Academic Journal of Science,
CD-ROM. ISSN: 2165-6282 :: 07(03):563–568 (2017)

A CONCEPTUAL FRAMEWORK FOR A REAL-TIME-BASED MONITORING AND DIAGNOSTICS FOR BUILDING PERFORMANCE AND OCCUPANT BEHAVIOR

Choongwan Koo and Seung Hyun Cha

The Hong Kong Polytechnic University, Hong Kong

The energy and environmental systems in buildings and the relevant occupant behaviors should be integrated with a transformative and innovative technologies for sustainable built environment. Research in this area is more needed to understand the past, present, and future for building energy and environmental performance from an occupant's point of view. This study aims to propose a conceptual framework for a real-time-based monitoring and diagnostics for building performance (i.e., energy efficiency and indoor environmental quality) and occupant behavior. The framework consists of three phases: (i) monitoring, real-time sensor network for energy efficiency and indoor environmental quality, and occupant behavior in buildings; (ii) diagnostics, space-time-scalable diagnostics for energy efficiency and indoor environmental quality in buildings from an occupant's point of view; and (iii) intervention, occupant-oriented intervention for energy efficiency and indoor environmental quality in buildings. The proposed framework will be implemented at different levels of physical entities in the complex built environments and be a starting point to achieving energy and environmental conservation, and public health. This study can contribute to adding economic, environmental, and ergonomic values to buildings in smart city by providing occupant-oriented, energy-efficient, eco-friendly, and comfortable environments in real time.

Keywords: Real time sensor network, Monitoring and diagnostics, Energy efficiency, Indoor environmental quality, Occupant behavior.

Introduction

The united nations framework convention on climate change was held in Paris in 2015 and adopted the POST-2020 climate agreement [1-3]. The Chinese government has set the goal with 60-65% carbon emissions reduction target from 2005 by 2030 in accordance with POST-2020 climate agreement. Particularly, since 89% of the electricity is consumed from the building sector in Hong Kong, the Hong Kong Green Building Council has launched the "HK3030" campaign, a vision for a low carbon sustainable built environment in Hong Kong by 2030. The "HK3030" campaign aims to reduce the absolute electricity consumption of buildings in Hong Kong by 30 percent of the 2005 level by 2030 [4-5]. Furthermore, China has suffered from its worst air pollution and released warnings to citizens about pollution reaching dangerous levels. It can directly affect the indoor environmental quality in buildings and the relevant occupants' health, comfort, and productivity.

In this context, it is necessary to develop a transformative and innovative strategy for enhancing the energy efficiency and indoor environmental quality in buildings. In particular, a real time sensor network should be established to monitor and diagnose such a building performance, which can be directly connected to occupant behavior. It can be developed with a "dynamic approach" concept under the new paradigm of an "urban organism" [6]. Various previous studies considered a real-time sensor network in buildings for the purpose of energy efficiency [7-10], indoor environmental quality [11-14], and occupant behavior [15-18]. However, there is a lack of fundamental understanding of the patterns of building energy and environmental performance in real time and its interactive effect on occupant behavior. In addition, the previous studies have not considered the interaction among the different levels of built environment. To overcome this challenge, this study aims to propose a conceptual framework for a real-time-based monitoring and diagnostics for building performance (i.e., energy efficiency and indoor environmental quality) and occupant behavior.

Conceptual Framework for the Proposed Real-Time-based Monitoring and Diagnostics for Building Performance and Occupant Behavior

The proposed conceptual framework is designed as a platform for a real-time-based monitoring and diagnostics to enable the interaction between occupant and built environment as well as to guide occupant behavior change. The proposed framework can be implemented at different levels of physical entities (e.g., room-level, building-level, and city-level) so as to enable the urban-based-scalable building energy and environmental management.

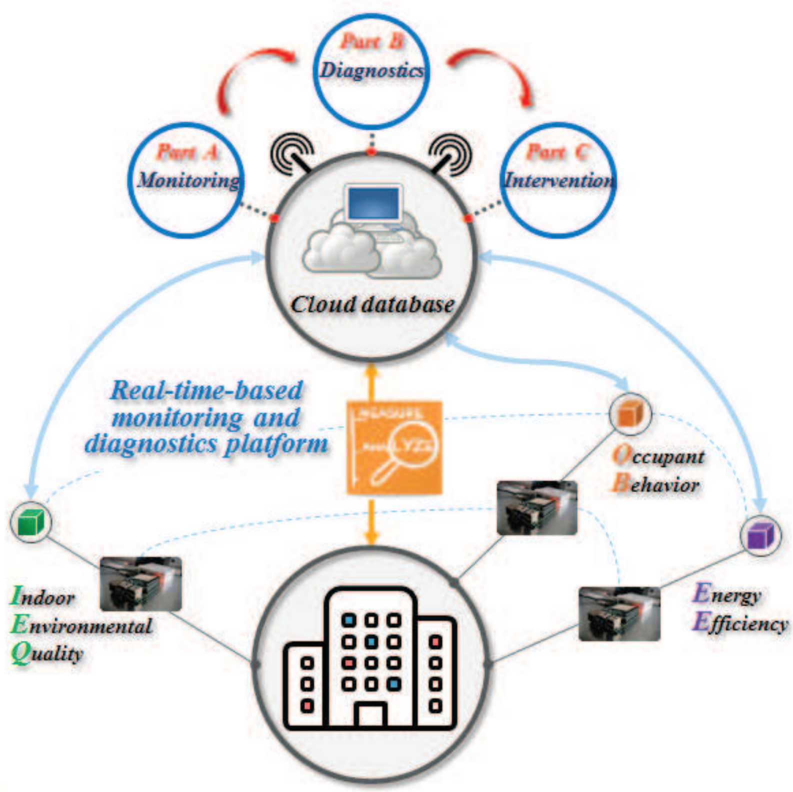

Figure 1. A conceptual framework for a real-time-based monitoring and diagnostics platform

As shown in Figure 1, the proposed framework can be developed in the three-phase cyclic process: (i) monitoring, real-time sensor network for energy efficiency and indoor environmental quality, and occupant behavior in buildings using the internet of things technology; (ii) diagnostics, space-time-scalable diagnostics for energy efficiency and indoor environmental quality in buildings from an occupant's point of view using predictive analytics; and (iii) intervention, occupant-oriented intervention for energy efficiency and indoor environmental quality in buildings using prescriptive analytics.

The first part A, *monitoring*, can be established with the emerging technologies of real-time sensor network (e.g., nonintrusive load monitoring, seamless connectivity, and Wi-Fi connection monitoring). The collected data can be used to analyze the energy usage patterns of electronic appliances and the various indoor environmental indices such as thermal comfort (e.g., temperature and humidity) and indoor air quality (e.g., CO_2 concentration, fine dust, and chemicals) as well as the relevant occupant behavior in a room of building at different hours of the day. Also, the specific building can be arranged as a test-bed project to implement the proposed framework and validate it. The room-based information can be integrated at higher levels of built environments such as building-, city-, and national-levels.

The second part B, *diagnostics*, can be developed to provide occupants with dynamic energy and environment diagnosis at different levels of the complex built environment. In particular, the research on energy policy can be conducted using predictive analytics such as machine learning and optimization techniques [19-20]. With the "dynamic approach" concept, the benchmark could be established by using the probability density function of the energy use intensity (e.g., energy per square meters per year). With the benchmark, the dynamic operational rating and the relevant letter rating can be determined. Furthermore, the space-time-scalable diagnostics can be developed using the real-time energy and environmental data. It can be used to diagnose the building performance and occupant behavior at room level on a daily or monthly basis. Such a space-time-scalable diagnostics tool can make it easier to recognize the current status and to encourage occupants to change their behavior.

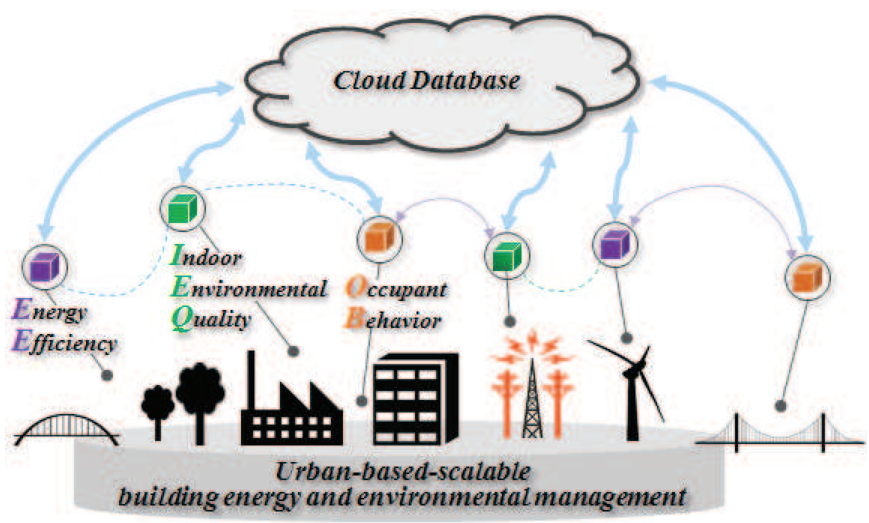

Figure 2. An urban-based scalable building energy and environmental management

The third part C, *intervention*, can be developed to provide occupants with real-time alerts for the building performance, which includes various information such as the real-time data on energy efficiency and indoor environmental quality, the peak load of electronic appliances, the outdoor and indoor temperature, and the benchmark. The collected data can be used to analyze the dynamic relationship with occupant behavior, which can motivate occupants to change their behavior. Agent-based modeling can be implemented to mimic the real-world occupant behavior and the relevant energy usage patterns and indoor environmental quality by defining an autonomous agent that interact with both the surrounding environments and other agents [21-22]. It can be achieved by allowing agents to learn and change behavior in response to experience related to the energy efficiency and indoor environmental quality.

As shown in Figure 2, the proposed framework can be extended to an urban-based-scalable building energy and environmental management in real time, which can be realized with a cloud database. Towards this end, it is required to implement the innovative and emerging technologies, including real-time sensor network, machine learning techniques, simulation technique, and visualization technique [23]. The developed platform will be implemented and validated with a test-bed project, and then it will be distributed to the public from a larger-scale such as building-level, district-level, city-level, and national-level. Ultimately, it will be more improved, more sophisticated, and more fit to the specific environment.

Conclusions

This study aims to propose a conceptual framework for a real-time-based monitoring and diagnostics for building performance (i.e., energy efficiency and indoor environmental quality) and occupant behavior. The proposed framework can be developed in the three-phase cyclic process (i.e., monitoring, diagnostics, and intervention).

The proposed framework can be realized based on a cloud database as an open knowledge platform so that it can provide practitioners and engineering/scientific/R&D personnel with the real-time big data at different levels of physical entities. Based on this characteristic, it is expected to develop various applications such as the automatic detection of deteriorating equipment and electronic appliances, the composition and trends of energy consumption, energy cost analysis, real-time optimization for distributed energy generation, occupant-oriented optimization for energy and environment, cognitive analytics for occupant satisfactory environments, enhanced security service, and proactive health care service.

Furthermore, the proposed framework is expected to contribute to adding economic, environmental, and ergonomic values to buildings in smart city by providing occupant-oriented, energy-efficient, eco-friendly, and comfortable environments in real time. Ultimately, it can contribute to the development of a global leadership in the field of an urban-based building energy and environmental management in real time as well as its interaction with occupant behavior.

Acknowledgements

The work described in this paper was fully supported by the Department of Building Services Engineering, The Hong Kong Polytechnic University.

References

1. World Energy Council (WEC). 2013 Survey of world energy resources. London; 2013.
2. European Environment Agency (EEA). Greenhouse gas emission trends and projections in Europe 2011: Tracking progress towards Kyoto and 2020 Targets. Copenhagen; 2011.
3. Barlow D. Paris 2015: UN climate negotiations. Scottish Parliament Information Centre: Edinburgh; 2015.
4. The Climate Group. A low carbon vision for Hong Kong: Hong Kong; 2010.
5. Hong Kong Green Building Council. Market drivers for transformation of green buildings in Hong Kong: A roadmap to deep energy reductions: Hong Kong; 2014.

6. Koo C. A Carbon integrated management system for monitoring, diagnosing, and retrofitting the dynamic energy performance of existing buildings in a city, an urban organism; Doctoral Thesis, Yonsei University: Seoul, 2014.
7. Doukas H, Patlitzianas KD, Iatropoulos K. Psarras J. Intelligent building energy management system using rule sets. Build. Environ. 2007;42(10):3562–3569.
8. Milenkovic M, Amft O. Recognizing energy-related activities using sensors commonly installed in office buildings. Procedia Comput. Sci. 2013;19:669–677.
9. Missaouia R, Joumaaa H, Ploixa S, Bacha S. Managing energy smart homes according to energy prices: analysis of a building energy management system. Energy Build. 2014;71:155–167.
10. Martani C, Lee D, Robinson P, Britter R, Ratti C. ENERNET: studying thedynamic relationship between building occupancy and energyconsumption. Energy Build. 2012;47: 584–591.
11. Snyder EG, Watkins T, Solomon P, Thoma E, Williams R, Hagler G, Shelow D, Hindin D, Kilaru V, Preuss P. The changing paradigm of air pollution monitoring. Environ. Sci. Technol. 2013;47(20):11369–11377.
12. Kolokotsa D, Pouliezos A, Stavrakakis G, Lazos C. Predictive control techniques for energy and indoor environmental quality management in buildings. Build. Environ. 2009;44:1850–1863.
13. Kim JW, Jeong YK, Lee IW. Automatic sensor arrangement system for building energy and environmental management. Energy Procedia 2012;14:265–270.
14. White RM, Paprotny I, Doering F, Cascio W, Solomon P, Gundel LA. Sensors and 'Apps' for community-based atmospheric monitoring. AirWaste Manage. Assoc. 2012;5:36–40.
15. Das T, Mohan P, Padmanabhan VN, Ramjee R, Sharma A. Prism: platform for remote sensing using smartphones. Procedings of the ACM MOBISYS 2010.
16. Zhang X, Yan J. Feng S, Lei Z, Yi D, Li S. Water filling: unsupervised people counting via vertical kinect sensor, in: IEEE Ninth International Conferenceon Advanced Video and Signal-Based Surveillance (AVSS), 2012, Beijing, 2012, pp. 215–220.
17. Shih HC. A robust occupancy detection and tracking algorithm for the automatic monitoring and commissioning of a building. Energy Build. 2014;77:270–280.
18. Duarte C. Van Den Wymelenberg K, Rieger C. Revealing occupancy patterns in an office building through the use of occupancy sensor data. Energy Build. 2013;67:587–595.
19. Koo C, Hong T. A dynamic energy performance curve for evaluating the historical trends in the energy performance of existing buildings using a simplified case-based reasoning approach. Energy and Buildings 2015;92:338–350.
20. Koo C, Hong T, Park HS, Yun G. Framework for the analysis of the potential of the rooftop photovoltaic system to achieve the net-zero energy solar buildings. Progress in Photovoltaics: Research and Applications 2014;22(4):462–478.
21. Dibley MJ, Li H, Miles JC, Rezgui Y. Towards intelligent agent based software for building related decision support. Advanced Engineering Informatics 2011;25:311–329.
22. Langevin J, Wen J, Gurian PL. Simulating the human-building interaction: Development and validation of an agent-based model of office occupant behaviours. Building and Environment 2015;88:27–45.
23. Hastak M, Koo C. Theory of the intelligent planning unit for the complex built environment. Journal of Management in Engineering 2016;10.1061/(ASCE)ME.1943-5479.0000486.