A Preliminary Review of Building Informatics for Sustainable Energy Management

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Abstract. Building sector is a major energy consumer that represents a significant area of research in energy sustainability efforts. Building system is essentially a complex system that can be viewed from a number of perspectives, including occupants, thermal conditions, climate, engineering systems, and management practices. In this paper, we have conducted a preliminary review on the research issues, challenges and opportunities in the field of sustainable energy management, from the perspectives of building informatics. Based on literature survey, we have reviewed the status-quo of existing practice and related research challenges in building energy management. We then present the existing building information collection and processing strategy, follow up with a discussion on how informatics is being applied for sustainable energy management. Based on our discussion, we have summarized four essential research areas that are worth investigating for future research, with in-depth discussion on the rationale, main issues and existing efforts in respective area.

1. Introduction
Building is the fastest growing energy consuming sector [1]. Building sector (residential, commercial and public) accounts for 20%-40% of final energy consumption [2]. In a modern office environment, building systems such as lighting, HVAC and office equipments are the main energy consumers. According to US Green Building Council [3], buildings consume about 70% of final energy consumption via HVAC system and artificial lighting, and contributed approximately 39% of CO₂ emissions. Another survey by US Energy Information Administration also showed that total energy usage in commercial buildings has increased 7% since 2003, where electricity consumption in buildings has doubled from 38% in 1979 to 61% in 2012 [4]. Locally, in the context of Malaysia, approximately 48% of all available electrical energy are consumed in commercial and office buildings [5].

The aforementioned facts indicate that building energy consumption and management is a pressing issue and a key sector worth investigating for energy sustainability. Understanding the use of energy in buildings requires an insight into the amounts of energy consumed and the different aspect of the usage. For energy users, energy management can be described as the sum of measures planned and carried out to achieve the objective of using the minimum possible energy while the comfort levels (in offices or residential) and the production rates (in factories)
are maintained [6]. The challenge is particularly difficult in the area of energy management, where rising utility costs, a lack of discounted tariffs and restrictive legislations are creating major issues in the process. With the prolonged global economic downturn, energy management is seen as a concept limited to monitoring and controlling utility consumption and reducing leakage. From the implementation perspective, building information management (BIM) system is often used to provide a common platform for information sharing that can be used by all stakeholders in design, construction, and facility management after a building is completed and occupied. A building management system (BMS), on the other hand, offers intelligent decision making process to allow integration and automation of all building technologies to optimize energy consumption. A BMS provide intelligent functionality to respond to the energy demand and comfort of office building environments for normal daily operation. Nevertheless, few have successfully identified emerging energy management opportunities beyond utility consumption [7].

With that in regard, building informatics (BI) has become an emerging research area in the building research community in order to achieve an overall operational and energy sustainability. BI is an emerging area of research where it involves the collection, processing, storage and retrieval of building related information, such as occupants data, building operation data, etc. for the purpose of building operational analysis, knowledge discovery and decision making. In the academia, building informatics is an active research area with progress in fields such as smart home [8], intelligent buildings [9], heating, ventilating and air-conditioning (HVAC) system monitoring [1] and occupants activity analysis [10]. Nevertheless, the exploration on knowledge discovered from collected building information and the application of such knowledge for optimized building operation is still less emphasized. Given the latest development in building activity sensing technology and data analytics, we reckoned that there is a need to review the latest works in this area for a better understanding of research issues, challenges and opportunities.

In this paper, we wish to discuss on the state-of-the-art research and development in the field of sustainable building energy management, from the perspective of BI. The rest of this paper is as follows: next section (Section 2) elaborates on the state-of-the-art research in building energy management. We explain the recent advances of building informatics in Section 3, and further explained this field of study in two sub-sections (Section 3.1 and Section 3.2). Lastly, we discuss the research issues pertaining this emerging field of study in Section 4 with brief discussion on future works, and conclude our work in Section 5.

2. Building Energy Management
The performance of the energy management in building might be carried out in two terms which is applying predicted method using building energy modeling software where it relies on certain assumption that the building services is perfectly efficient [11]. Another method is performing frequent energy audit in term of the building energy management and control, thermal comfort and building quality besides detecting the unregulated load by the facility managers [12]. This is relevant as the term Post Occupancy Evaluation (POE) which is the evaluation method designed for facility managers to identify and evaluate the building performance of the building could be sustained. From this perspective, several assessments can be conducted to determine the performance of buildings either it met the user needed resulting with a suggestion of measures necessary to improve overall building design, performance, and fitness [13].

In broad view, the scope of energy management should not only be limited to utility consumption by air conditioning and mechanical ventilation (ACMV) systems in facilities or IT infrastructure. In the recent years, the growing development of building energy efficiency technologies around the world has increased the interest of implementing building energy management concept in Malaysia. The Malaysian government has demonstrated the
commitment towards this concept among the government buildings which include Diamond Building at Putrajaya and Low Energy Office Building of Ministry of Energy, Water & Communications. Both buildings have been designed with energy efficiency features, such as a comprehensive Energy Management System (EMS), and can achieve a Building Energy Index (BEI) less than 150 kWh/m²/year [14].

It has become imperative for organization to build dedicated teams and departments to implement processes and technologies that can help reduce consumption. However, with numerous avenues of energy consumption to be considered, it has been a challenge for such teams to measure and control it. By taking this as an opportunity, some IT service providers, environmental consultants, energy consultants and technology manufacturers dealing in energy consumption monitoring services are developing software products and proposing process reforms that can help users monitor and control their energy usage [7]. However, these service providers deliver only basic consumption data without any detailed analysis that traces the patterns of usage based upon various influencing factors, such as the impact of the weather or the scale of operations. Currently, there is still a gap in obtaining approximate solution that addresses the entire aspect of energy management [7].

3. Building Informatics

In current situation, smart or intelligent buildings are highly adaptable to changing environmental conditions. They have automated systems, including wireless sensor monitoring, to facilitate energy efficient, comfortable and cost-effective environments by optimizing structure, systems, services, building management and their interrelationships [15]. In the context of Internet of Things (IoT), Intelligent Building Energy Management Systems (BEMS) can be considered part of a much larger information system. This system is used by facilities managers in buildings to manage energy use and energy procurement and to maintain buildings systems. It is based on the infrastructure of the existing Intranets and the Internet, and therefore utilizes the same standards as other IT devices. Within this context reductions in the cost and reliability of wireless sensor networks are transforming building automation, by making the maintenance of energy efficient healthy productive work spaces in buildings increasingly cost effective [16]. Figure 1 shows an overview of how building informatics can be applied for sustainable building applications. From the figure, in general there are three main parts: data and information collection, data analytics and sustainable application. We shall elaborate in detail the related aspects of building informatics in the following sections.

3.1. Data and Information Collection

Gathering information on building environment and building systems is the essential first step for overall operational assessment. In the practical sense, sensor technology is a widely adopted in terms of building environmental parameters sensing. Typically, sensors are used for measuring parameters such as temperature, relative humidity, air quality, movement and luminance [17]. There are also multiple state change sensors (e.g., presence or activity sensor) that are used for occupancy detection [18]. From the perspective of building energy, automated meter reading technology [19] is widely implemented at some developed countries for building monitoring, where hourly reading can be automatically logged.

In relation to this, smart meters is a more advanced sensing device that is connected to the Internet. Besides monitoring energy usage, it can also be used to monitor unusual usage patterns, temperature and pressure values [20]. Such a meter can be either connected through normal wired or wireless Internet connection. In the context of building operations, Wu and Clements-Croome [21] stated that the signal of the WSNs provides a dynamic scenario of the state of indoor environment, enabling real-time diagnostics of system and component anomalies as well as off-line analysis. They indicated that the benefits of utilizing such a network is two-
fold: energy consumption can be managed by using sensors to monitor occupant behavior, and occupants’ well-being can be measured by various environmental comfort indexes.

With the advent of the IoT and connected devices paradigm, the introduction of relatively low-cost, wireless electronic communication devices not only serve as an affordable mean to gather building information, it is also useful for gathering occupant related details, such as user activity. The analysis of user activity is essential to create thermal comfort conditions that suite different thermal requirements that relates to their level of activity. In terms of user activities, it can be logged and recognized in two ways: either actively or passively. Active monitoring involves the use of personal devices such as mobile phones, wearable devices (e.g., smart watch), smart thermostat and voice assistant (e.g., Amazon Echo/Google Home), with user’s consent. Wearable sensors enable high accuracy activity recognition. User activities can be accurately tracked via analyzing accelerometer sensor data [22, 23] that is present in some of these devices. In relation to this, latest software technology such as Google’s Platform Activity Recognition API have enabled precise recognition of user activities such as walking, jogging, cycling or driving using mobile phones or wearable devices (e.g. smart watch). Besides, voice recognition feature of these devices also enable users to provide active feedback to the environmental control system. For instance, user can either indicate their preference on the thermal environment (e.g., temperature and lighting conditions are automatically adjusted when user indicate “relax mode”) or issue direct request via natural language (e.g., ”I feel warm”). On the other hand, passive monitoring involves non-intrusive infra-red (PIR) sensor where it is triggered by user’s motion. The advantage of using infrared sensors over other types of sensing techniques is the privacy preserving property, where occupants’ identity cannot be identified, albeit at the cost of sensing precision. On the other hand, video recording can also be used to monitor user activities as a less-privacy preserving option.

3.2. Application in Sustainable Energy Management
As conventional building loads such as HVAC and artificial lighting are related to the way how a building is utilized by occupants, occupants detection and activity profiling are important building information. Such an informatics can be used to optimize the environmental control system, so that office conditions are adjusted in line with the individual preference [10]. Basically,
the first step is occupancy detection, which aimed at determining the number of occupants in a building. Langensiepen et al. [10] proposed a way for worker presence detection using a number of installed sensory devices. Dong et al. [24] used Hidden Markov Models (HMMs) to perform occupancy detection in an intelligent office environment setup, and achieved 73% of detection accuracy. Besides motion detection, their occupancy detection approach also includes acoustic and CO₂ detection for improved accuracy in an open office plan setting. Lim et al. [25] proposed a simple classification approach to predict occupancy patterns based on data collected from wireless sensor network. These are important for human-centered environmental control and energy usage in buildings.

Nevertheless, detecting the number of occupants only serve as one perspective of occupancy analysis. Occupant activity monitoring and recognition is one of the actively researched dimension of building research. Its primary aim is to build user profile based on recognized occupants’ activities to control indoor environmental parameters. A study by Akhlaghinia et al. [26] have found that occupants tend to have a more systematic behavior pattern that can be predicted using prior behavioral monitoring. Thus, it can be used as a know-how to better manage building energy resources and also ensure occupants safety. For instance, Luhr et al. [18] proposed a novel data mining approach named EFP-Tree to detect emergent behaviors of building occupants. Their mining algorithm is able to detect the presence of new, possibly anomalous behavior via comparison with mined rules from sensor event log. Such a characteristic is proven useful for helping elderly building occupants. From the literature of computer vision and sensor analytics, human activities can be detected recognized by using a number of ways, such as: (1) sensor-based techniques (i.e., infrared sensing [27] or mobile wearable sensors [28, 22, 23]); or (2) vision-based techniques (i.e., using video camera recording) [29]. In relation to this, a number of computational techniques that can be effective for activity recognition such as Hidden Markov Models (HMMs) [30], neuro-fuzzy inference [31] and Bayesian classifiers [22].

Next, building informatics is applied for discovering building related knowledge (e.g., know-how) for an overall efficient building operation. For instance, Xiao and Fan [32] proposed an applicable framework for mining building automation system (BAS) database. Their approach consists of five major steps, including data preparation, clustering analysis, association rule mining, post-mining and application of discovered knowledge in two application context, which is proven useful in ensuring energy efficiency of building operation. Doukas et al. [17] proposed a rule-based expert system in BEMS that incorporates historical records and expert rules for efficient building energy control. The system is able to evaluate current building loads with desirable ones (from historical data), perform decision making, and link such a decision with building actuators for optimized building control. Another perspective of research involves the prediction of building operational performance through informatics. Such a prediction is important for building energy planning. For example, Li et al. [1] focused on hourly cooling load in a building. They have applied artificial neural network (ANN) and support vector machine (SVM) to predict hourly cooling load in a building with high accuracy. Chou et al. [20] predicted the coefficient of performance of a refrigeration system using data mining techniques. Based on the data collected via smart meters, various data mining techniques including artificial neural network (ANN), SVM and classification and regression tree (CART) are used to effectively predict performance.

With the application of computational techniques, building informatics also serve as an important source of knowledge to assist designers in proposing energy efficient building design. Ahmed et al. [33] proposed the use of data mining algorithms on real-time sensed weather data, coupled with internal daylight analytical tools, for proposing best design of building lighting. For this purpose, they have applied support vector machine (SVM) to estimate indoor daylight levels and decision tree algorithm for evaluation of multiple building design with different daylight
methods and procedures, to assist building designers with a reliable and simple approach in lighting assessment and decision making. On another related research work, They have also proposed a data mining model that incorporates thermal comfort standards and indoor daylight procedures, to observe correlation between weather conditions, building characteristics and low-energy comfortable rooms [34]. They have conducted their study at a low-energy building with many sustainable energy features such as solar panels, geothermal heat pumps and heat recovery system, monitored by a building management system that is complete with wireless and wired sensors in every room. Their research indicates that Naive-Bayes classifier outperformed SVM and decision tree in thermal comfort prediction, and such a result is used to optimize energy savings.

4. Discussion

From our discussion on previous sections, we reckoned that building informatics is a significant research area for ensuring an energy-efficient and sustainable building operation. Nevertheless, we do observe a few research issues that are worth for further investigation, and these may serve as future research directions. We discuss each issues as follows:

(i) **Energy-Efficient Monitoring:** We notice that building related research often neglect the energy consumption aspects of monitoring devices, or regard these as insignificant with respect to the energy consumption of building operational equipments. With the increasing number of sensing or monitoring devices installed in buildings, the sensing activity itself can be a significant energy consuming factor. Aiming at minimizing the overall energy consumption of such an activity, WSN is deemed a promising solution. However, how to best configure WSN for prolonged operation is not a trivial task. To the best of our knowledge, there are only a few related research. For instance, Liu et al. [35] proposed a cluster-based architecture design to minimize the energy dissipation for gathering sensor node data in a wireless mobile sensor network. They have proposed algorithms for cluster-head election and cluster formation, aimed for low power consumption wireless sensor network design. Ploennigs et al. [36] proposed a simple and scalable model-based virtual sensor for building heat consumption analysis using simple temperature sensors. Virtual sensors are used to estimate a projected sensor value from other measurement. They have suggested a relational model which resulted in reasonable estimations for heat consumption estimation.

(ii) **Data Design and Cleaning:** This is a typical issue in informatics field. Typically in the field of building informatics, there are heterogeneous building systems involved (e.g., different BAS and BEMS installed) from different solution providers that might be using different communication protocol and standards. Consequently, different application programming interfaces (APIs) are required to obtain building data, inconsistency in data structure definition and description (e.g., "RH" vs "Humidity") may present, causing difficulties in data integration efforts for comprehensive, overall building analysis. Besides, sensory data are normally very noisy and at times incomplete. Among the techniques used to ensure data validity and consistency is clustering algorithm (e.g., k-means) for outlier detection [21]. We do suggest that additional research involving the techniques for building related data cleaning are essential to ensure high quality input for data mining activity at later stage.

(iii) **Knowledge Discovery and Modeling:** From the literature, there are multiple techniques (e.g., in data mining) used for knowledge discovery and modeling schemes proposed for knowledge reuse, with the aim of decision making. Some of these studies [32, 17] have indicated that we are able to discover significant knowledge patterns from building related data. While these are useful in the perspective of existing building, previously collected operational data may not be always useful for designing future buildings due to design
changes. This is known as the "cold start problem", where the required dataset is not always present. In relation to this, there are researcher that proposed a building simulation approach in training machine learning model for building energy management [19]. Their studies showed that the model trained with such an approach has comparable internal consistency with model trained using actual field data in the energy consumption prediction task. On the other hand, another issue worth noting is how can we incorporate existing human know-how into the decision making mechanisms or systems. Human inputs can be important where actual building operational constraints can be better included. We believe that a synergy between human and machine-assisted knowledge can be very useful in completing the knowledge discovery and modeling process.

(iv) Conflict Resolution: With the increasing number of building occupants, ensuring overall thermal comfort of occupants is a challenging issue. From previous studies, it is well-understood that dissatisfaction with indoor thermal conditions is the most common source of occupant complaints in office buildings [37]. There are also numerous studies that have indicated how a poor indoor thermal condition can impact health, productivity and occupants’ behavior [38]. With regards to building energy consumption, achieving a balance between occupant’s comfort and building energy efficiency is challenging. This is mainly due to heterogeneous thermal preference of building occupants, and resolving conflicts between occupants’ needs is one of the key towards achieving such a balance. Research area related to such an adaptive building control is emerging. For instance, Camacho et al. [39] proposed an ontology-based approach towards realizing an adaptive home and building automation system (HBAS). Their proposed solution is able resolve conflict among building occupants’ in terms of multiple needs of environmental needs, by using pre-defined ontology of user environmental preference as knowledge support. Their case study showed that using such a system energy efficiency can be maximized while ensuring the comfort of occupants.

5. Conclusion
In this paper, we have conducted a preliminary review on building informatics for sustainable energy management. We have discussed the status-quo, issues and challenges of existing building energy management practice, and how building informatics are being applied in modern practice. In the perspective of building informatics, we have discussed the aspects of building information collection and processing, and also how information processing and knowledge management are being applied for enabling sustainable building energy management. Based on these review, we have summarized and discussed four essential research issues for future research. We do believe that these are important areas that require further research focus to realize sustainability in building energy management.

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