its source followed by anomaly mitigation to attempt canceling out its effect on the system.

Looking into the literature, there are several strategies deployed for anomaly detection, diagnosis, and mitigation which are model-based, rule-based, data-based, and hybrid approaches. In model-based methods, as inferred from the name, the knowledge of the system dynamical behavior and parameters -formulated as a representation model- is required. That is, a representation of the BMS in a form of a mathematical or physics-based model is used as the core of the diagnosis and/or mitigation framework. Rule-based approaches rely extensively on expert knowledge in formulating a set of rules and conditions derived from the understanding of the system structure, operation, and interdependency of its components. Data-based approaches employ algorithms such as statistical analysis, machine learning, and artificial intelligence applied on the data to develop data-driven representation models. There are three types of data-driven approaches, which are supervised learning based in which labeled data is required to develop the model, unsupervised learning based in which unlabeled data is used, and finally semi-supervised learning based in which only normal operation data of the system is used in the model development phase. Finally, hybrid approaches combine at least two of the previous approaches. They are powerful as they attempt to optimize the tradeoff between the pros and cons of the individual approaches, yet they can be complex to develop. In the scope of this paper, there are two types of anomalies in BMSs, which are 1) system faults and failures, and 2) system attacks and intrusions. Further discussion about each of them is provided in the following sub-sections.

3.2.1 Fault diagnosis and mitigation

Fault diagnosis is concerned with the detection, identification, and isolation of anomalies or failures in the system. Fault mitigation is the process of removal or reversing the impact of the fault occurrence on the system operation aiming for system resilience and immunity against faults. For BMSs in general, the subject of fault diagnosis and mitigation is of high importance as those systems are known to be prone to faults that can occur in the communication networks, sensors and metering devices, actuators such as valves, dampers, pumps, fans, etc., and other components and equipment such as filters, pipes, ducts, etc. The importance of BMSs fault diagnosis and mitigation is stemmed from the potential impacts of faults on the different sub-systems that extends to performance, safety, and security aspects of the system operation. That is, they can be missed and remain undetected as it can be challenging and time consuming for operators to reliably identify the occurrence of faults, and to take the appropriate corrective measures accordingly. If they remain undetected for extended time periods, the system can sustain irreversible damage, increased operation costs or it can alter the reliability of the building operation performance. According to (Reppa et al 2015), BMS faults can result in reducing the energy efficiency due to faulty and unnecessary increase in the building energy consumption, interfering in the execution of safety supervision schemes such as evacuation, safety drills, etc., affecting their effectiveness and correctness by resulting in executing crucial tasks based on faulty decisions, and causing components wear, reducing their lifetime and increasing the maintenance cost. Table 1 lists the commonly recorded faults in BMSs of smart buildings. According to (Lazarova-Molnar et al 2016), among other types of faults, BMS faults leading to improper control strategy, i.e., the HVAC system and/or lighting system are operating in unoccupied spaces, make for about 40% of the total energy waste in buildings annually.

Table 1. Type of BMS faults in buildings.

Fault	BMS component
Duct leakage Airflow imbalance Dampers malfunction Reduced evaporator airflow	Air distribution system
Valve leakage and malfunction	Water distribution system
Coils fouling Sensor malfunction	HVAC system
Control component failure or degradation Software programming defect Improper control strategy	Automation and control system

There have been extensive research works covering BMSs fault diagnosis and mitigation in general using various methods. For example, a model-based approach was proposed in (Trothe et al 2019) for fault diagnosis in smart buildings in which a dynamic model of the building was utilized. In (Kučera et al 2013), a rule-based framework was proposed for fault detection in BMS networks utilizing computer-software monitoring applications and device behavior analysis. That is, ensuring of the viability and the proper operation of communication links is essential especially for complex BMSs. They play a vital role in the overall system operation since continuous data transfer and inter-communication between the sub-systems of the BMSs are carried over those links. In (Lin et al 2020), a rule-based HVAC system fault diagnosis and mitigation technique was developed for faulty programmed schedules, sensor bias, suboptimal setpoints, and others. The proposed framework seems promising and has potential in terms of integration with the existing BMS technology. However, there are a number of associated challenges mainly regarding securing a reliable and firm communication link between the diagnosis and mitigation tool and the BMS, incorporating authorization properties, and managing potential conflicts and limitations between the proposed diagnosis and mitigation framework and the BMS control actions.

A comprehensive review was presented for artificial intelligence-based fault diagnosis approaches for building energy systems in (Zhao et al 2019). In (Yan et al 2020), chillers faults diagnosis in HVAC systems were studied utilizing a generative adversarial network (GAN). In (Han et al 2020), a data-based fault diagnosis framework for chillers was proposed utilizing three machine learning algorithms, which are k-nearest neighbor, support vector machine, and random forest. In (Bouabdallaoui et al 2021), a data-based predictive maintenance framework for building installations was proposed and demonstrated on a sports facility. Data collected from the HVAC system using Internet of Things (IoT) devices and a building automation system were used to train a deep learning model for fault detection. Even though the proposed approach demonstrated effective performance on the case study, it is conditioned to the availability of sufficient amount and adequate quality of data. In (Liu et al 2021), a fault detection framework for sports equipment based on optical imaging technology was proposed since their safety is one of the basic conditions for the development of national traditional sports.

3.2.2 Security of BMSs: Attack and intrusion diagnosis and mitigation

Security management of sports facilities is considered one of the critical research topics in sport management (Hall, & Finch, 2009). Attacks targeting the field devices or the communication networks in the IoT system can reduce the energy efficiency of the facility due to excessive and unnecessary energy use induced by malicious agents. Moreover, other implications of attacks on the BMS of sports facilities are (Finch 2015):

- Operation disruption due to falsifying information to disrupt evacuation execution in emergency cases or interrupt on-going activity due to false alarms, altering with the HVAC system or the lighting system to perturb the athletes/users' experience, and many others.
- Physical harm to users and/or athletes, which can be due to overloading utility systems or disabling safety programs.

BMSs are generally equipped with standard security systems that conduct measures to prevent the common types of breaches. This includes the conventional procedures of authentication and authorization, standard implementations to protect the system from malware in addition to defense and mitigation systems against attacks and intrusions. However, there are still some challenges as identified by (Stamatescu et al 2020) especially that the used technologies in BMSs were not developed with security as a primary requirement, and so most of them operate with low-grade security practices. However, the research community has not yet investigated the BMSs security aspect as extensively as the other matters, i.e., energy optimization and fault diagnosis, as only limited research works were found in the literature developing security systems for the buildings in general and none directly investigating the subject for sports facilities. For example, in (Hernandez-Ramos et al 2015), a network-based approach for smart buildings security was developed utilizing anomaly behavior analysis for intrusion detection. A secure network architecture based on multivariate correlation analysis for Denial-of-Service (DoS) attacks was proposed in (Singh et al 2017) for the real-time network traffic in a smart home. In (Paridari et al 2018), a hybrid security system for BMSs was proposed that consists of a hybrid detection model using a rule-based structure and one-class support vector machine algorithm, and a model-based attack mitigation framework using Kalman filters. In (Elnour et al 2021), a data-driven process-based attack detection approach was proposed for HVAC systems in buildings employing machine learning algorithms. Even though those works were not exactly conducted for or demonstrated on sports facilities, they seem promising for the different types of buildings.

4 Discussion and analysis

4.1 General observations

Given the conducted literature review, the following was noted. Most of the surveyed works investigated the energy management of commercial and residential buildings since they make most of the buildings stock worldwide, with minimal application on sports facilities, and those few were mainly focused on facilities in cold regions. However, the operation of BMSs is subjected to various factors that determine their specifications and optimization requirements as discussed in the following sub-sections.

4.1.1 Type of building and its application

Residential buildings are used for dwelling purposes and they are characterized by their low occupancy density and low users flow. Commercial buildings are used for commercial purposes and they include office buildings, shopping malls, warehouses, retail, etc. They operate round the year with special operation and activity schedules and they typically have relatively high occupancy density and users flow. Recreational buildings among which are sports facilities, have special occupancy and use patterns such that they experience high passenger flow rates and occupancy density during certain times of the year, i.e., events season. Even though they operate less frequently than commercial or residential buildings, they utilize extensive energy given the operation requirement due to the high number of users. The extent of the BMS duty is different for those buildings such that it is minimal for residential buildings and utmost for commercial and recreational buildings as extra components of the BMSs are required and hence operational (i.e., lighting system, surveillance system, elevator system, etc.). Moreover, among sports facilities, considerations about their special requirements should be taken such that swimming pools, for instance, require extensive water and air conditioning, while football stadiums require energy demanding lighting and broadcasting services in addition to air conditioning, and so on. Those features determine the specifications and requirements of the management and optimization systems of BMSs.

4.1.2 The climatic and geographic zone

In terms of HVAC systems, which are known to be the most extensively operated equipment and the greatest energy consumer in buildings, for those located in regions that are characterized by overly cold to average weather conditions, it is expected that BMSs energy consumption will be fundamentally due to heating as opposed to hot climatic zones where mainly cooling is required. Depending on the technologies used, generally it is known that heating is more energy-intensive than cooling. Nevertheless, for cold regions, heating is only required for less than 50% of the year and minimal and economical air conditioning is sufficient during the rest of it due to the fair and amiable weather conditions. On the other hand, some regions require energy-intensive air conditioning for nearly most of the year. For instance, in the Gulf region, extensive space cooling in buildings is required for about 70% of the year due to the hot and humid climate, while standard air conditioning is applied for the rest of the year (i.e., winter season) to maintain air quality and ventilation requirements. Another important factor is the energy sources and their sustainability. Power plants can be dependent on solar power, hydro power, wind power, fossil fuel, and many others. The electricity generation driving fuel is bound by the geographic region in terms of both the available resources and the technology advancement and popularity. For example, the Gulf region is rich in oil and gas which are mainly used for electricity generation as well as freshwater production, while the renewable energy plants harvesting solar power and wind power are still evolving and their promising potential is not yet fully harnessed.

4.2 Management and optimization approaches of BMSs in sports facilities

Since the Gulf region has started to get more interested in sports tourism, the following is essential for BMSs of sports facilities in the region bearing in mind, the extreme hot and humid weather conditions, the complete dependency on fossil fuels for energy generation and freshwater production, the growing attention to the region for sports tourism, and the global increased BMS threats and attacks in the buildings sector:

- efficient energy consumption of BMSs of the facilities,
- reduction of CO2 emission towards mitigating the global warming and climate change dilemma, and
- secured and successful hosting of sporting events in terms of the overall management and execution, fans and athletes experience and satisfaction, and their safety, security, and health.

The aforementioned objectives are to be achieved in terms of the two main aspects of the BMS operation, which are: system operation management and optimization., and fault & attack diagnosis and mitigation.

4.2.1 Energy and operation optimization of BMSs in sports facilities

Compared to other types of buildings, further studies about energy management and optimization of sports facilities are imperative, especially for regions characterized by hot and humid weather conditions. There are two important aspects to be considered, which are the energy profile of the sports building and the climate zone. Sports buildings have their unique characteristics that distinguish them from other common types of buildings. Careful attention and consideration to the characteristic features is essential when studying the management and operation of those facilities. This includes their energy usage profiles, occupancy levels and patterns, types of users' activity, types of systems and equipment present, and types of spaces encompassed in the building. On the other hand, the regional context plays a vital rule in the overall achieved performance given that sports recognition, technologies used, and energy requirements vary accordingly. The popularity of the sports facilities is diverse for the different countries such as in the Gulf region, football is the most popular and dominant sport and so the number of stadiums is expected to be more than other types of sports facilities, and so forth for other regions/countries. In addition, investigating the use of renewable energy system in sports facilities to exploit solar and wind energy will be advantageous.

4.2.2 Fault and attack diagnosis and mitigation of BMSs in sports facilities

One step towards performance optimization and management of the BMS operation in sports facilities is the deployment of effective and reliable fault and attack diagnosis and mitigation schemes to ensure efficient energy usage, secured operation, proper management of sporting events, and safe and pleasant fans and athletes experience. The diagnosis and mitigation scheme is advised to cover both process and network aspects of the BMSs system. That is, hybrid frameworks are powerful because they employ information about the system from two distinctive elements of the BMS architecture, i.e., the process and the communication network, which enhances the performance and capability of the approach. That is, both the process and the communication network can be affected by different types of faults, attacks/intrusions with identical impact on the BMS operation. Studies on hybrid anomaly detection and mitigation strategies for BMS in general are rare. It will be advantageous to consider adopting them for sports facilities and stadiums in the Gulf region towards the reduction of total energy consumption and consequently the reduction of their carbon footprint as well as the success of the sports events' execution and management and reassuring the safety of users.

5 Conclusion

The management and optimization of energy use and operation of BMSs of sports facilities in the Gulf region became increasingly important considering the increased number of mega international sport events that are scheduled for the next decade. This paper presented a literature review of the state-of-the-art works regarding the management and optimization of BMSs in terms of operation and energy optimization, and fault & attack diagnosis and mitigation. It was found that studies focused on sports facilities are scarce compared to other types of buildings, and they are rare for facilities located in hot regions compared to amiable and cold ones. This gap was identified where it was concluded that further investigation and studies are required for BMSs of sports facilities in general in terms of energy optimization, health monitoring system, and security systems, with emphasis on their importance for facilities located in hot climatic regions such as the Gulf region. An analysis was presented about the considerations for the management and optimization of sports facilities' BMSs based on their type and their regional location when compared to other types of buildings as well as the impacts and considerations related to the security and the reliable operation of the BMSs of sports facilities given the advancements in the deployed technologies.

It was concluded that the successful management and optimization of sports facilities require accounting for their special requirements and characteristics in terms of the type of BMSs and technologies used, activity and operation schedules, occupancy and energy demand profiles, and their geographic location towards more efficient and sustainable facility. Moreover, the reliable and secured operation of BMSs determines the success and prosperity of the sporting events in terms of the execution as well as fans and athletes experience and safety.

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