Energy and Buildings 84 (2014) 252–257

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Monitoring thermal comfort in subways using building information modeling

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ARTICLE INFO

Article history:
Received 7 July 2014
Accepted 5 August 2014
Available online 13 August 2014

Keywords:
Wireless sensor networks
Building information modeling
Indoor environmental quality
Subways
Facility management

ABSTRACT

Metro transit systems have gained a lot of importance because of the large number of passengers depending on that vital mode of transportation. Most of metro transit systems contain subways which need to be efficiently ventilated in order to maintain health and comfort of passengers. Therefore, it is necessary to monitor the thermal comfort inside subways. Subways are large facilities that require an efficient and huge ventilation system. Monitoring thermal condition for the subway is an important issue because of the variations that may occur in different spaces within the subway. These variations may affect energy consumption and the level of thermal comfort for the passengers as well. This research presents an application that utilizes wireless sensor network (WSN) and building information modeling (BIM) in order to monitor thermal conditions within a subway. BIM-based model is used to visualize the readings of air temperature and humidity levels in the subway spaces. Whereas, WSN is used to measure air temperature and humidity at different spaces within the subway via a group of transmitter nodes attached with different sensors. A case study is presented in order to illustrate the capabilities of the system developed. Finally, conclusion and future recommendations to expand this research is presented.

1. Introduction

Recently, world's transportation systems are booming because of a lot of reasons such as population's increase, need to reach new areas, and the need to increase the efficiency of transportation system. One of the most important modes of transportation is rapid transit systems. Across the world, many countries possess giant network of rapid transit system which contains underground stations (subways) and above ground stations. For example, London underground network has 11 lines with 270 stations [1]. Another example, Egypt has three lines of its metro system in Cairo consisting of 57 stations and 17 of them are underground [2]. As for underground stations, air temperature in underground stations is higher than air temperature in the outdoor environment and as a result subways require an efficient ventilation system or HVAC system. The large number of commuters that gave rapid transit system significant importance requires different subway authorities to maintain the commuters' satisfaction and well-being. One of the most important aspects that the authority shall maintain, assess and predict is the thermal comfort of passengers. It is important to ensure that different thermal comfort conditions are within acceptable limits.

A lot of subways were built long time ago, for example, London underground began operation in 1863. Other countries started their rapid transit system more recently. The age of different subways and maintenance strategies are the main factors, affecting the performance of different systems in a subway [3]. Ventilation or HVAC systems are one of the systems that are affected by the age and maintenance strategies and practices. If ventilation/HVAC system is not maintained properly, the energy consumption increases, the thermal comfort of passengers decreases and the rate of satisfaction between passengers decreases. As number of passengers increase within a subway, the temperature of air increases and as a result the degree of thermal comfort decreases among passengers.

Surveys and mathematical models are the two main methods that are used in order to assess the degree of thermal comfort among occupants of a building and the expected comfort temperature. Lee et al. [4] have examined the relationship between the learning performance of students and indoor environmental quality (IEQ). The study took place in Hong Kong Polytechnic University teaching rooms which were air conditioned. They examined the IEQ of the university in terms of thermal comfort, indoor air quality and

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http://dx.doi.org/10.1016/j.enbuild.2014.08.006
0378-7788/

visual and aural levels. Measurement devices were used in order to collect data from certain lecture halls every 30 min. The authors distributed a survey among students in order to measure the level of satisfaction between students. EPIQR (energy performance, indoor air quality and retrofit) is an European project that is used to assess and determine the energy performance of buildings, indoor air quality and possible replacement/maintenance actions. The developed tool allows the user to answer a questionnaire related to IEQ in his/her facility associated with the facility information (e.g., address and age of persons living in the apartment). It acts as a diagnosis and analysis tool for the complaints and it takes corrective actions [5]. The development of this tool was a great attempt to associate information about facility with questionnaires and complaints; however, this attempt does not include any digital representation or geometric modeling for the facilities. TOBUS (a decision making tool for office building and upgrading solutions) is another tool that contains nine modules to model building dimensions and geometry and other useful information about the facility. One of the modules is concerned with the assessment of the indoor air quality in which it collects data from questionnaire answered by occupants of the building. After that data can be analyzed and TOBUS can indicate complaints and major problems. TOBUS can provide statistics about different complaints and problems [6,7]. Kim et al. [8] have monitored and predicted indoor air quality (IAQ) of subways. Air pollutants, air temperature and humidity were measured at a subway in Korea. The authors have monitored and assessed the effect of different seasons on the IAQ in metro systems using seasonal models. A multivariate analysis of variance test (MANOVA) is developed in order to know if different seasons influence the IAQ of subways. A measurement device is installed at the platform level of the subway and continuously measures different parameters.

Energy consumption depends mainly on the efficiency of the energy-related systems such as HVAC and refrigeration systems, lighting and daylighting controls, domestic hot water systems, and renewable energy systems. According to Lu et al. [9] HVAC system in a subway station can consume more than 40% of the total power. So, a major way to save energy for the HVAC systems is to design optimal control strategies to minimize the overall energy consumption while still maintaining the satisfied indoor thermal comfort and healthy environment [10]. Freire et al. [11] has examined the indoor thermal comfort control problem in buildings equipped with HVAC (heating, ventilation and air conditioning) systems. He proposed different strategies to reduce energy consumption and maintaining acceptable indoor air conditions related to thermal comfort. One of these strategies tries to find the optimal value for the HVAC consumption while maintaining acceptable thermal comfort conditions to reduce energy consumption.

Building information modeling (BIM) is considered as a way in order to represent the physical characteristics of different elements in digital form [12,13]. BIM has several advantages; therefore, many research studies have been directed to the possible applications of BIM. Azhar et al. [14] have developed a framework that aims at utilizing one of the valuable advantages of BIM, multi-disciplinary information, with LEED accreditation process. The authors stated that the accreditation process using BIM will be more efficient and precise than other traditional methods. The framework depends on exporting the BIM-based model using Revit software to Integrated Environmental Solutions (IES) software in order to perform different analysis on the facility and create LEED documentation. Lee et al. [15] have integrated the BIM-based model of the project and a group of sensors in order to create a navigation system that helps in solving blind lifts problems. The developed system is capable to determine the location of the lifted object with respect to the project and other existing buildings. The authors have used laser and encoder sensors and video camera in order to visualize the lifted object and determine information about its location. The location of the object is then integrated with the BIM-based model and updated in real time manner. Zhang et al. [16] have developed a tool that checks safety in construction models using BIM-based models taking advantage of the information existing in the BIM-based model such as quantities and schedules. The authors have used the safety measures and guidelines such as the measures and guidelines given by OSHA as a rule check that can used with Revit or other BIM software. The safety checking system developed by the authors is updated at the same time the BIM model is updated throughout different construction phases in order to identify different hazards. Schlueter and Thesseling [17] have used BIM in order to calculate the energy performance of buildings using information from different disciplines. Calculations are done by a tool developed by C# programming language and integrated with a BIM software. The authors use BIM capabilities of storing different information and parameters in order to do energy and energy performance calculations at early design stages. BIM has allowed the authors a rapid assessment of energy performance at early design stages.

BIM-based models contain a lot of useful information about different project elements. A specific chiller in a subway can be associated with information like dimensions, materials, year of manufacturing, URL link for the manufacturer and much other information. This integration between geometric properties of different elements and their other non-geometric properties offers the opportunity of fast information retrieval. A lot of meaningful information can be extracted from the BIM-based model, as elements is not only represented by its geometric parameters as CAD drawings do but also associated with useful information such as the place of the element and its material [18]. BIM-based models offer a better visualization for facilities, improved coordination between different specialties and integration of other facility management applications. Most of BIM software packages offer the user the ability to add customized parameters or functions in order to add more information and expand the BIM-based model capabilities. Indoor environmental quality (IEQ) monitoring can be used as an application of BIM-based model. Readings of air temperature, humidity, air velocity, noise level, illumination level and gas levels can be associated with the BIM-based model. The BIM based model allows integrating the previous readings in spatial manner. For example, readings can be associated with every lecture hall in a university which gives a better visualization and understanding for different problems. Marzouk and Abdelaty [3] have proposed a framework for the integration between wireless sensor network (WSN) and BIM-based model in order to assist asset managers in facilities inspection. WSN is very useful and effective way in order to collect data within a facility in addition it is easy to install within an existing facility. Most, if not all, of subways have a building management system (BMS) which is a customized system designed specifically for a certain building/facility in order to manage certain tasks within the facility. BMS can be used in order to control the temperature of the facility and control many other systems within the facility. However, these tasks done by the BMS can easily be done with a customized BIM-based model. BIM-based model complements the use of BMS with more comprehensive features. This research aims at integrating WSN with BIM-based model in order to partially monitor and assess IEQ. The developed system is capable to measure temperature and humidity in a subway by the installation of WSN and linking information with BIM-based model in a spatial manner. The system also proposes linking simple mathematical model with the BIM software in order to predict the level of thermal comfort among passengers. The research provides a novel approach toward the expansion of BIM applications in facility management.