SUSTAINABLE BUILDING RENOVATION AND INDOOR ENVIRONMENTAL QUALITY

Raghad Sameh[1], Walaa S E Ismaeel and Fatma Othman

Architectural Engineering Department, The British University in Egypt, El-Sherouk City, 11837, Egypt

Indoor environmental quality (IAQ) should be considered for any renovation process. This paper aims at identifying this link pointing out the health effects associated with the renovation process in an educational building. The study focused on four types of spaces: lecture halls, classrooms, laboratories, and staff rooms. This investigated the materials and finishes used during the renovation process for wall painting as well as floor and ceiling finishing. Then further investigation using lab tests were conducted for specimens of wall finishes. This was followed by structured questionnaires with full-time occupants such as staff members and lab engineers, as well as transient occupants such as labours and students to determine symptoms of Sick Building Syndrome. The results showed that wall painting had the greatest impact on IAQ and this corresponds to previous literature. Furthermore, it was found that high VOC was indicated; this was not the result of the material used for wall painting but due to the process undertaken. Also, the surveys enabled determining the short-term and long-term health hazards on different space users and how this varied according to space dimensions and ventilation system. Eventually, the study provides recommendations for proper planning for building occupancy during and after the renovation process.

Keywords: indoor air quality; material selection; renovation practices; sick building

INTRODUCTION

There is a proven relationship between building construction and Indoor air quality (IAQ). This is particularly true for renovation activities that involve a considerable amount of construction, demolition and finishing e.g., public buildings with intensive occupation density and long stay e.g., educational facilities (Al-Sulaihi *et al.,* 2015). Furthermore, a postulation was made to relate student's health hazards and learning performance with poor IAQ (Al-Sulaihi *et al.,* 2015; Polidori *et al.,* 2013).

Previous research proved that 30 percent of buildings worldwide whether new or renovated receive a high number of long-term health-related complaints. This can be referred to as sick building syndrome (SBS) (EPA and Environments Division, 1991). Building renovation and systems renovation are the main causes for SBS. This is due to their release of a considerably excessive number of pollutants where they act as a potential contributor to unsuitable IAQ. These include high concentrations of Volatile organic compounds (VOCs) and particulate matter (PM) viable and non-viable into the air. Furthermore, the release of excessive pollutants accompanied by inadequate ventilation in the indoor spaces may cause SBS prevalence (Thomas *et al.,* 2019).

[1] Walaa.Salah@bue.edu.eg

Sameh, R, Ismaeel, W S E and Othman, F (2021) Sustainable Building Renovation and Indoor Environmental Quality *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 37th Annual ARCOM Conference,* 6-7 September 2021, UK, Association of Researchers in Construction Management, 574-583

Therefore, this study investigated the relationship between building renovation, IAQ and SBS; taking a case study of a renovated educational building at the British university in Egypt. The research started with a comprehensive literature review about the effect of renovation activities on IAQ. Then, on a case study renovated building, followed a series of steps as shown in Fig 1; 1) observation for the best practices implemented during the renovation process for floors, ceiling and wall finishes in chosen spaces, 2) followed by gas chromatography test investigating the level of VOC emissions caused by wall painting and admixtures and 3) designed questionnaires and interviews to identify the long and short term associated symptoms of SBS. Eventually, the study provides recommendations for proper planning for building occupancy during and after the renovation process.

This study followed 2 approaches presented in Fig 1.

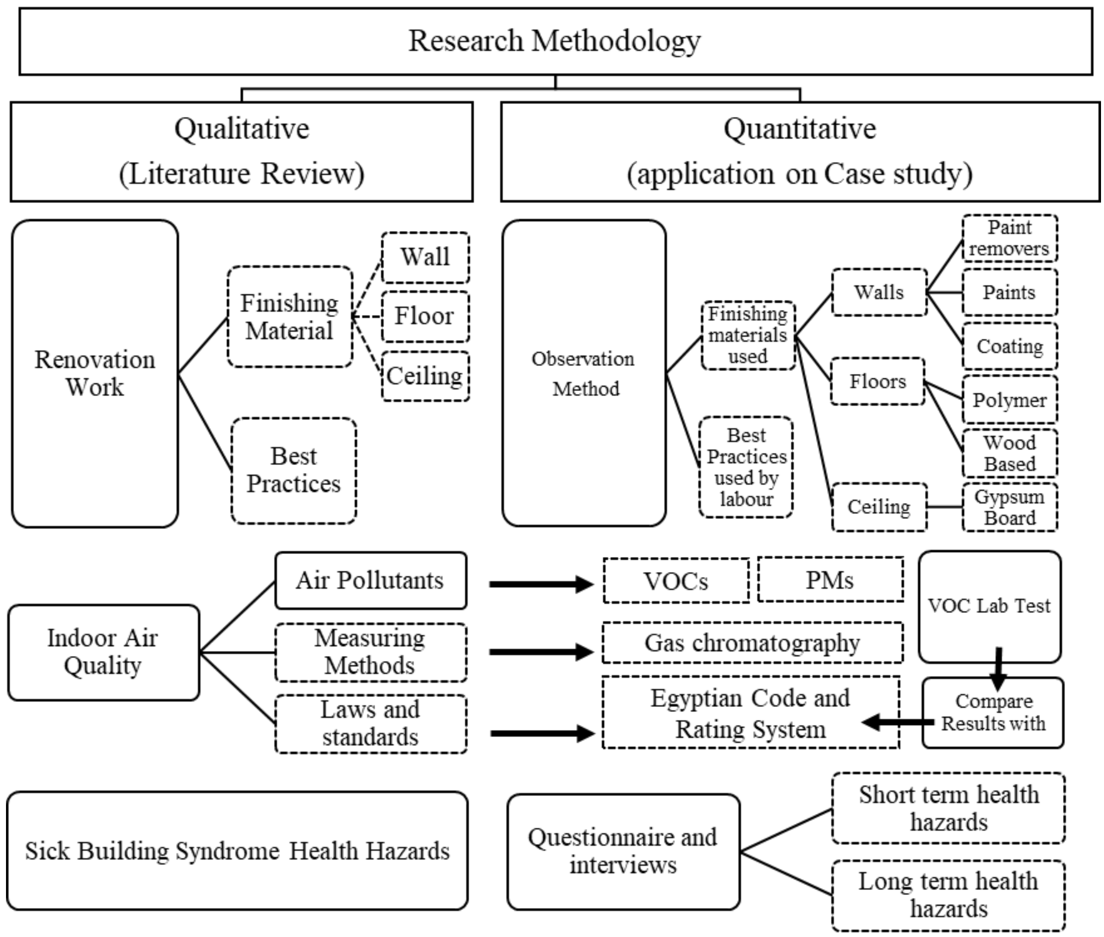

Fig 1: Research Methodology

The study started with a thorough investigation to identify the relation between renovation activities, IAQ and SBS. This was determined by analysing the previously published literature in the last three years. Elsevier SciVerse Scopus database was used. Keywords were set to identify scholarly output about renovation work, IAQ and SBS. The subject area was limited to environmental science, material science and engineering. The results showed a number of publications in terms of SBS and its relationship with renovation work and IAQ-as shown in Fig 2 (left). Furthermore, a number of publications investigating the renovation work independently were identified, and then any included work was screened to identify relations to different SBS effects and presented in Fig 2 (right). The analysis of scholarly output about IAQ of building renovation was divided into three groups with different SBS effects (wall, floor, and ceiling). Moreover, the analysis showed that walls (structure) received the highest focus in this research scope. However, further screening of the results showed that wall renovation in terms of finishing material was neglected. Hence, this research investigated the chemical composition related to wall renovations in term of finishing materials and their effect on human health.

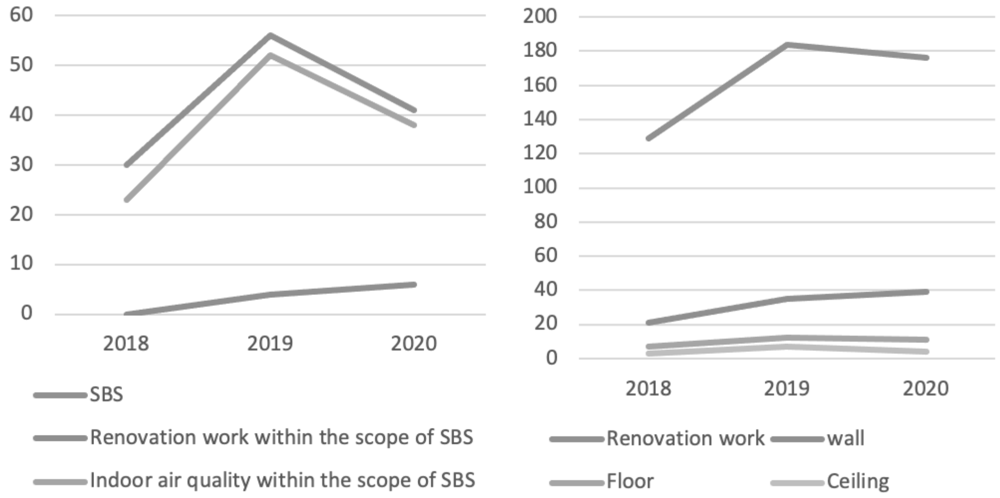

Fig 2 relevant publications in year and scope

LITERATURE REVIEW

Establishing the relation between IAQ, SBS and the building renovation process
According to previous studies, IAQ was discussed in relation to space design, different sources and pollution conditions as well as human activities and behaviour. This affects indoor temperature and relative humidity, noise, climate change and carbon dioxide emissions. Moreover, studies showed various frameworks addressing occupants' exposure to the indoor environment using VOC data obtained through passive sampling (Schlink *et al.,* 2016). In general, building renovation is regarded as a sustainable solution with less environmental impact and carbon emissions (Balaban and Puppim de Oliveira, 2017; Kylili *et al.,* 2016). However, renovation activities, as well as the selection of building materials, may pose harmful impacts with regards to IAQ (He *et al.,* 2012). Building materials used for renovation may be categorized into three groups: wall finishes, floor finishes and ceiling finishes.

Significant air pollutants and health hazards
Particulate Matter (PM) (referred to as aerosol) indicates the presence of air pollution produced by activities in the atmosphere. It is known to cause significant damage to human health when inhaled. Therefore, the reduction of PM levels in the built environment became an essential need to reduce diseases. PM simulation is considered a complex process due to its physical and chemical characteristics. Whereas, during the renovation activities, high concentrations of PM are released containing harmful elements as sulfate, chloride, lead, nitrate and fungi causing inadequate IAQ and health problems. These health problems were categorized by the world health organization according to the duration of exposure to short and long-term effects. The former includes severe impact on the respiratory system such as lung inflammatory reactions, Cardiovascular malfunction and increased death rates. The latter includes respiratory malfunction, lung damage, increased chronic obstructive

pulmonary disease as well as a reduction in life expectancy owing mostly to cardiopulmonary mortality and chronic respiratory diseases (Pope *et al.,* 2016).

Volatile Organic Compounds (VOCs) are identified as air pollutants found at ground level in the atmosphere containing various compounds. It was stated that "A VOCs Compound is an organic compound with a vapour pressure less than 760 Torr (101.3 KPa) and more than 1 Torr (0.13 KPa) at 20 ºC (Derwent, 2007). Furthermore, the Environmental Protection Agency (EPA) identified the VOCs compounds as any substance containing carbon in the atmosphere except for coal, carbon monoxide and carbon dioxide (EPA, 2017). It has been found that VOC concentrations within newly renovated spaces are higher than those found in a normal state of atmospheric air. It is believed that this affects IAQ causing health problems to occupants. Whereas reported toxicological evidence indicates the unlikelihood of organ intoxication but mucous membranes irritation is expected in the nose and eyes. Moreover, discomfort can be expected due to sensory stimuli. This is believed to be caused by occupants' exposure to indoor air containing xenobiotic and anthropogenic molecules (Mishra *et al.,* 2015).

IAQ measuring methods: IAQ detectors should be used to measure the chemical standards and percentage during the renovation process. This should start at the beginning of any renovation activity to account for materials that include VOCs and PM, i.e., the toxicity of chemical composition and solvent used should be assessed. The measuring methods include VOC charcoal tube, gas chromatography, air samples in canisters, radon detectors, metone particulate matter monitor and Sedimentation Method (Dewulf *et al.,* 2002).

IAQ related laws and standards: information on contaminants identification and tracking can be easily obtained worldwide due to air quality laws. Moreover, IAQ is a major concern in Green Rating systems which makes it an important factor for any sustainable building process; design, construction or renovation (Ismaeel, 2019, 2020). Nonetheless, IAQ data is still minimal in Egypt which results in a lack of information related to indoor air pollutants. This was confirmed by D. Wagdi (2015) who stated that one of the main reasons causing SBS is that most of the pollutants found in the IAQ are not clarified in the standard (Wagdi, 2015).

IAQ investigation through academic literature

Previous studies concerning renovation activities and IAQ followed three directions; identifying the levels of PM indoors, determining the average duration needed to regain a safe emission level and material selection for proper IAQ. The former showed a lack of benchmarks and variations in local codes and standards. Furthermore, each study used a selected set of VOCs for the test. Previous studies had various conditions whether it is the location of sampler placement (indoor or outdoor), the approximate distance between the renovation activity and the sampler location, sampling duration and different renovation materials. All results stated that PM constitutes health-hazardous agents as lead, sulfate, nitrate, chloride, ammonium and fungi as Aspergillus s Furthermore, PM levels tend to be higher inside buildings even when minimal renovation activity is taking place (Massolo *et al.,* 2010). Another research direction assessed the duration required to reach the normal emission level after renovation activities take place. The passive sampling method was used followed by Gas chromatography. The results indicated that VOC needed two to eight weeks to degrade after renovation activities whereas normal VOC levels might take up to three months (Derwent, 2007). Another group of studies discussed the effect of using different materials and finishing during building renovation. Different assessment methods were used e.g., field measurements compared to the international standards for IAQ, life cycle assessment of used material, the impact of insulation on the emission levels, different materials capabilities and how varying the combinations of the materials can lead to different results (Morsi *et al.,* 2020; Ros-Dosdá *et al.,* 2019; Thomas *et al.,* 2019).

Case Study Application
The study discussed the renovation activities for the educational building (A) located at the British university in Egypt as regular maintenance after 10 years of operation of the facility. Four different types of spaces were selected: a lecture hall, classroom, laboratory and staff office. This provided a comprehensive view of the effect of renovation activities on occupants' health and wellbeing.

METHOD

The research method started with an observation method for the best practices followed during the renovation process for the floor, ceiling and wall finishes in the spaces shown in Fig 3. This step recorded the renovation process according to the best practices undertaken by the labours, compared to recommendations from international standards e.g., OSHA standards or the Occupational Safety and. Health Act and EPA guide for better IAQ**.** Then VOC lab tests were performed for 4 different colours of a well-known wall painting product widely used in the Egyptian market. This was done using a gas chromatography test to investigate the level of VOC emissions caused by the wall painting and admixtures. The measurement was done following the normal procedure of testing according to Dewulf, Van Langenhove and Wittmann (2002). This was followed by a final step of designed questionnaires and structured interviews carried from March 2018 to March 2019 to investigate the long term and short-term symptoms of SBS. For the purpose of this study, the former was defined as immediate impact and after 2 weeks, while the latter was defined after 1, 3, 6 and 12 months, respectively. These were carried out on a sample of 150 participants who agreed to commit to this study. It was performed to indicate the short-term health effects experienced by workers, students (limited to the school of architecture; from year 1 to 4) and staff members. Similarly, the survey was repeated for the same participants of students and staff to indicate the long-term effect of occupants' SBS. Their distribution is shown in Table (1) to represent a sample of full time and transient occupants. This investigation aimed at assessing a number of criteria based on the previous literature review. The survey included 4 questions.

1. Investigating the type of symptoms experienced in each of the four defined spaces. Participants should choose one or more from a list determined according to previous literature; aches and pains, chest tightness, cough, difficulty in breathing, dry blocked nose, dry skin and skin rashes, fever, generalized malaise, headache, lethargy and tiredness, sore dry eyes, sore throat, symptoms of an allergy such as fever, watering/itchy eyes and runny nose or wheeze.
2. Indicating the duration taken to start feeling these symptoms.
3. Indicating how long they lasted after leaving the space.
4. Indicated if they have any history of chronic diseases.

The results of the survey were then classified into SBS type 1 or 2 indicating exposure period and duration and highlighting the impact on vulnerable occupants with medical history.

FINDINGS

During the observation method

It was generally noted that labours did not adhere to safety regulations of putting their goggles and facemasks during work.

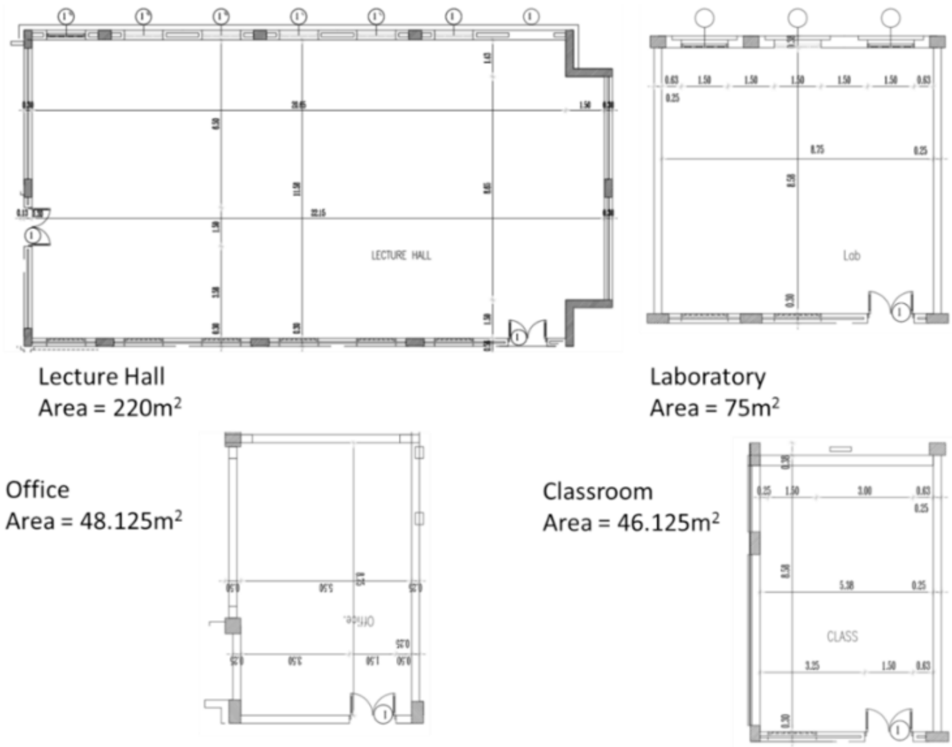

Fig 3: Selected spaces located on the ground floor of Building (A) at the British University in Egypt

Table 1: The population sample investigating the short-term and long-term symptoms of SBS

Category of occupants	Short-term	Long-term
Workers	12	0
Students	23	67
Staff members	15	33
	50	100

Further observations for each renovation activity were noted. The floor finish started with a preparation step of the existing surface beneath, removing the old floor carpet, cleaning the surface from any debris and adjusting surface levelling. Then the new vinyl plank flooring was applied on top of the underlayment after cleaning. The vinyl covering was fixed using the adhesives on the back of the planks. Also, wearied false ceiling panels were replaced with new ones following the same modular division of the suspended metal frame. Moreover, wall painting followed a traditional best practice where two-thirds of the paint was diluted with a liquid solvent. It was noted that wall finishing differed for existing and new wall structures. In classrooms, a new wall painting was performed on an old one. It was also noted that an extra amount of paste was added to obtain a smoother surface in some cases. By observation, it was noted that in one hour, workers covered about 7 m2 of an ordinary surface for a single layer of coat.

Questionnaires and surveys

The short-term effect was investigated for workers, students and staff members. The major effect was experienced by the former due to working in confined places with poor ventilation, e.g., classrooms, staff rooms, labs and lecture halls. It was noted that all workers didn't use personal equipment and this made them more prone to health effects. Most of them (84%) experienced the same symptoms of nose and eyes mucous membrane irritations, discomfort in the respiratory system, dizziness and asthma. Most students experienced SBS type 1 which developed to type 2 when their stay period exceeded 2 continuous hours in the confined classroom but it is noted that these symptoms developed in a longer 3 to 4 hours in larger spaces such as lecture halls. This affected students' attention and ability to comprehend. On the other hand, staff members suffered from SBS type 1 which developed to type 2 after one week of full-time occupancy. Hence, this caused an increase in sick leaves and absentees. The long-term effect was investigated for students and staff members. Over time, students suffered severe indoor discomfort symptoms which gradually decreased except for those with asthma. This slow rate of decrease was because indoor spaces were not properly aerated. Similarly, staff members suffered some symptoms of SBS but notably less due to maintaining proper natural ventilation in staff rooms. The data analysis showed the percentage of exposed people to SBS during renovation activities in Building A. This was divided as shown in Fig (4) into symptoms appearing in the first month, during the next 3 months and after 6 months of building operation.

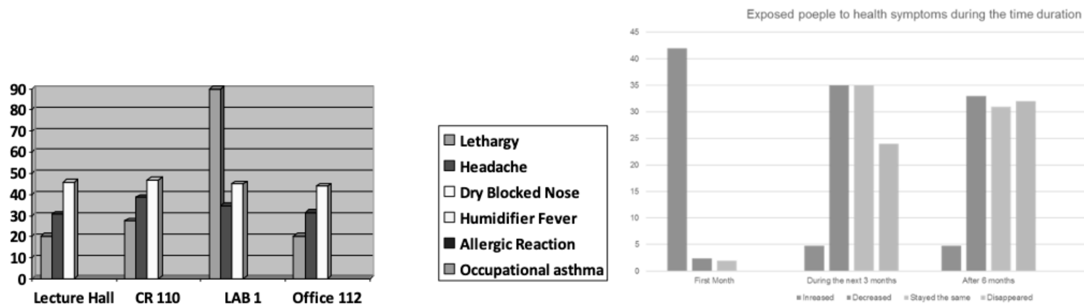

Fig 4: The results of the online questionnaire

The lab test results

The test results for the used painting product were favourable indicating VOC of 630 PPM, 20.9 % of O_2 and 0.00 PPM for both H_2S and Ammonia (NH_3) which adhere to the environmental laws in Egypt (Environment, 1994). Nevertheless, the result of a chromatography analysis as presented in Fig 5 indicated a high VOC concentration for one painting product used in the lecture halls located in the ground floor buildings. This occurred during the manual preparation and mixing practices of the liquid mixture paint. The lecture hall used white Paint with a VOC of 5229.4010 ppm. This space had the least percentage of VOC among other spaces. The large space dimension of the lecture hall reduced the perceived impact of the VOC emission level. Hence, during the survey, the majority of the exposed participants indicated that there they experienced the least symptoms of SBS. The laboratory space used the grey wall painting and brown paste of VOC level of 78,217.14 and 814,844.64 ppm, respectively. It was noted that due to the relatively smaller size of the lab space, it demonstrated higher symptom effects as well as the used painting which had higher VOC than used in lecture halls and offices. Also, a considerable number of occupants felt an increase in symptoms. The office space used white wall painting and brown paste of VOC level of 5,229.4010 ppm. The results showed that the VOC concentration was lower in offices than in labs because the workers used white paint not grey, also less occupancy in that small space reduced the symptoms. Moreover, office spaces were better ventilated which reduced the amount of VOC concentration. Furthermore, the classroom space used grey wall painting and brown paste with VOC level of 78217.14 and 814844.64 ppm, respectively. Hence, the majority of exposed participants indicated that their symptoms increased the most while attending classrooms. This occurred as a result of the poor ventilation and high VOCs concentration.

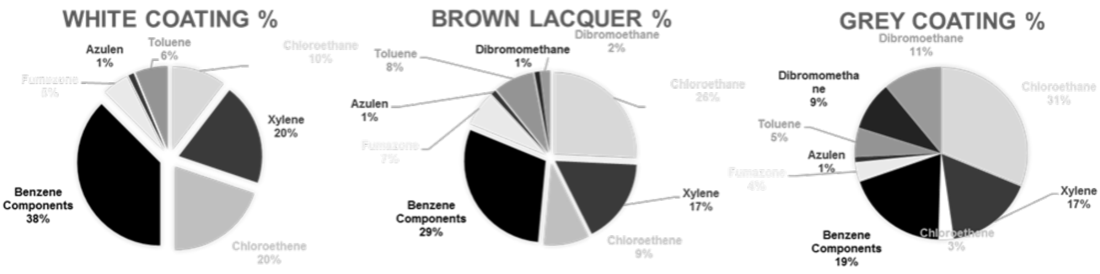

Fig 5: VOC components result in each coating

DISCUSSION

The study pinpointed the importance of adopting sustainable renovation practices, particularly in public buildings. This necessitates accounting for all associated parameters that may compromise the sustainability of the entire renovation process. In the current study the selection of educational institutions which have intensive occupancy rate, pattern and density for all studies spaces which varied in type and dimensions reflected this effect on IAQ. The scope of renovation did not include demolition or new construction of the studied spaces which mitigated several health hazards and minimized environmental impact (Ismaeel and Ali, 2020). It only included new finishing for walls, floors and ceiling. Hence, material selection and construction best practices were the main detrimental to the sustainability of the entire process. Nevertheless, these two factors alone were responsible for several short and long term SBS according to lab tests and occupants' survey responses. Hence, establishing a management and control strategy is a necessity in this regard. This should be performed by revising the material data sheet and regular lab tests for building products. This is in addition to supervision for any manual labour work to ensure it adheres to standards and codes of practices for maintaining IAQ. The novelty of the work is to show with evidence that sometimes-using green materials and products may not be enough to guarantee a sustainable renovation activity if the best practices used still follow the traditional renovation methods. It also shows that IAQ should be monitored and controlled during the entire renovation process or else serious health effects may occur during and after the renovation activities take place. Also, material selection should preferably be investigated during early project stages for proper pollutant source control.

CONCLUSION

The study pinpointed the importance of adopting a sustainable approach for building renovation in educational facilities and its direct effect on IAQ. This investigated long term and short-term health effects for a number of full time and transient occupants. Hence, sustainable renovation procedures should be undertaken during construction and before occupancy. This includes a selection of building materials and construction best practices including the wall, floor and ceiling finish both in terms of activities undertaken and materials used. It also requires investigating building materials quality and quantity, and search for market availability for green materials.

The result indicated that IAQ should be planned before any renovation activity takes place. During the construction process, air pollutants including VOCs, particulate matter, ammonia and radon while toluene and xylene, benzene were present in high VOC concentrations. After construction, the concentration of indoor pollutants was high as a result of construction activities then the formaldehyde concentration decreased over time. Ammonia remained high for an average of 12 months. Furthermore, the results confirm the importance of defining the standards and monitoring procedures of indoor air pollutants and the necessity to reduce the presence of harmful emissions in the built environment. This recommends 1) source control referring to material selection in terms of quality, and quantities of materials used and their datasheets, 2) adhering to acceptable emission levels and exposure periods according to international standards and 3) monitoring IAQ during and after construction to ensure workers follow safety regulations and international standards.

REFERENCES

Al-Sulaihi, I, Al-Gahtani, K, Alsugair, A and Tijani, I, (2015) Assessing indoor environmental quality of educational buildings using BIM, *Journal of Environmental Science and Engineering*, **4**(8), 451-458.

Balaban, O and Puppim de Oliveira, J A (2017) Sustainable buildings for healthier cities: Assessing the co-benefits of green buildings in Japan, *Journal of Cleaner Production*, **163**, 68-S78.

Derwent, RG (2007) Sources, distributions and fates of VOCs in the atmosphere, *In*: R E Hester and R M Harrison (Eds.) *Volatile Organic Compounds in the Atmosphere*, London: Blackwell Publishing, 1-16.

Dewulf, J, Van Langenhove, H and Wittmann, G (2002) Analysis of volatile organic compounds using gas chromatography, *Trends in Analytical Chemistry*, **21**(9-10), 637-646.

Environment (1994) LAW NUMBER 4 of 1994* (4).

Environmental Protection Agency US and Environments Division I (1991) *Indoor Air Facts No 4 Sick Building Syndrome EPA - Air and Radiation (6609J), Research and Development (MD-56)*, Available from: https://www.epa.gov/sites/default/files/2014-08/documents/sick_building_factsheet.pdf [Accessed 13 July].

He Z, Zhang, Y and Wei, W (2012) Formaldehyde and VOC emissions at different manufacturing stages of wood-based panels, *Building and Environment*, **47**, 197-204.

Ismaeel, W S E (2019) Drawing the operating mechanisms of green building rating systems, *Journal of Cleaner Production*, **213**, 599-609.

Ismaeel, W S E (2020) An integrated model for energy-efficient building practices, *In*: *The 9th International Conference on Software and Information Engineering (ICSIE 2020)*, Cairo, Egypt, November 11-13, New York: Association for Computing Machinery, 204-208.

Ismaeel, W S E and Ali AAMM (2020) Assessment of eco-rehabilitation plans: Case study ‘Richordi Berchet’ palace, *Journal of Cleaner Production*, **259**, 120857.

Kylili, A, Fokaides, P A and Jimenez, P A L (2016) Key Performance Indicators (KPIs) approach in buildings renovation for the sustainability of the built environment: A review, *Renewable and Sustainable Energy Reviews*, **56**, 906-915.

Massolo, L, Rehwagen, M, Porta, A, Ronco, A, Herbarth, O and Mueller, A (2010) Indoor–outdoor distribution and risk assessment of volatile organic compounds in the atmosphere of industrial and urban areas, *Environmental toxicology*, **25**(4), 339-349.

Mishra, N, Bartsch, J, Ayoko, G A, Salthammer, T and Morawska, L (2015) Volatile organic compounds: characteristics, distribution and sources in urban schools, *Atmospheric Environment*, **106**, 485-491.

Morsi, D M A, Ismaeel, W S E, El Hamed, A E A and Othman, A A E (2020) Applying LCA-BIM Integration for a Sustainable Management Process. *In:* Scott, L and Neilson, C J (Eds.), *Proceedings 36th Annual ARCOM Conference*, 7-8 September 2020, UK, Association of Researchers in Construction Management, 416-424.

Polidori, A, Fine, P M, White, V and Kwon, P S (2013) Pilot study of high-performance air filtration for classroom applications, *Indoor Air*, **23**(3), 185-195.

Pope, C, Marks, E, Back, E, Leopard, T and Love, T (2016) Renovation versus new construction and building decision tool for educational facilities, *Journal of Construction Engineering*, 1-10.

Ros-Dosdá, T, Celades, I, Vilalta, L, Fullana-i-Palmer, P and Monfort, E (2019) Environmental comparison of indoor floor coverings, *Science of The Total Environment*, **693**, 133519.

Schlink, U, Röder, S, Kohajda, T, Wissenbach, D K, Franck, U and Lehmann, I, (2016) A framework to interpret passively sampled indoor-air VOC concentrations in health studies, *Building and Environment*, **105**, 198-209.

Thomas, N M, Calderón, L, Senick, J, Sorensen-Allacci, M, Plotnik, D, Guo, M, Yu, Y, Gong, J, Andrews, C J and Mainelis, G (2019) Investigation of indoor air quality determinants in a field study using three different data streams, *Building and Environment*, **154**, 281-295.

United States Environmental Protection Agency (2017) *Technical Overview of Volatile Organic Compounds*, Washington D.C.: United States Environmental Protection Agency.

Wagdi D (2015) *Effect of Building Materials on Indoor Air Quality in Residential Building in Egypt: A Pre Occupancy Assessment*, Masters Thesis, The American University in Cairo, School of Sciences and Engineering.