Assessing Indoor Environmental Quality of Educational Buildings Using BIM

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Abstract: Indoor Environmental Quality (IEQ) deals with providing a healthy and comfortable indoor environment. Most of international sustainability rating systems consider IEQ as a key perspective for developing sustainable buildings. Educational buildings include large number of people which increase the need to provide appropriate IEQ. Accordingly, there is a critical need to frequently assess of IEQ in this type of buildings in order to maintain the satisfactory level of IEQ. This paper aims to develop a framework for assessing and improving the IEQ of educational buildings in Saudi Arabia through measuring the IEQ parameters and integrating these results with Building Information Modeling (BIM). The key IEQ parameters considered in this study include thermal comfort, indoor air quality and visual comfort. These parameters have been measured by comfort-sense system, indoor air quality meter and light meter respectively. The measured data are integrated with BIM model in order to track the IEQ problems, and to develop IEQ history over time. By using the proposed framework, the IEQ can be tracked and improved. The IEQ assessment framework has been implemented on educational building in Saudi Arabia as a case study to validate the process and perform the necessary modifications and improvements.

Key words: IEQ, environment, BIM, thermal comfort, visual comfort, building.

1. Introduction

Indoor Environmental Quality (IEQ) is one of the major issues that should be considered in developing sustainable buildings. IEQ of buildings is a result of the interaction between several factors such as the external climate, the buildings' elements, the region and the user behavior. Most of sustainability rating systems such as LEED, NABERS, Green Star and Green Globes cannot ignore IEQ during assessing the sustainability of buildings. In buildings, the IEQ depends mainly on three main parameters includes thermal comfort, visual comfort and air quality [1]. Each of these parameters depends also on some related measureable factors. For example, the thermal comfort parameter depends on three main factors including temperature, humidity and air velocity, while the indoor air quality parameter depends on many factors including carbon monoxide (CO) and

carbon dioxide (CO₂). In addition, visual comfort depends mainly on light intensity inside the building. Measuring these factors and parameters helps in evaluating the IEQ in buildings.

The importance of maintaining acceptable quality of indoor environment in buildings is to provide healthy and comfortable environment inside the building. This importance increases in public building such as educational buildings. According to U.S General Accounting Office [2], unlike other buildings, educational buildings are seen as particularly likely to have environmental deficiencies because of shortages in funding which can contribute to inadequate operation and proper maintenance. The quality of indoor environment in educational buildings is a public concern because it is usually include large number of people in limited area and also the people spend a lot of time inside these buildings. A poor quality of indoor environment will lead to an unhealthy environment in buildings [3]. In addition, the quality of indoor environment contributes in the

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learning performance of pupils [4, 5]. Lee et al. [6] confirmed this relationship between IEQ and learning performance through studying this relationship in university teaching rooms through subjective assessments and objective measurements and concluded that there was a good correlation between learning performance and IEQ. Poor and compromised IEQ is thought to have bad influence on learning and academic activities [7]. Mendell and Heath [8] also stated that an adverse environmental condition can impaired the learning process and performance of the students and this can have both immediate and lifelong effects for the students and the society at large. Also, Polidori et al. [9] postulated that students are prone to health hazards related to poor IEQ. Thereby, the quality of indoor environment should be maintained in this type of buildings in order to facilitate learning activities [10].

BIM technology is a latest and promising approach in the AEC (Architecture, Engineering and Construction) industry which is gradually gaining acceptance of clients, architects, engineers and designers as the innovative process of generating and managing building data during its lifecycle. This sophisticated technology is both a visually accurate model of a building and a database for recording the breadth of information developed and associated with building components. This technology offers a platform for enhanced interdisciplinary collaboration, the capability to manage changes, and the ability to extend information support throughout the building lifecycle [11]. In a BIM, elements are virtual simulations of building components. A column exists as a column, a wall exists as a wall and all objects have identity and attributes. As a data application, BIM can track the types and quantities of materials, equipment and spaces. Marzouk et al. [12] described BIM technology as a software that allows the physical and functional characteristics of a facility to be modeled digitally. This technology helps in integrating different facility within a 3D model. Jung

and Joo [13] have developed a framework that integrates some facilities into the model in their work. Among what was integrated were geometric data, non-geometric data and some others applications. This paper aims to develop a framework that uses BIM for assessing and improving the IEQ in educational buildings that suffering from extreme weather condition in Saudi Arabia. Maintaining adequate IEQ improves the learning performance through providing healthy and comfortable environment.

2. Background

The quality of indoor environment of a building affects the comfort, health and productivity of the occupants [14]. The need to ensure proper IEQ increases in educational buildings. Thermal comfort is one of the key parameters of IEQ. Schoer and Shaffran [15] conducted a research to assess the performance of students in classrooms with and without air-condition. They concluded that providing a suitable temperature in classrooms helps students to achieve better performance. For similar purpose, Witterseh et al. [16] set up a controlled laboratory to assess the occupant performance based on standardized tasks, symptoms and perceived performance using a questionnaire, in association with specific temperature ranging among 22-26-30 °C, with absolute humidity and other factors kept constant. They found that increased eye, nose, throat irritation and headache intensity happened at a higher temperature. Ventilation plays a major role in maintaining thermal comfort, thereby, inadequate ventilation will increase carbon dioxide concentration which also have adverse effects on respiratory system [6]. Fang et al. [17] used a controlled field lab setting, with 30 female subjects and exposed them to 280-min sessions at different combinations of ventilation rate. They concluded that fatigue, headache and difficulty in thinking were results of poor indoor ventilation, also, there is a decreased productivity of the subjects. Furthermore, ambient concentration of carbon dioxide predicted

daily absenteeism in schools, based on a multivariate analysis controlling for weather and other confounders using auto regression analysis [18]. They further specified that when carbon dioxide increases, absence rate increases about 3.79%. In addition, low visual comfort is a vital problem in poor IEQ [3]. Failure to provide a proper visual comfort causes negative impact of the students' academic performance [19].

BIM provides a very powerful tool that can be used for tracking the IEQ problems and achieving better IEQ assessment. Marzouk and Abdelaty [20] proposed the application of BIM into asset management. They have developed a semi-automated inspection system using a wireless sensor network and data were obtained for temperature, gas, humidity and others and were incorporated into BIM-based model. Their proposed model helps the asset manager to predict the location of any future problem of the facility. Marzouk and Abdelaty [21] also used the wireless sensor network to obtain different parameters indicating the level of thermal comfort in different subways and imported it into BIM model to detect the location of poor environment quality.

3. Materials and Method

Assessment and improving the IEQ of educational buildings facilitate the learning process and reducing the related hazards as a result of poor IEQ. The proposed framework in this study tracks the IEQ in the educational buildings through data obtained from different measurements. This data is incorporated into a BIM model framework in order to detect the immediate and future threats. Fig. 1 shows the main components for this framework. The following subsections describe the main framework components.

3.1 Thermal Comfort

The human body has a very effective system of regulating the temperature according to the surrounding environment [7].

Katafygiotou and Serghides [3] identified different

means by which occupants exchange heat with the environment via heat transfer or convection, by radiation from human body to the surrounding environment and vice versa. Steemers et al. [22] highlighted some factors that influence thermal comfort of occupants, which was categorized into environmental and personal factors. The environmental factors are the air temperature, the air relative humidity and the air velocity. The personal factors are metabolic rate and the insulation through clothing.

Thermal comfort is one of the most important parameters of the IEQ that has been defined by different standard such as ISO 7730 (1994) and ASHRAE 55 (2010), as the state of mind that expresses satisfaction with the thermal environment in which it is located [23, 24]. These standards give conditions for obtaining thermal comfort under thermal equilibrium between the human body and its environments [1]. Accordingly, thermal comfort has been considered as one of the main component of the proposed IEQ assessment framework in this study.

Comfort-sense system (Fig. 2a) has been used to measure the thermal comfort data required to the IEQ assessment framework. The Comfort-sense system is a tool for indoor climate studies which can be used for measuring the thermal comfort through multi-point measurement of thermal comfort factors. It is a multichannel system for measurement humidity, air temperature, air velocity and operative temperature. Accordingly, the system measuring the thermal comfort factors and identifying the thermal comfort level in accordance with EN 13182, ISO 7726, ISO 7730, ASHRAE 55 and ASHRAE 113 [25].

3.2 Air Quality

Indoor air quality is a subset of indoor environmental quality which is as carbon dioxides (CO_2) as its major indicator. Air quality can be regarded as "harmless" if CO_2 levels are below 1,000 ppm, "elevated" if between 1,000 and 2,000 ppm and "hygienically unacceptable" if its above 2,000 ppm [26]. Marzouk

Fig. 1 Components of IEQ assessment framework.

Fig. 2 Measurement equipment of IEQ parameters ((a) comfort-sense system, (b) indoor air quality meter and (c) light meter)

and Abdelaty [21] stated that particulate matters (PM 10 and PM 2.5) can also be used to measure the degree of indoor air quality. Park and Ha [26] observed the indoor air quality by monitoring the concentration of PM 10, PM 2.5, carbon dioxide and

carbon monoxide. Indoor air quality meter (Fig. 2b) has been used as a tool to measure the indoor air quality as a part of IEQ. This tool used to check indoor air quality in office buildings, laboratories, and anywhere that levels of carbon dioxide is a concern.

3.3 Visual Comfort

Visual comfort depends primarily on the lighting conditions of the indoor environment. When there is poor glare phenomenon, the ability to see objects will be reduced. The adequacy and the distribution of the lighting depend on the geometry of the windows and the space. Also, the proper management of lighting directly affects the energy consumption of the building. Light meter (Fig. 2c) has been used to measure the amount of light inside the building. This tool calculates the luminous intensity in lux or foot-candles units.

3.4 External Database

IEQ assessment framework depends on frequent measuring for IEQ parameters and its factors over time. The measured data is stored in external database that should be able to be integrated with BIM model. Microsoft Access has been used to in the proposed framework as an external database. This database tool has the ability to link with BIM model that developed via Revit software through Revit DB link.

Revit DB link maintains a relationship among a BIM-Revit model, Microsoft Access and Open Database Connectivity (ODBC) database. This tool helps in exporting BIM model data to the database, make changes to the data and import it back into the model.

The IEQ assessment framework exports the BIM data to the external database using Revit DB link. The database displays BIM model information in a tabular view that can be edited before import it again. Thermal, air and visual data have been inserted in the external database through creating new Revit parameters by adding new fields for those parameters in the related tables. Any changes made to these new fields within the database will update the developed new Revit parameters upon future imports. The dynamic data exchange between the external database and BIM model helps in achieving IEQ assessment over time.

3.5 IEQ Tracking

This part of IEQ framework starts with inserting the standard values for the IEQ parameters to the database. After that, the updated database with all new Revit parameters data should be imported to the BIM model. Accordingly, the framework then can determine the IEQ situation by comparing the measured IEQ parameters data with the standards values. Consequently, the BIM model identifies the type of IEQ problem, the position of poor IEQ, and also provides IEQ history over time for each position in the BIM model. Furthermore, the proposed framework can be used also for thermal simulation and energy analysis through linking the database with other BIM software such as Ecotect and green building studio. According to IEQ assessment results, some treatments can be done to address the IEQ problems and insuring sufficient IEQ.

4. Results and Discussion

The measurement procedure starts with identifying the probes locations and room dimensions. In educational buildings, the measurement locations should cover the places that include large number of people such as classrooms. In addition, the measurement process should be done in different situations for a building such as measuring at different times during a day and when classrooms are empty and full of students. The building of college of engineering in King Saud University has been selected to implement the proposed framework. The probes were located in several classrooms and labs in the building. A sample of IEQ measurements was shown in Figs. 3a and 3b. These results come also in a table format that can easily be transferred to the database. The IEQ parameters and their factors has been considered in BIM model as new parameters as shown in Fig. 4. The BIM model with new parameters has been integrated with the database that includes the measured data (Fig. 5). Accordingly, the framework is able to track the IEQ and achieve their purposes

Table 1 Sample of air velocity and temperature measurements.

Probe TAG	X (m)	Y (m)	Z (m)	Velocity (m/s)	Turbulence intensity (%)	Temperature (°C)
Vel. 1	3.10	0.68	0.45	0.08	62.62	21.22
Vel. 2	3.10	0.82	0.45	0.07	64.46	21.21
Vel. 3	3.10	1.07	0.45	0.07	60.46	21.22
Vel. 4	1.10	0.96	4.60	0.06	53.97	21.41
Vel. 5	1.10	1.50	4.60	0.04	53.30	21.60
Vel. 6	1.10	1.65	4.60	0.04	59.36	21.69
Vel. 7	5.00	1.09	4.95	0.05	77.04	21.37
Vel. 8	5.00	1.34	4.95	0.06	88.10	21.37
Vel. 9	5.00	1.54	4.95	0.06	81.07	21.42

Table 2 Sample of relative humidity and operative temperature measurement.

Probe TAG	X (m)	Y (m)	Z (m)	Relative humidity (%)	Operative temperature (°C)
Hum. 1	3.10	0.50	0.45	25.69	
Hum. 2	1.10	1.25	4.60	25.14	
Hum. 3	5.00	1.63	4.95	25.10	
Temp. 1	3.10	0.92	0.45		21.25
Temp. 2	1.10	0.73	4.60		21.41
Temp. 3	5.00	1.24	4.95		21.46

Fig. 3 Developing new IEQ parameters in Revit.

A	B	C	D	E	F
Air Velocity -	Carbon Dioxide	Humidity- %	Operative Temp	Lux-lux	Air Temperatur
0.08	774	25.69	21.25	509.8	21.22
0.07	846	25.14	21.41	520	21.21
0.07	799	25.10	21.46	544	21.21
0.06	778	24.10	21.43	566	21.41
0.04	776	25.20	21.37	602	21.60
0.04	805	25.20	21.42	442	21.69
0.05	821	25.30	21.42	508	21.37
0.06	992	25.70	21.41	536	21.37
0.06	778	25.66	21.43	507	21.42

(a)

Humidity-%	AirTemperat	AirVelocity-m	OperativeTer	CarbonDioxi	Lux-lux
25.69	21.22	0.08	21.25	774	509.8
25.14	21.21	0.07	21.41	846	520
25.10	21.21	0.07	21.46	799	544
24.10	21.41	0.06	21.43	778	566
25.20	21.60	0.04	21.37	776	602
25.20	21.69	0.04	21.42	805	442
25.30	21.37	0.05	21.42	821	508
25.70	21.37	0.06	21.41	992	536
25.66	21.42	0.06	21.43	778	507

(b)

Fig. 4 Integrating BIM model with database ((a) measured data as a new parameters in revit model, (b) measured data in Microsoft Access database).

through comparing the measured data with the allowable values of IEQ parameters as discussed in the previous sections.

5. Conclusions

Tracking and improving the quality of indoor environment in educational building help in providing healthy environment and improving the educational performance. This research provides a framework to integrate the indoor environmental quality data into BIM model to detect and track the indoor environment problems. BIM is a technology that is enriched with visualization capabilities and interdisciplinary information, this very useful in tracking and monitoring environmental process of the model. The proposed BIM-IEQ framework will help the educational authority and other stakeholder in monitoring the conditions of IEQ parameters at any

section and at any time. Furthermore, this framework can be used also as a tool for thermal simulation and energy analysis for the building depending on the measured data that included in BIM model.

Acknowledgment

This project was funded by the National Plan for Science, Technology and Innovation (MAARIFAH), King Abdulaziz City for Science and Technology, Kingdom of Saudi Arabia, Award Number (11-BUI2090-02).

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