Indoor Environmental Quality Assessment and Occupant Satisfaction

Subjects: Transportation

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As occupants spend almost 90% of their day indoors, especially in the workplaces, Indoor Environmental Quality (IEQ) plays a primary role in health and wellbeing, productivity, and building energy consumption. Adopting the IEQ and Post-Occupancy Evaluation (POE), data has been gathered from nine multilevel open offices within a university building located in Al Ain, in the United Arab Emirates (UAE) for three winter months. Physical parameters were monitored using data loggers to record the main IEQ factors.

Keywords: indoor environment quality ; occupant satisfaction ; post occupancy evaluation ; United Arab Emirates

1. IEQ at the Workplace

Since the early 2000s, studies on IEQ display a direct relationship to outdoor environmental conditions [1][2]. Presently the outdoor environment detects a concern regarding the increasing concentration of several harmful pollutants due to global warming and climate change. Higher pollutant concentrations were correspondingly found in the indoor environment; some of which include NO_x, SO_2, O_3, CO, volatile and semi-volatile organic compounds (VOCs), particulate matters (PMs), as well as microorganisms [3][4][5]. These contaminants can cause a set of health symptoms in humans that vary in severity; according to each's toxicity, concentration, and exposure time [6][7]. A common effect of these contaminants' exposure is known as Sick Building Syndrome (SBS) [8]. SBS is experienced when people show a series of uncomfortable health-related symptoms. These symptoms include eye, nose, and throat irritations, allergies, headaches, fatigue, asthma-like symptoms, and several more [9][10]. Although people may not know the exact reasons for these syndromes, the syndrome may disappear once the affected person leaves the office or building [11].

Several studies at workplaces find that better IEQ decreases the risk of experiencing SBS and increases user comfort which in turn increases individual work productivity [12][13][14]. The increase in work productivity comes with an increase in economic benefits to companies, universities, or schools. Studies show green buildings to have significantly higher rates of occupant satisfaction when it comes to IEQ as well as allow a reduction in energy consumption [15][16][17]. Focusing on IEQ can reduce unnecessary energy costs while having a positive effect on thermal comfort which in return can optimize work productivity [18].

Several factors contribute to IEQ including ventilation and it can vary from different ventilation typologies, facility management, and occupant behaviour. How well air conditioners are being maintained and operated affects IAQ and overall IEQ [19]. For example, having a good air filtration system will help to significantly reduce the amount of PMs or fine dust that enters the building from the outside, thus providing better air quality for the occupants. This approach stresses the quality of the ventilation system used, the facility management methods, as well as the indoor occupant's behavioural activities. Moreover, a study that focuses on assessing the IAQ and ventilation rate in schools, finds relations concerning several pollutants exposure and health symptoms experienced [20]. The most-reported health symptoms were found to be SBS and asthma. Investigations show responsible pollutants to be TVOCs, and allergens that were measured in floor dust. This IAQ assessment demonstrates how low ventilation rates increase health risks among all building occupants.

Another study compares green buildings and non-green buildings through quantitative measurements of IEQ and qualitative occupant satisfaction surveying. The study finds better quantitative performance for the green building in terms of IEQ factors and pollutant concentrations, which translates to better occupant satisfaction and fewer acute health symptoms experienced by occupants in the better IEQ conditions of the green buildings [21].

A commonly seen strategy in several previous studies on IEQ [20][22][23] includes the building's occupant perception as a form of investigative POE study to enhance IEQ. Investigative POE is when a correlation between physical environmental measures and subjective occupants' response measures is studied [24]. POE can be in the form of questionnaires,

surveys, or interviews that focus on subjectively measuring certain IEQ criteria or satisfaction levels. Benefits of performing POE include identifying and resolving issues regarding user comfort, overall satisfaction, and productivity [25]; as well as offering documentation as direct input to create a feedback loop for future building cycles [24][26]. Challenges, however, can be linked to the instrument's reliability and the confounding IEQ variables and correlations [27].

This briefly summarizes the findings of the literature review of previous research related to the topics of IEQ and POE. More details on each study and its, date, location, focus, and relative findings can be found in **Table 1**.

Table 1. Literature review findings on IEQ effects at the workplace.

Title of the Study	Region Studied	Study Focus	Key Findings	Year
Occupant productivity and office indoor environment quality.	-	Literature study.	The literature review shows both the economic and health related benefits of good IEQ. It illustrates the significance of the impact of the IEQ on occupant comfort and productivity.	2016 [28]
Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan	Taiwan	A post-occupancy evaluation was employed in the study consisting of a field survey of subjective perception among indoor occupants and on-site environmental measurements.	The overall IEQ satisfaction was statistically significantly greater in the certified green building than the conventional buildings. However, a re-visit of thermal comfort-related criteria may be required.	2014 [22]
Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platinum campus building.	USA	POE approach with GIS-based spatial mapping method was used to analyse and visualize the survey results of building occupant satisfaction and the measured indoor environment quality.	Occupants complained regarding thermal comfort, reporting it was too cold. CO_2 level was also predominantly higher. Light levels in the building were found to be higher than preferred as artificial lighting was excessively used even when daylight was available.	2014 [23]
Patients and the sick building syndrome.	USA	Suggest physician approaches to identify disease in individual and group effects on patients and analyse the impact of indoor environmental exposure.	Sick building syndrome can show several recognizable symptoms that include eye irritation, nose irritation, throat irritation, headache, fatigue, asthma-like symptoms, and more.	1994 [9]
Indoor Air Quality in the 21st Century: Search for Excellence.	-	Studies key principles for a new philosophy of excellence.	Improved indoor air quality increases productivity and decreases sick building syndrome symptoms. Individual control of the thermal environment should be provided to increase user comfort.	2000 [12]
Comparative study on the indoor environment quality of green office buildings in China with a long-term field measurement and investigation.	China	This study analyses the subjective questionnaires and objective measurements of the indoor environment quality (IEQ) in green building.	Results show that the green buildings in China possess significantly higher IEQ satisfaction levels than conventional buildings. This emphasises the importance of operation management and individual control methods in the building.	2015 [15]
Thermal comfort and behavioural strategies in office buildings located in a hot-arid climate.	Australia	The effects of indoor climate on thermal comfort levels and adaptive behaviour of office workers.	Shows office workers prefer adjusting the set temperature of the building to 22.21 °C for both seasons. As opposed to the ASHRAE scale, it occurred at 20.31 °C in winter. Further research can reduce overcooling cost with a positive effect on thermal comfort and workplace productivity.	2001 [18]
Perception of indoor environment quality in differently ventilated workplaces in tropical monsoon climates.	Sri Lanka	The research investigates the perception of indoor environment quality (IEQ) in differently ventilated workspaces.	Air conditioning (AC) and ductless mini split system air conditioning (MM) buildings were rated more satisfactory than naturally ventilated (NV) systems for overall comfort of indoor environment conditions.	2015 [19]
Indoor air quality, ventilation, and health symptoms in schools: An analysis of existing information	USA	investigates causal relationships between health symptoms and exposures to specific pollutants in schools	Reported ventilation and CO_2 data strongly indicate that ventilation is inadequate in many classrooms, possibly leading to health symptoms.	2003 [20]

Title of the Study	Region Studied	Study Focus	Key Findings	Year
Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings	Singapore	This study compared IEQ performance in green and non-green office buildings. Adopting a cross-sectional study design between objective measurements and subjective measurements.	This study offered a positive association of green buildings with qualitatively and quantitatively measured performance of IEQ.	2018 [21]
Listening to the occupants: a Web-based indoor environmental quality survey	-	Developing a benchmarking survey that can be used as a diagnostic tool to identify specific problems and their sources	The research discusses survey guidelines to create a feedback loop for building industry professionals, so that they can learn how various building design features and technologies affect occupant comfort, satisfaction and productivity.	2004 [25]
Measured energy use and indoor environment quality in green office buildings in China.	China	Energy consumption and indoor environment quality (IEQ) are compared in green office buildings with common ones through energy data collection, physical parameters measurement and satisfaction survey.	User satisfaction in green buildings is statistically significantly higher than those in common buildings. Especially in the field of thermal environment, IAQ, facilities and operating & maintenance.	2014 [29]

2. IEQ Factors

As stated in the Indoor Environment Handbook, IEQ includes four main factors of IAQ such as thermal comfort, lighting quality, and acoustic quality [30]. Each is measured by a set of parameters, and has several control methods and related issues; which are summarized in **Table 2**.

Table 2. IEQ factors, parameters, control methods, issues, threshold, and health.

IEQ Factors	Parameters	Control Method	Issues	Parameter Measures	Threshold	Health Symptoms
Thermal Comfort	Temperature Relative humidity Air velocity User activity	Air conditioning system Building design	Adaptation Building integration Energy use	Temperature	24–26 °C **	Respiratory problems
				Relative Humidity	30–60% **	Microbial growth, skin drying, irritation of mucus membranes, and dry eyes
Indoor Air Quality	Pollution sources Ventilation rate and efficiency	Source control Ventilation system maintenance	Pollution Fine dust	PM2.5	15 μg/m^3 *	Respiratory and cardiovascular diseases including asthma, myocardial ischemia, high blood pressure and heart disease
				PM10	50 μg/m *	
				CO_2	800 ppm *	Increased risk of sick building syndrome and symptoms such as headache
				TVOCs	312 ppb *	Dry throat, runny nose, asthma attacks, poisoning, and cancer
Lighting Quality	Luminance Reflectance Colour, temperature View, and daylight	Luminance distribution Artificial lighting and daylighting integration	Daylight relation to thermal comfort Energy use	Lux level	300–500 lux *	Headaches, circadian phase disruptions, breast cancer, sleep disorder, and depression
Acoustical Quality	Sound level Absorption Sound insulation Reverberation time	Acoustical control Passive noise control Active noise control	Vibrations and annoyance long term health effects	Sound level	55 dBA *	Hypertension, stress, poor concentration, memory retention and mental arithmetic

Thermal comfort is a subjective evaluation of one's satisfaction with the thermal environment [31]. It can differ from the perception of one person to another according to a set of factors such as age, gender, activity level, clothes, etc. Generally, thermal comfort is the most responsible factor for human health, well-being, and productivity. As it has a direct effect on the body's respiratory system. For example, too cold an environment or highly fluctuating temperature can trigger asthma and flu symptoms.

IAQ is an essential factor to assess the quality of the air within a building. health and well-being. The building's ventilation system may be the most underestimated aspect of the indoor air pollution level. Thus, the design and maintenance of such systems are vital.

Sustaining comfortable lighting levels is another crucial factor in the work environment. Major lighting issues need to be avoided such as excessive lighting, glare, flickering, reflection, inconsistent distribution, and lack of integration of daylighting and artificial lighting. Focusing on these issues creates a comfortable workplace environment that increases work productivity. Moreover, user control further increases the lighting quality of the indoor space.

To make an indoor space perform better acoustically, control strategies can be implemented to limit unwanted noise and reverberation. Simple strategies involve using absorbing material, closing sound leaks, reducing contact sound transmission, and/or applying active noise control. Long-time exposure to disturbing noises can lead to a range of health issues such as stress, poor concentration, and productivity losses in the workplace.

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