Evaluating the effects of Indoor Air Quality on teacher performance using Artificial Neural Network

Abstract

Purpose *- Indoor Air Quality has a direct impact on occupant health and productivity. Understanding the effect of Indoor Air Quality (IAQ) in educational buildings is essential in both the design and construction phases for decision-makers. Hence, it is equally important to recognise and appreciate the influence of design judgements on occupants' performance, especially on teacher and students.*
Design *- This study aims to evaluate the effect of IAQ on teachers' performance. This study would deliver air quality requirements to BIM-led school projects. the methodology of the research approach uses quasi-experiment using questionnaire surveys and physical measurements of indoor air parameters to associate correlation and deduction. A technical college building in Saudi Arabia was used for the case study. The study developed an Artificial Neural Network model to define and predict relationships between teachers' performance and indoor air quality.*
Findings - *This paper highlights a detailed investigation into the impact of indoor air quality via direct parameters (relative humidity, ventilation rates and carbon dioxide) on teacher performance. Research findings also indicate an optimal relative humidity with 65%, ranging between 650 ppm to 750 ppm of CO2, and 0.4m/s ventilation rate. This ratio considered optimum records for both comfort and performance.*
Originality – *This paper focused on teachers' performance in Saudi Arabia and used Artificial Neural Networks to define and predict the relationship between performance and indoor air quality. There are few studies focusing on teachers' performance in Saudi Arabia and very few that uses ANN in data analysis.*

Keyboard: Indoor Air quality; Teacher Performance, Occupant comfort; Artificial Neural Network

Introduction

The physical environmental factors that affect Indoor Environmental Quality (IEQ) include many parameters that may affect occupant's performance, such as Indoor Air Quality (IAQ) (IAQ), thermal comfort, ventilation flow rate, lighting quality and background noise (Geng *et al.,* 2019; Wang, C. *et al.,* 2021; Al Horr *et al.,* 2016a; Kaushik *et al.,* 2020; Leccese *et al.,* 2020; Şentop Dümen and Tamer Bayazıt, 2020). There is ample literature on indoor environmental quality and its impact on occupant comfort and performance. However, there is a limited number of detailed investigations on IAQ on educational buildings in the Middle East. This paper presents a part of the experiment which focused on establishing the relationship between IEQ and teacher performance. It presents the IAQ analysis of the experiment.

The gaseous composition and cleanliness of the air make an essential contribution to the health and comfort of occupants. Indoor air quality is identified by physical and chemical components, such as relative humidity, temperature, and contaminants (Jones, 1999; Wyon, D. P., 2004; Wolkoff, 2018). These components are influenced by climate, building properties (age, materials, and construction), ventilation and air conditioning (HVAC) system, air pollution sources and occupants' activity and behaviour (Ashrae, 1989; Seguel *et al.,* 2017). These elements are all linked in dynamic interactions (Szczurek *et al.,* 2015), making it challenging to identify direct causes of health symptoms and discomfort in the presence of both indoor pollutants and other indoor environmental parameters.

Washington State Department of Health indicates that 25% of schools have IAQ problems. Finding these problems cost an average of $135,000 due to interrelated construction and building systems factors (Schneider, 2003; Bryk and Schneider, 2002). It complicates the process to recognise the exact causes of indoor air problems. Generally, IAQ is improved by decreasing sources of pollution and increasing ventilation flow rates by both natural and mechanical systems. Literature indicates that it affects the performance of students and teachers (Burns *et al.,* 2002; Park *et al.,* 2002). Poor IAQ is also known to cause disease and sickness, affecting student and teacher attendance in school. It leads to severe health conditions that reduce performance levels (Wargocki, 2017; Lan, Wargocki and Lian, 2011a; Frontczak, Schiavon, Goins, Arens *et al.,* 2012b; Lan, Wargocki and Lian, 2011b).

The physical environment affects teachers' comfort, both physical and mental. Various studies have measured carbon dioxide (CO_2) levels to estimate air quality and freshness of the air delivered to occupants (Toftum *et al.,* 2015; Coley, Greeves and Saxby, 2007; Bakó-Biró *et al.,* 2012; Mendell *et al.,* 2013; Lin *et al.,* 2020; Chaloulakou and Mavroidis, 2002). The level of indoor air pollutants, including CO_2 concentration caused by the inadequate ventilation level in classrooms, can affect teaching because the high concentration of CO_2 is organised as a source of air pollution that causes directly increased fatigue and loss of attention (Kajtar *et al.,* 2006).

The freshness of the air is also estimated by measuring the concentration of Volatile Organic Compounds and suspended particulate matter (Shin and Jo, 2013; Chao and Chan, 2001). In contrast, bioaerosols such as fungi and bacteria are evaluated generally by microscope or artificial growth tools (Stetzenbach, Buttner and Cruz, 2004). However, controlling Volatile Organic Compounds and the specific composition of particulate matter is costly in money and time, which may expose why these methods are usually reserved for controlled environment studies and sensitive occupancies.

Ensuring good indoor air quality in an indoor environment is done by providing access to outdoor air. However, it is a challenge when the outside environment also contains contaminants (Clements-Croome *et al.,* 2008). Occupants may complain about odours and

CO_2 concentration. However, they are less likely to complain about either high organic pollutants or low ventilation level in a condition with less odour. It means that building users may present discomfort, health symptoms, and behavioural changes without linking these subjects to poor air (Heinsohn and Cimbala, 2003).

Many previous studies have specified that the concentration of CO_2 inside buildings is a suitable indicator of indoor air quality (Lai *et al.,* 2009; Wong, Mui and Hui, 2008; Seppänen, Fisk and Mendell, 1999). Similarly, a study also supported that the concentration of CO_2 in buildings can be used as an accurate indicator of pollutant concentration. The study presented that CO_2 values above 1000 ppm in classrooms were related to a 10-20% increase in absenteeism (Shendell, 2012). It is also debated that absence from school reveals poor IAQ amongst other indoor variables, and those respiratory illnesses are more common in classrooms with inadequate ventilation. Many studies show that higher ventilation level improves performance because poor indoor air quality negatively affects teachers' comfort and health, thus reducing motivation to teach, increasing absenteeism, and ultimately impairing student outcomes (Wargocki, 2017; Schneider, 2003; Kielb *et al.,* 2015; Toftum *et al.,* 2015). Another study found that higher airflow level considered variance in students and teachers' performance for some tasks. They also reported that when the fresh air rate increased, students felt less hungry (Wargocki and Wyon, 2006). The study suggested mechanism for this relationship is that fresh air reduces stress, of which hunger has proposed a proxy. It analysed thermal and air quality studies highlighting the importance of these factors for student performance (Mendell and Heath, 2005).

Moreover, higher humidity and organic pollutants are associated with augmented respiratory illness and asthma, leading to reduced attendance and performance (Smedje *et al.,* 2017; Hou *et al.,* 2021; Wang, J. *et al.,* 2013; Zhong, Yuan and Fleck, 2019; Hameen *et al.,* 2020). Another study has indicated that CO_2 concentration is a reliable parameter for bio-effluents from occupants. It is consequently a good indicator of the occupants' numbers in an architecture space and can forecast user's complaints about odour. However, CO_2 concentration in spaces is not an accurate indicator to measure the quantity of outdoor air supplied (Lan *et al.,* 2014).

There are several studies on IAQ that focus on determining the sources of contaminants. The material of the flooring surface affects IAQ and leads to respiratory illness in schools. It measured 80 carpeted floor classrooms that load organic pollutants, finding that 30% of them contained unacceptable values of fungal and insect allergens (Tortolero *et al.,* 2002). Foarde and Berry compared classrooms with mostly carpeted floors to one that mainly was tiled, finding that the carpeting illustrated as a contaminant sink, giving higher surface loadings (Foarde and Berry, 2004). However, hard flooring was correlated with higher aerosol particulate concentrations. The psychological and acoustic variances between carpeting and hard flooring complicate the association of student and teacher performance with IAQ. Bullock also reports that students' scores in mathematics with tiled floors classrooms were higher than those with carpeted floors. However, the study's validity was limited because only 5% of the total schools surveyed had carpeted classrooms (Bullock, 2007). A significant flooring-related finding of a study by Fisk was that the removal of carpeting from buildings was associated with enhanced performance. It also showed reduced levels of physical contaminants, better air quality and less intense symptoms of sick building syndrome (SBS) and reduced levels of physical contaminants. The absence of carpets improved performance by 2.5% and 3.8% on a logical reasoning test, by 6.5% in the amount of text typed, and by 3.1% on a timed test. Self-assessments of performance show that improved performance may have been a consequence of the reduced incidence of headache (Fisk, 2000).

Poor IAQ may lead to building-related illness and SBS, a condition in certain buildings where users feel uncomfortable, sleepy, suffer headaches, or lose concentration (Heinsohn and Cimbala, 2003; Sateri, 2004). Studies also conclude that SBS is increased by the presence of high concentrations of indoor air pollutants, particularly biological components, such as volatile organic compounds and formaldehyde (Takigawa *et al.,* 2009; Yang *et al.,* 2020; Jiang *et al.,* 2017).

Literature also outlines that poor air quality in offices make employees uncomfortable and affects their performance (Al Horr *et al.,* 2016b; Niemelä *et al.,* 2002; Al Horr *et al.,* 2017; Hawkins *et al.,* 2020). Air quality is also one of the main factors influencing occupant health. Another study surveyed teachers in Washington, DC and Chicago to investigate school conditions. The finding included that air quality was the highest health complaint referring to school facilities. Over half of respondents reported some problems, and that a third of the sample reported suffering from health issues due to poor school conditions (Schneider, 2003). A study of teachers in New York State schools reported classroom environments potentially related to poor air quality. Over 40% indicated at least one health symptom such as throat irritation, headache and allergies connected with buildings conditions. Most of the poor classroom conditions identified were associated with one or more symptoms, the strongest correlations being the incidence of paint odours, dust, and mould (Kielb *et al.,* 2015).

ASHRAE (2013): *Ventilation for Acceptable Indoor Air Quality*, published by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), specify a minimum level of the supply of outdoor air to buildings based on a reduction approach to controlling pollutants. A typical classroom designed the minimum ventilation requirement to be approximately 3 litres of outdoor air per second per person, corresponding to 0.47 cubic feet per minute (cfm). In contrast, a ventilation rate of less than 0.152 m^3/s is classified as 'still air'. Such stagnation is adverse to IAQ because particles of contaminants are static in the air that occupants breathe, affecting their health and comfort.

The Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH) have indicated limits for safe exposure to contaminants. NIOSH uses a ten-hour exposure period for establishing concentration limits, while OSHA uses eight hours (Heinsohn and Cimbala, 2003). The OSHA 8-hour maximum average for "particulates not otherwise designated" is 10,000 $\mu g/m^3$ of PM10 and 5000 $\mu g/m^3$ for PM2.5, although these are higher than the IAQ suggestions above.

The IAQ Tools for Schools action kit addresses the school administrators and teachers. This resource includes simple yes/no checklists to classify sources of air quality problems and makes suggestions for indicating items of concern tools (Roy, 2012).

A review of several studies concludes that increasing the natural air ventilation rate would enhance the performance and speed of classroom works by about 14%. The interventions reported that performance on classroom tasks was significantly affected. The results demonstrate that classroom air quality is a significant factor in the learning process and should be considered the highest educational priority, together with teaching material and resources. Furthermore, classroom air quality was much worse than in offices because this context was neglected (Daisey, Angell and Apte, 2003).

In common with other workers, teachers should exercise some control over temperature and ventilation conditions in classrooms because this would lead to improved performance, fewer symptoms of illness and less absenteeism. Employees' performance improved by 6.5% in a controlled environment. However, while providing adequate ventilation and removing sources of pollutants are associated with improved health and performance (Yu *et al.,* 2011). There are indoor air quality studies that uses deep neural network and IOT sensors (Chen *et al.,* 2020; Woo *et al.,* 2011).

Teachers prefer to be able to open classroom windows. A comparison study of schools found that operable windows in classrooms improve students' achievement of 7% better results in maths and reading than those in classrooms with fixed windows (Heschong, Wright and Okura, 2002). Another study found that topics in a controlled study in a test chamber had higher skin temperature and drank more water when windows were not open, possibly due to worse air pollution (Schweiker *et al.,* 2013). A study recommends that shading devices, orientation, the size, and the position of windows should be considered at the design phase to avoid overheating, glare and poor air quality (Barrett *et al.,* 2015).

The literature review has highlighted the importance of indoor air quality in educational buildings and its need to study in the middle eastern climate.

Methodology

This study investigated the relationship between Indoor Air Quality (IAQ) and teacher performance (Alzahrani, 2018). The approach adopted was constructed evidence of the association between IAQ and teacher performance using the following hypothesis:

H_0: There is a link between indoor air quality and teacher performance in classrooms.

In order to evaluate this hypothesis, a mixed-methods approach used questionnaire surveys and physical measurements of IAQ parameters to figure out the correlation and inference (Holt and Goulding, 2014). The outcome of this study is based on the assumption that when teachers are more comfortable with indoor air quality, they will perform better in the classroom.

Figure 1 outlines the research process in the form of a flowchart. It outlines five stages of the research study through three phases: Input, Process, and Output phases. The first stage, Preliminary Literature Review, involved identifying the main gap in the literature that serves as the input to the study. The second stage focused on identifying the purpose of the study. It outlines the literature on indoor physical parameters. The third stage focused on identifying the relationship between IAQ and occupant comfort and performance. The fourth stage focused on experiment design and outlined the data collection using sensors and survey instruments. All these three stages are part of the process phase. The fifth stage and third phase focused on analysis and conclusion, which utilised data analysis using an Artificial Neural Network to support the discussion and conclusion.

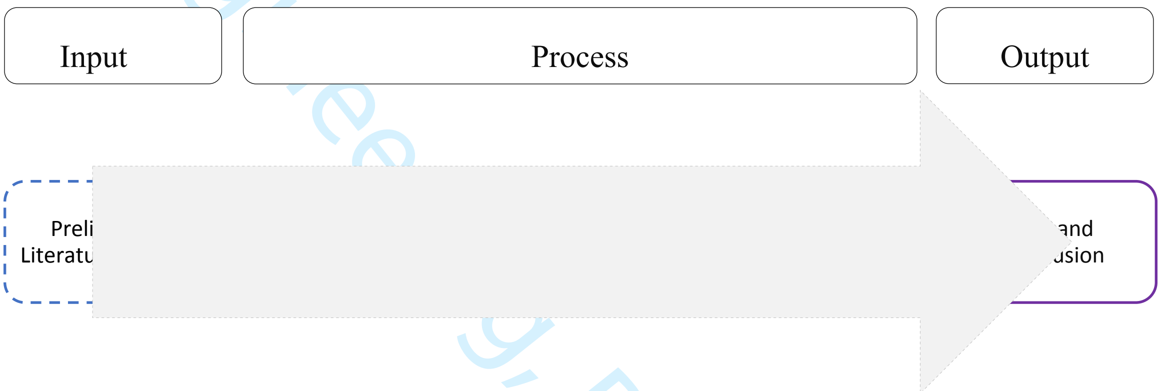

Figure 1: Methodology flowchart

Case Study Location and Context

This study was undertaken on the Jeddah Technical College campus in Saudi Arabia. The campus is located on the west coast of the Red Sea at

Jeddah has an approximate population of 4.4 million

where air conditioning is in constant operation. For data reliability comparison purposes, indoor air parameter measurements were recorded during autumn, winter and spring. The autumn readings were taken in September 2016, when the average temperature in Jeddah was 35°C, with the maximum being 40°C, and the minimum 28°C. The winter readings were taken in January 2017, with corresponding temperatures of 27°C, 31°C and 24°C.

The spring temperatures were taken in April 2017, representing 32°C, 36°C and 26°C, respectively (Figure 2).

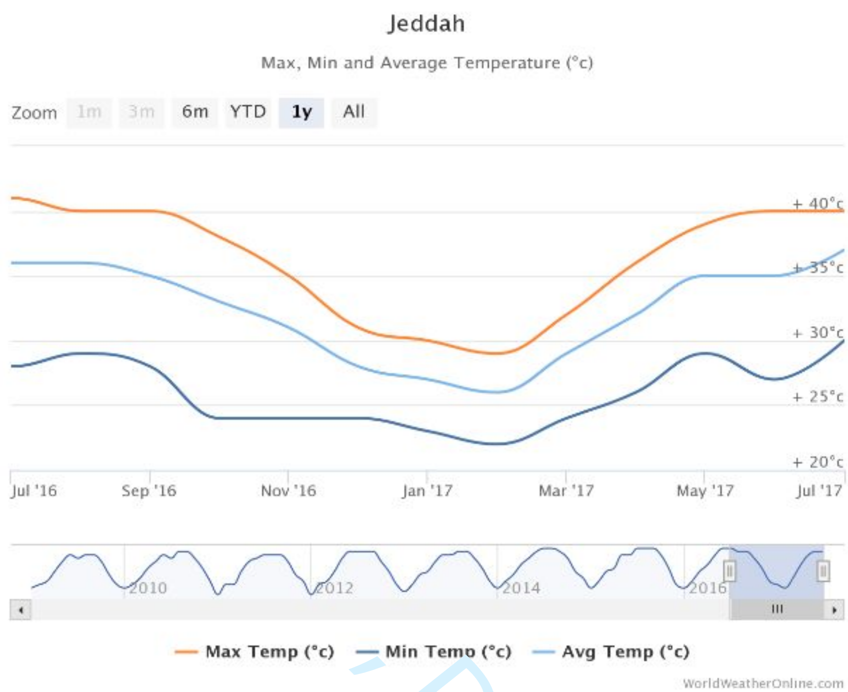

Figure 2: Temperature variations in Jeddah

Indoor air predictor parameters were constructed of physical measurements recorded from the classrooms in academic buildings at the technical college. The academic day typically starts at 8:00 am and ends at 2:45 pm, five days a week. From a classroom setting perspective, lectures generally lasted for two hours, with a few extending to three hours.

From an observation perspective, 42 classrooms were studied during the autumn period, where the indoor air parameters were recorded three times a day, making 126 records. This method was repeated for the winter term (44 classrooms) and spring term (38 classrooms), making 372 records for the whole year. The indoor air variables were collected from a questionnaire using teachers' perceptions. In total, 124 teachers participated in this survey.

Questionnaires used a five-point Likert scale (1= Strongly disagree to 5 = Strongly agree) examining indoor air conditions. It also included one multiple-choice item on thermal sensation and five Likert scale items on air movement and mechanical ventilation, humidity, CO2 concentration and accessibility of a thermostat and overall acceptability of indoor air quality. Teachers' response to indoor air conditions reflects their comfort. Literature on indoor air comfort suggests that teachers' performance is highly affected by their perception of indoor air quality (Gou and Lau, 2013; Frontczak *et al.,* 2012; Al Horr *et al.,* 2016; Lan, Wargocki and Lian, 2011; Akimoto *et al.,* 2010; Djongyang, Tchinda and Njomo, 2010). The measurement of indoor air variables used standard instruments, the parameters of which were recorded at three places (front, centre and back) in each classroom. From this, the average was calculated, following the method used by Awang (Awang, Mahyuddin and Kamaruzzaman, 2015). The measurements were recorded 'live' in the presence of students and teachers, interrupting classroom activities as little as possible to capture the actual classroom environment.

Data Analysis

This study used Artificial Neural Network (ANN) to develop an assessment model and validate findings. MATLAB was used to develop and assess the ANN model. The data were quantitatively analysed to determine general trends regarding the statistical data associated with the model. The data analysis stage also involved testing the hypotheses to determine the causal link (or not) between IAQ and performance. ANN data was divided into three segments of algorithm learning: 70% of the data for training the model, 15% for validation, and 15% for testing the learning. The performance of the network was evaluated using standard statistical standards, specifically: squared coefficient of determination (R^2) for the regression between the observed and modelled values of the output variable; Mean Square Error (MSE); Root Mean Square Error (RMSE); and Mean Absolute Error (MAE) for the modelled values. The hyperbolic tangent function was selected as the transfer function. It can monotonically increase weights on the nodes to process and identify patterns between input and output variables.

Research Findings and Discussion

Data analysis commenced with three inputs and one output variable. The three input variables included: relative humidity, ventilation, and CO2 concentration (Table 1).

Table 1: Statistical values of input and output data

	Input data			***Output***
	Humidity	*Ventilation*	*CO2 level*	*Performance*
Mean	53.02	0.236	798.5	3.524
Standard Deviation	7.34	0.158	8.69	1.128
Minimum	37	0.12	606.8	1
Maximum	75	0.40	1200	5
Kurtosis	-0.09	0.85	1.02	0.97
Skewness	0.315	-0.16	0.834	0.242
Log value	1.724	-0.27	0.678	0.547
Count	321	321	321	321

Table 1 shows that indoor air parameters varied as follows: humidity 37% to 75%, ventilation flow rate from 0.12m/s to 0.54 m/s and CO2 concentration rate between 606.8 ppm to 1200ppm.

The ANN model was developed in several stages to ensure the highest accuracy. In this case, a total of 321 records of indoor air parameters were used to assess the associations of these parameters against performance. The four main linear regression models (robust, stepwise, linear, interaction regression) with fivefold cross-validation were run all together in MATLAB R2017a, and the best values for these regression models were set to be: R^2 = 0.94, Mean Squared Error (MSE) = 0.00, Root Mean Square Error (RMSE) = 0.06 and Mean Absolute Error (MAE) = 0.05. The results can be seen in Figure 3.

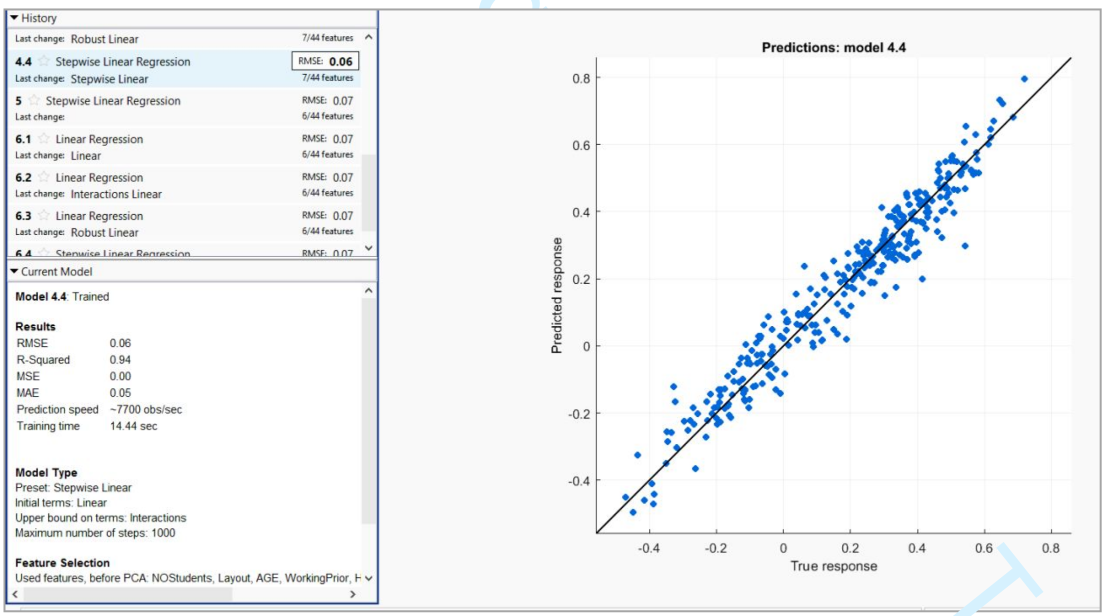

Figure 3: Relationship between indoor air quality and performance

These results indicate that a strong relationship exists between indoor air quality and teacher performance. The five-fold cross-validation was set to avoid overfitting. It involved partitioning the dataset into folds to estimate each fold's accuracy to improve data reliability.

Sensitive Analysis: Relative Humidity and Performance

In the present study, the relative humidity parameter was conducted to determine its effect on teacher performance varied between a minimum of 37% and a maximum of 75%. Figure 4 indicates the association of relative humidity to performance, showing that it improved with increasing humidity up to 65%, which is almost the optimal level for maximum performance, then fell when humidity increased further. Therefore, the optimal results of relative humidity corresponded to 55-65%.

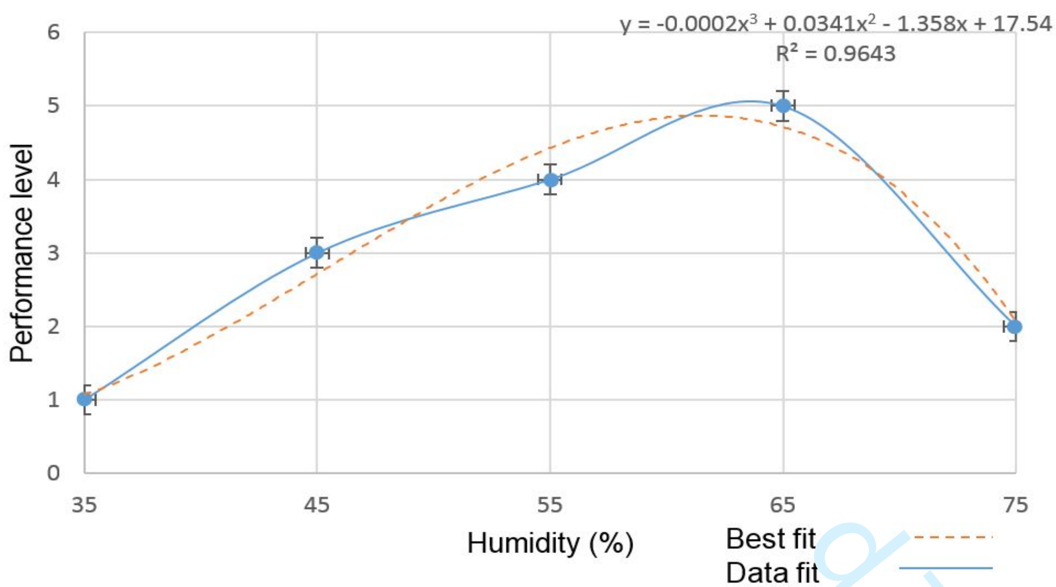

Figure 4: The relationship of humidity level with performance

Statistically, the R^2 value was 0.9643, representing a strong relationship between relative humidity and performance. The findings of this study are corresponding with Ismail et al. (2008). They determined at a significance level of $p < 0.01$ that workers in the electronics industry were most productive when relative humidity was 59.5%. Likewise, it was noted that maximum performance linked to a relative humidity of approximately 60% (Sarbu and Pacurar, 2015). Contrastingly, another study found increased relative humidity rate from 30% to 70% significantly augmented the complaints among employees and consequently affected performance (Tsutsumi *et al.,* 2007).

Sensitivity Analysis: Ventilation Rate and Teacher Performance

Ventilation, the second contributor to indoor air quality, protects against odours, chemical compounds, allergens. However, to ensure a suitable ventilation rate, the mechanical ventilation system must work properly, which requires attention to be considered on design and operation phases to minimise annoyance and symptoms of illness among occupants. The study found that increasing the ventilation flow rate in classrooms improved teaching performance and student achievement. The lowest mechanical ventilation rate was recorded at 0.20 m/s and the highest at 0.40 m/s. Figure 4 indicating a significant correlation with an R^2 value of 0.9643, showing that increasing the flow rate was associated with improved performance. However, when the rate exceeded 0.35 m/s, performance declined slightly.

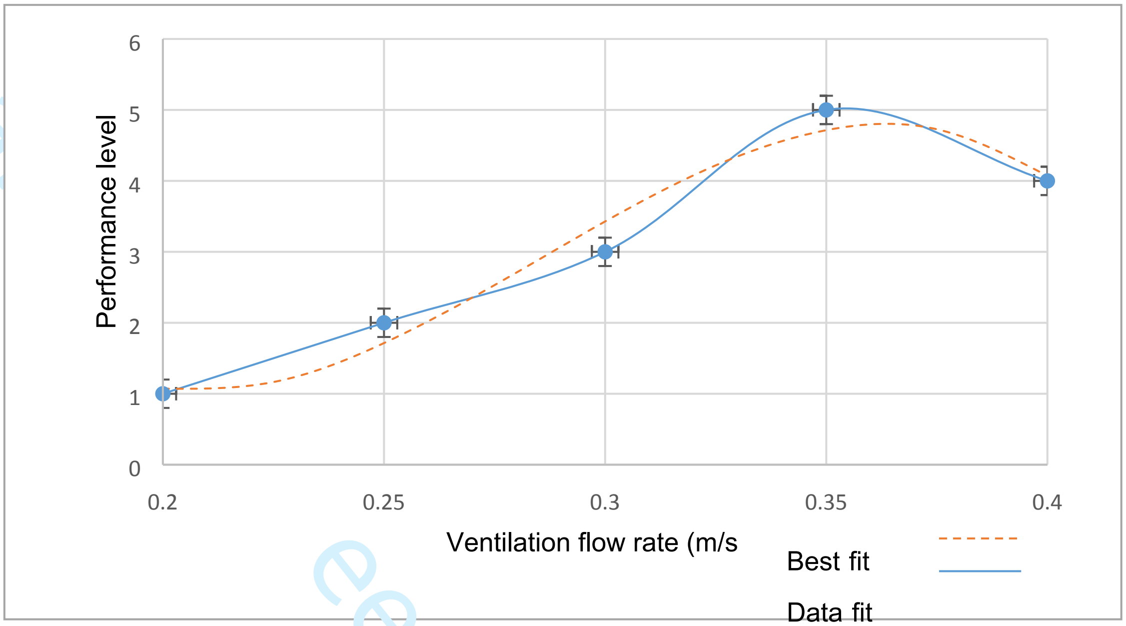

Figure 5: The relationship of ventilation rate with performance

The present study found is consistent with (Wargocki *et al.,* 2000; Frontczak, Schiavon, Goins, Arens *et al.,* 2012a; Wargocki and Wyon, 2006). It reports that increasing the ventilation rate improves performance on office tasks. In contrast, some studies found no differences in work performance, which may be attributed to the limitation of the collected data on this contrast (Federspiel *et al.,* 2002; Fang *et al.,* 2004).

Sensitivity Analysis: CO_2 concentration and Teacher Performance

Carbon dioxide concentration is the third parameter of IAQ, which considered the primary indicator of indoor air quality. CO_2 is a good indicator of ventilation performance, as its concentration tends to drop with increasing ventilation flow rate. The sensitive analysis Figure 6 found a significant relationship between performance and CO_2 concentration, $R^2 = 0.9753$. Performance was maximum when the air contained less than 650 ppm of CO_2 and fell gradually up to 1050 ppm. No difference in performance was detected when CO_2

concentration was between 850 and 950 ppm, where a moderate level of performance was maintained. These results may be correlated with ventilation flow rate and air quality, given the reverse relation between ventilation and CO_2 noted above.

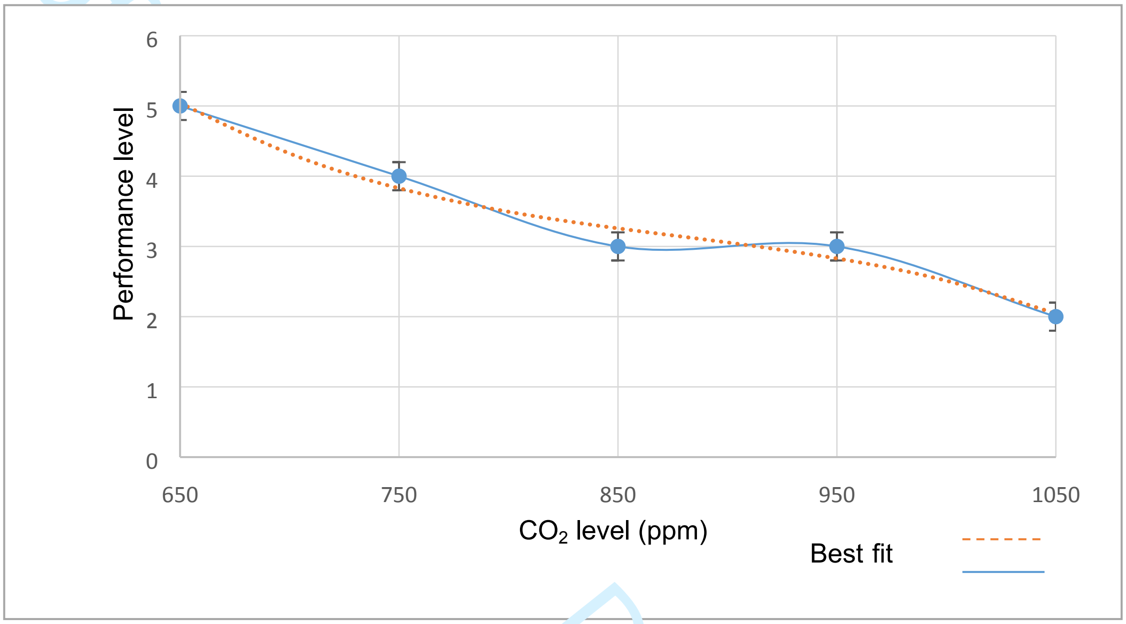

Figure 6: The relationship of CO_2 level with performance

The findings of this study indicate the relationship between CO_2 as an indicator of IAQ and performance, which is that performance improves when CO_2 concentration decreases; the optimal CO_2 concentration to maximise performance was in the region of 650 ppm. This finding is validated by finding that good air quality significantly affects performance in workstations (Kildesø *et al.,* 1999). Wargocki reported results likewise, whereby when employees perceived that fresh air; they performed better, made fewer errors and experienced fewer SBS symptoms (Wargocki *et al.,* 2002).

A study found that above 850 ppm of CO_2, the performance level was almost steady, and no significant decreases of less than 1%, even if CO_2 concentration was recorded higher

(Sarbu and Pacurar, 2015). Another study states that even a slight enhancement of air quality, consistent with only 10% of users were uncomfortable with air quality (Wyon, D. and Wargocki, 2013). Chatzidiakou, in a study that CO_2 concentrations above 1000 ppm are related to a 10-20% increase in absenteeism and recommend that reducing CO_2 might improve occupants' health and comfort and their performance which would enhance the learning process (Chatzidiakou, Mumovic and Summerfield, 2013).

Conclusion

This study presented the impact of indoor air parameters (relative humidity, ventilation rates and CO2 concentration level) on performance. It focused on one academic campus in Jeddah, Saudi Arabia, using data collected during autumn, winter and spring. The rationale for this study aimed to test the correlation between indoor air quality and performance through the hypothesis: "H_0: There is a link between indoor air quality and teacher performance in classrooms". It was developed to investigate this association scientifically, as buildings are generally constructed to provide teachers with good quality indoor air, mainly where this affects teachers' performance. This study measured humidity, ventilation flow rates and CO_2 level, including teachers' responses on IAQ. An Artificial Neural Network was implemented to predict the relationship between IAQ and performance, the results of which indicated a strong correlation between IAQ and performance.

Several studies have investigated the effect of IAQ on performance, often using CO_2 level as an inverse indicator of ventilation rate and fresh air delivery to occupants. Higher levels of CO_2 and indoor air pollutants, caused by insufficient ventilation in classrooms, may impair teaching processes and outcomes by losing attention and increasing tiredness. Conversely, higher ventilation rates indirectly improve performance and learning outcomes because fresh air improves teachers' comfort and health, strengthening motivation to learn and reduce absenteeism.

Optimal levels for IAQ and performance for relative humidity range between 55% and 65%, with an optimum ventilation rate between 0.32m/s and 0.4m/s and an optimum level of CO_2 between 600ppm and 700ppm. It proves the null hypothesis for the existing link between indoor air quality and teacher performance.

Generally, this study only focused on IAQ in mechanical system ventilated buildings, with three measurement periods (autumn, winter and spring), within the context of Jeddah, Saudi Arabia. Therefore, results may be assessed within these factors. Though similar studies have been included in this study, it would be valuable to extend further case study with different climatic areas and building types. It would not only advance data reliability but would also be able to assess variables and their interventions. This study would also help improve the design guidelines for the indoor environmental quality of office buildings in the middle east.

Finally, this study was limited to teacher performance only and did not consider student performance. However, as students typically represent a significant proportion of the college population, it is recommended that additional work is undertaken to capture a representative sample frame of this demographic to supplement these findings. Notwithstanding this, the findings from this study highlight the correlation between IAQ and performance. It presents designers and specifiers with additional evidence to re-evaluate design specifications and designs, such as building façades (sunlight access), HVAC systems, energy loads, and innovation opportunities using passive design techniques to optimise air quality and performance. These re-evaluations can be conducted in the BIM environment and suite of technologies in both refurbishment and new projects to improve the building performance and reduce the carbon footprint of the existing educational building stock.

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