CE-BEMS: A Cloud-Enabled Building Energy Management System

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Abstract— **Energy consumption in smart buildings is monitored and controlled using Building Energy Management Systems (BEMS). A BEMS provides a set of methods to monitor and control a building's energy needs while maintaining a good quality of living in all of the building's spaces. Energy efficiency and costs savings in smart buildings significantly depend on the monitoring and control methods used in the installed BEMS. This paper proposes a Cloud-Enabled BEMS (CE-BEMS) for Smart Buildings. This system can utilize cloud computing to provide enhanced management mechanisms and features for energy savings in smart buildings. This system is connected to the cloud to have access to a number of advanced cloud-based services to enhance energy management in smart buildings. In this paper, we discuss the current limitations of BEMS, the conceptual design of the proposed system, and the advantages, opportunities, and challenges of using the system.**

Keywords- Smart Building, Cloud Computing, Building Energy Management System, Energy Efficiency

I. Introduction

Energy consumption in buildings is responsible for a significant portion of the total energy use and carbon emissions in a city. For example, energy use in buildings is around 40% of the total energy used in the EU area and it contributes by around 36% in the carbon emissions. Due to these important issues, the European Commission aims to cut the annual use of primary energy by 20% by 2020 [1]. The main target for the cuts in energy consumption is to convert buildings into smart buildings by applying two approaches. The first is to use special materials in the buildings' walls such as insulators and energy absorbing material that can result in improved energy efficiency. The second approach is to use smart techniques to control buildings' equipment such as HVAC (heating, ventilating, and air-conditioning) systems, home and office appliances, and lighting systems.

Energy saving in smart buildings requires the deployment of different types of sensor nodes that monitor the current energy usage and environmental conditions. These sensors report their observations and measurements to a centralized monitoring and control system. The control system implements intelligent algorithms to control the systems used in the buildings to optimize energy use based on the sensed observations. These algorithms are designed to control several actuator nodes that control small subsystems within the buildings. These subsystems implement different energy saving applications in smart buildings such as automatically switching off office lights when an employee leaves an office, adjust the heating or air conditioning levels based on current occupancy levels and external temperatures, and send employees' computers to standby or energy saving mode when not in use [2].

In this paper we offer a new approach to facilitate building energy management in smart buildings by utilizing Cloud Computing. We propose a CE-BEMS (Cloud-Enabled Building Energy Management System) that can add advanced features and enhancements to the current BEMS. This system is connected to the cloud to utilize the software, data, and hardware resources available on the cloud. With CE-BEMS, advanced cloud services can be developed to utilize cloud resources to collect more monitored data from multiple smart buildings, process this data to provide better updated mechanisms and configurations to the CE-BEMS for better energy efficiency management in smart buildings.

In this paper Section II provides background information about BEMS and discusses their current limitations. Section III provides background information about cloud computing and discusses the advantages and opportunities it offers. A conceptual design and the functions of the proposed system, CE-BEMS, are provided in Section IV. Section V discusses the considerations and opportunities gained from utilizing cloud computing for smart buildings. The section also discusses the challenges of utilizing such services. Section VI offers an overview of some related work while Section VII concludes the paper.

II. Building Energy Managemnet Systems

A smart building is usually equipped with a Building Energy Management System (BEMS). This system provides a sophisticated tool to monitor and control the building's energy needs while maintaining a good quality of living in all building's spaces. It provides control functions for heating, ventilation and air conditioning (HVAC) systems, lighting as well as control functions for other devices and appliances in the building. This system can contribute to the continuous energy management efforts and therefore to the achievement of better energy efficiency and results in more cost savings.

While the first generation of BEMS systems was electronic-based devices, the second generation consists of more computerized devices. This allows for developing and utilizing more sophisticated control and monitoring algorithms for different building systems. Examples of these algorithms are genetic algorithms [7] and neural networks [8], empirical models [9], weighted linguistic fuzzy rules [10], and simulation optimization [11], which are proposed for the control optimization of specific HVAC systems. In addition, more sophisticated integrated control systems that build knowledge-based and intelligent systems utilizing occupancy predictions, optimized fuzzy controllers, and genetic algorithms [12] are proposed, developed, and successfully evaluated [13]. Furthermore, more approaches that provide better and more cost-effective decision making for BEMS are proposed. Examples of these approaches are using rule sets [14], multi-agent control [15][16], supervisory control and data acquisition [17], scheduling-based real time energy flow control strategy [18], and energy prices based control [19].

Although a BEMS can enhance energy efficiency and reduce energy costs in smart buildings, there are some limitations with such systems. In the following, we list some of the main limitations:

1. Updating BEMS control models: There are huge and continuous developments in new enhanced control algorithms for efficient energy consumption in smart buildings. However, it is very difficult to update the current BEMS with these algorithms. Some control algorithms could provide better results than other algorithms for some buildings, yet they need to be installed tested and configured correctly to achieve their goals. These steps require planning and long intervals of time to deploy and evaluate, which may not be possible as the BEMS is currently in use and cannot be taken offline. In addition, this usually requires technical specialists to handle the upgrades; as a result, high costs are also involved.

2. Including new sensors and devices: Most current BEMSs are designed to deal with specific types of sensors and devices. There is continuous development in sensors technologies and energy-efficient devices. Connecting and utilizing these new devices may require adding software models, as well as changing system configurations. This makes the process of effectively utilizing new sensors and devices very difficult.

3. Fault Detection and Diagnostics: One of the challenges facing smart buildings are faults in the energy subsystems. As energy subsystems in smart buildings rely on different software and hardware components such as sensors, actuators, and other devices for energy savings, faults in these components may create faults in the subsystems. These faults eventually accumulate and lead to increases in energy consumption. Furthermore, some of these faults are hard to detect so the increases in consumption could run unnoticed for extended periods of time. It is estimated that faults contribute between 15% and 30% of the energy consumption costs [3]. As a result, Fault Detection and Diagnostics (FDD) is a very important issue in smart buildings. It has been shown that by deploying automated FDD as part of the BEMS, the operational costs of buildings can be significantly decreased [3]. However, this requires advanced diagnostic algorithms, high processing capability, and large storage capacity for storing building energy information collected over extended periods of time.

4. Separated BEMS: Multiple BEMS are usually used to control energy efficiency in multiple buildings. These buildings can be very similar in their locations, designs, usage, and operating conditions. However, current BEMS deployments does not integrate multiple buildings together. With separated BEMS for each building, it is very difficult to collect some common observations that can be utilized for better energy efficiency among these multiple buildings. In addition, it is difficult to build a unified knowledge-base to collect and organize energy consumption data from these similar buildings.

5. Integration with other systems: BEMSs operations and capabilities can be enhanced by integrating them with other systems such as the smart grid [23]. This enables the utilization of advanced techniques and control algorithms such as energy prices based controls [19]. However, this integration is not always achievable in a smooth way as it requires upgrades and alterations in the installed BEMS.

III. Cloud Computing

Cloud computing is an on-demand computing model that eliminates or reduces the need for companies and organizations to have in-house high-cost software, hardware, and network infrastructures. It also reduces the cost of recruiting technical professionals to support these infrastructures and operate the in-house IT solutions [4]. Cloud computing has rapidly evolved into a service oriented computing paradigm enabling various services to be provided to interested consumers at reasonable and lower costs [5]. Consequently, establishing a formal definition and description of Cloud Computing and its requirements is a pressing necessity. The recent NIST definition of Cloud Computing [6] describes it as a paradigm allowing users to access shared configurable computing resources. The NIST definition is based on five main characteristics:

- User clients can automatically benefit from the wide-range of Cloud services without communicating with the service providers.
- Standard mechanisms and protocols are used to access the computing resources over the Internet.
- Cloud services follow a multi-tenant model allowing resources to be pooled and shared among users.
- Computing capabilities can be quickly scaled in or out based on the users' varying demands.
- Users pay for utilized computing capabilities based on a pay-per-use model.

Beyond the NIST definition, various definitions came into the picture and most evolve around the general characteristics defined by the NIST. Offering various types of services to the consumers, the cloud computing paradigm follows three main service models: Software-as-a-Service (SaaS), where a user can utilize a number of application software provided by the Cloud provider's applications that run on the Cloud infrastructure; Platform-as-a-Service (PaaS), where a user can develop and deploy applications onto Cloud platform infrastructures; and Infrastructure-as-a-Service (IaaS) where a user can benefit from the computing and storage resources offered and managed by a cloud service provider. Consumers can utilize make use of one or more of these models to satisfy their technology solutions needs, while not having to acquire and maintain their own computing infrastructures.

IV. CE-BEMS Conceptual Design and Functions

The smart building energy management with CE-BEMS is structured in a three-tier architecture as shown in Figure 1. The first tier is available in each smart building and consists of multiple energy consuming subsystems and devices. In addition, it includes distributed sensor nodes that monitor the current energy usage and environmental conditions. Moreover, all active control devices and actuators are included in this tier as they will respond to the measured conditions and execute the controls and adjustments delivered form the upper tiers. The second-tier is composed of the CE-BEMSs. One CE-BEMS is available in each smart building. This CE-BEMS connects all energy consuming subsystems and devices, sensors and actuators (all components of the first tier) in the building. The main function of CE-BEMS is very similar to a regular BEMS and that is to monitor and control the building's energy needs while maintaining a good quality of living in all building's spaces. It contains all algorithms and mechanisms to provide this important function. The CE-BEMS resides on a computing device that has one or more processors, memory, storage, and communication interfaces to connect with the different buildings' energy subsystems, devices, sensors and actuators. Each CE-BEMS is capable of storing and processing a number of software models that implement different algorithms and mechanisms that provide the functions of control and monitoring for the energy consumption in the smart building. One main difference between CE-BEMS and BEMS is that all CE-BEMSs managing the different buildings are connected to cloud services, the third-tier, through the Internet.

The cloud services forming the third tier are managed by a cloud service provider (or multiple providers) and implemented over a cloud infrastructure. The service provider(s) offer multiple basic functions for different smart buildings. This may include but not limited to the following functions:

1. Providing all required CE-BEMS software models that implement different control and monitoring algorithms.
2. Providing some parameters or data that are needed by software models executing on the CE-BEMSs for more efficient energy monitoring and control.
3. Providing regular updates for the CE-BEMSs software models that can deal with new energy subsystems, devices, sensor nodes and actuators; or that contain more energy-efficient control models using better or more advanced algorithms.
4. Configuring the connected CE-BEMSs to collect a certain type of data for the current energy usage and environmental conditions in the participating smart buildings. This collected data can be used to enhance the decision making process, which in turn help improve the control software models.
5. Offering access and usage facilities for incorporating more advanced data analytics and applications requirements.

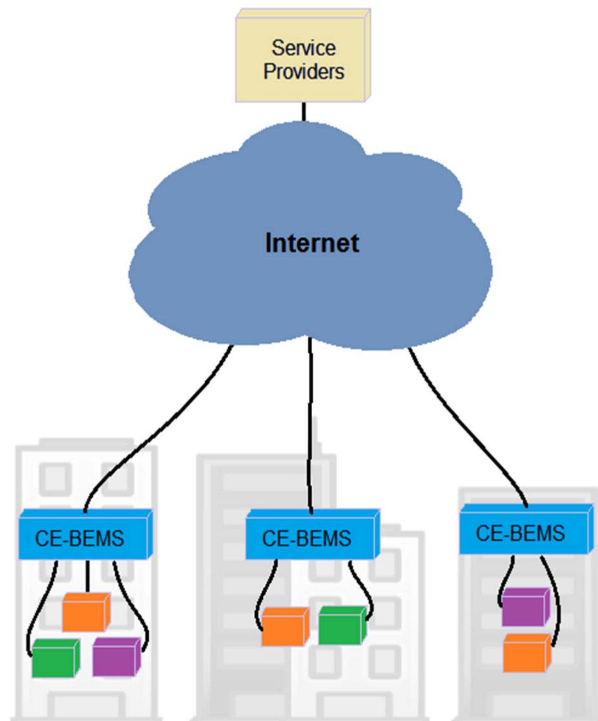

Figure 1. Using CE-BEMS as part of three-tier architecture for smart building energy management.

Using cloud services to help in data collection and creating a collective knowledge base for multiple smart buildings help further improve the CE-BEMSs functions. The data collection rate can be configured based on the requesting applications and based on the available communication, processing, and storage resources. A diagnostics service on the Cloud can for example turn this collection process on or off. It can be turned on at certain times to perform more energy consumption diagnostics. In addition, it can configure the CE-BEMSs to perform pre-processing on the collected data before sending it to the Cloud. This mechanism results in a more efficient approach for collecting the needed information where data can be combined and processed before being transmitted over the Internet. For example, the pre-processing and sending rate can be configured such that data is collected every minute, while a summary of collected data will be sent to the cloud once every hour. This reduces communication costs and providing optimized diagnostics information collection process. In addition, CE-BEMSs can be further equipped with emergency real-time data collection and transmission in case of an anomaly being detected. For example, a steady stream of data collection is underway once a minute with a summary being sent to the cloud once an hour; however, when one or more of the readings indicate abnormal values, the CE-BEMS will automatically increase the data collection rate and transmit this data in real-time to the cloud for processing and providing proper responses.

Based on the above-mentioned basic functions, more advanced energy management functions can be provided for smart buildings by the cloud. This includes, but is not limited to:

1. Providing virtual sensors software models for more accurate sensing. Virtual sensing is an approach to provide logical sensors that provide economical alternatives to costly physical sensors. A virtual sensing system utilizes information available from other lower cost or more widely available physical sensors such as fixed physical sensors and other mobile sensor devices such as smartphones to calculate an estimate of the quantity of interest. In this regard, there are two techniques of virtual sensing: analytical virtual sensing and empirical virtual sensing [20]. The analytical virtual sensing technique is based on the calculation of the measurement estimate using approximations of the physical laws including those that involve distances of the available physical sensor devices. The empirical virtual sensing technique is based on the calculations of the measurement estimate using the available current and previous measurements. The cloud can store the layouts of the buildings along with collected diagnostic data for energy consumption and environmental conditions to add these virtual sensors to the participating smart buildings. Generally, virtual sensors can provide inexpensive extra logical sensing capabilities while expanding the data collection process for better smart buildings energy management.

2. Providing fault diagnostic services for smart buildings. One of the advantages of this model is that as the cloud service provider can collect, store, and process more data from multiple smart buildings; it can enhance the fault detection and diagnostic processes using this collected data. In addition, this will enable cloud service providers to implement automated knowledge-based systems for building energy diagnostics such as the one proposed in [21] and other advanced mechanisms such as fault detection analysis using data mining as proposed in [22]. For example, the cloud service provider can provide monthly diagnostic reports for any possible faults in the energy systems in the buildings to the owners. This may initiate maintenance actions in the building by the owners for more energy savings. The reports may also offer forecasts for possible faults based on historical data collected and analyzed from all participating smart buildings.

3. Supporting better integration with other systems. Integrating CE-BEMS and smart building subsystems with other relevant can help achieve more energy cost savings. An example of this service is the integration between the smart grid and the CE-BEMSs. A CE-BEMS can for example use information about high and low energy load periods can be used to improve appliances utilization times and scheduling non-essential energy consuming tasks to low energy load periods. The information flow between the smart grid and smart buildings can be efficiently handled by the cloud. This allows for maximizing energy efficiency through the energy market connection [23]. In addition, the cloud can provide software models for the CE-BEMSs to provide dynamic management mechanisms of building energy management based on available optimal price options from other systems for reducing the total energy costs.

4. Managing similar buildings. As we mentioned in Section II, multiple buildings can be very similar in their locations, designs, usage, and operating conditions. With the integration with the cloud that collects information about energy consumption and environmental conditions, multiple enhancements can be developed to improve energy efficiency in these similar buildings. These enhancements include better energy consumption prediction, better diagnostics, and better data collection quality control in which all will lead to higher energy efficiency.

The examples offered here provide a glimpse into the endless possibilities to create and use many features and functions supported through cloud computing. As part of a larger cloud-based system, a CE-BEMS can use localized and general data collected from other smart buildings to improve functionality, enhance operations and optimize energy use and costs in smart buildings. As the model is service-based, adding, modifying and removing services as needed becomes easier, more practical and more cost-effective for smart building owners and managers.

V. Discussion

There are several benefits to utilizing cloud computing for smart buildings' energy management. As more data is gathered from multiple smart buildings for analysis; storing, processing, and understanding this data will require huge computation and storage resources as well as advanced software that implements innovative algorithms for accurate energy consumption analysis and management. This can be extremely costly for buildings owners. Cloud Computing can provide scalable and cost-effective solutions for such needs. Relying on cloud services designed to support smart buildings owners' needs leverages the high costs of the technologies required and reduces the operational requirements. Smart buildings can use different solutions and services offered by cloud providers such as data storage services, processing services as well as advanced services such as fault diagnostics services which usually require huge data sets [24]. Another advantage of this model is that as the cloud service provider can collect more data from multiple smart buildings; it can enable cloud service providers to develop automated knowledge-based systems for smart buildings management and diagnostics. This can involve other factors such occupants' contexts [25] for the benefit of the smart buildings' owners.

Although integrating with cloud computing can provide many features for building energy management, there are some challenges that need to be addressed before some benefits can be gained from these features. One of these challenges is security and privacy. As CE-BEMS will be connected to the cloud through the Internet, the system of the participating smart buildings can be vulnerable for some security attacks. However, there are many security mechanisms developed recently for the cloud to prevent many attacks [26]. Smart building information may contain various types of sensitive information such as occupancy times and occupant's information. This information must be properly protected to avoid loss or misuse of data. In addition, it is also important to provide methods to hide personal and private information when collecting and sharing data from multiple smart buildings. This creates important privacy protection issues that smart buildings owners must handle correctly and assure occupants about.

Another challenge is in how facilitate effective integration between the CE-BEMSs and cloud services. This integration should enable efficient utilizing of cloud services and acceptable levels of response times and actions. One possible approach that can be evaluated for integration purposes and was successfully used in other similar environments is to use service-oriented middleware [27]. Service-oriented middleware can provide a number of services to enable smooth and uniform integration between CE-BEMSs and cloud services on one side and also between CE-BEMSs and building sensors, actuators and other devices on the other side [28]. Various non-functional requirements facilitating effective and efficient integration can also be supported through middleware. Some examples include offering specific QoS requirements, enhancing response times, increasing the availability and reliability of the services, and allowing for better handling of multiple consumers (i.e. multiple CE-BEMSs). Moreover, separating some of the integration concerns into a middleware layer, simplifies the overall design of the services and subsystems needed through abstractions and unified interfaces.

VI. Related Work

Cloud-based solutions are proposed to provide control and support mechanisms in different environments. One of these environments is smart homes to eliminate the heavy computational burden on the local computers when dealing with numerous data sources and complex controls of the smart homes. In addition, this also facilitates easier access to smart home features over the Internet from anywhere at any time [29]. Another example is the wireless body area networks used for pervasive healthcare and remote patients monitoring. Cloud computing can help in massive deployment of pervasive healthcare applications [30]. In addition, it was used to provide an intelligent parking service for vehicles [31]. Furthermore, Intelligent Transportation Systems can be enhanced using cloud services. Road safety, transport productivity, environment protection, travel reliability, informed travel choices, and traffic resilience can be improved with cloud services [32]. Integration of cloud computing with other physical systems such as robots and unmanned aerial vehicles is also proposed [33][34][35].

Web solutions are proposed to provide enhanced interfaces and controls for building energy management [36] [37]. The authors in [36] proposed web-based energy information systems for energy management and demand response in commercial buildings while the authors in [37] proposed a web-based energy management and control system to optimize the algorithms that are implemented in existing BEMS. The issue of linking collected buildings data in the cloud is investigated in [38]. The authors addressed the issue of data interoperability problems and proposed the use of linked data as an enabling technology for cloud-based buildings data services.

VII. Conclusion

This paper discussed utilizing cloud computing for enhancing the operations of smart buildings energy management systems. Generally, cloud computing can provide many advantages for smart buildings energy management. In addition, this integration opens the door for adding new services, enhancements, and optimizations for these systems. The main functions of a cloud enabled building energy management system (CE-BEMS) were listed and discussed in this paper. However, there are also challenges to be addressed to achieve best results. The two main challenges are security and privacy issues and effective integration methods between the CE-BEMS and the cloud services. Various approaches may be used to address these challenges and more research is needed to find the most suitable approaches and offer effective cloud services to support smart buildings management systems.

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