



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

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# 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 CO<sub>2</sub>, 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.

**Keyword:** 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 Bayazit, 2020). There is ample literature on indoor

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3 environmental quality and its impact on occupant comfort and performance. However,  
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5 there is a limited number of detailed investigations on IAQ on educational buildings in the  
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7 Middle East. This paper presents a part of the experiment which focused on establishing  
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9 the relationship between IEQ and teacher performance. It presents the IAQ analysis of the  
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11 experiment.  
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15 The gaseous composition and cleanliness of the air make an essential contribution to the  
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17 health and comfort of occupants. Indoor air quality is identified by physical and chemical  
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19 components, such as relative humidity, temperature, and contaminants (Jones, 1999;  
20  
21 Wyon, D. P., 2004; Wolkoff, 2018). These components are influenced by climate, building  
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23 properties (age, materials, and construction), ventilation and air conditioning (HVAC)  
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25 system, air pollution sources and occupants' activity and behaviour (Ashrae, 1989; Seguel  
26  
27 *et al.*, 2017). These elements are all linked in dynamic interactions (Szczurek *et al.*, 2015),  
28  
29 making it challenging to identify direct causes of health symptoms and discomfort in the  
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31 presence of both indoor pollutants and other indoor environmental parameters.  
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36 Washington State Department of Health indicates that 25% of schools have IAQ problems.  
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38 Finding these problems cost an average of \$135,000 due to interrelated construction and  
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40 building systems factors (Schneider, 2003; Bryk and Schneider, 2002). It complicates the  
41  
42 process to recognise the exact causes of indoor air problems. Generally, IAQ is improved  
43  
44 by decreasing sources of pollution and increasing ventilation flow rates by both natural and  
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46 mechanical systems. Literature indicates that it affects the performance of students and  
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48 teachers (Burns *et al.*, 2002; Park *et al.*, 2002). Poor IAQ is also known to cause disease  
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3 and sickness, affecting student and teacher attendance in school. It leads to severe health  
4 conditions that reduce performance levels (Wargocki, 2017; Lan, Wargocki and Lian,  
5 2011a; Frontczak, Schiavon, Goins, Arens *et al.*, 2012b; Lan, Wargocki and Lian, 2011b).  
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10 The physical environment affects teachers' comfort, both physical and mental. Various  
11 studies have measured carbon dioxide (CO<sub>2</sub>) levels to estimate air quality and freshness of  
12 the air delivered to occupants (Toftum *et al.*, 2015; Coley, Greeves and Saxby, 2007; Bakó-  
13 Biró *et al.*, 2012; Mendell *et al.*, 2013; Lin *et al.*, 2020; Chaloulakou and Mavroidis, 2002).  
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18 The level of indoor air pollutants, including CO<sub>2</sub> concentration caused by the inadequate  
19 ventilation level in classrooms, can affect teaching because the high concentration of CO<sub>2</sub>  
20 is organised as a source of air pollution that causes directly increased fatigue and loss of  
21 attention (Kajtar *et al.*, 2006).  
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30 The freshness of the air is also estimated by measuring the concentration of Volatile  
31 Organic Compounds and suspended particulate matter (Shin and Jo, 2013; Chao and Chan,  
32 2001). In contrast, bioaerosols such as fungi and bacteria are evaluated generally by  
33 microscope or artificial growth tools (Stetzenbach, Buttner and Cruz, 2004). However,  
34 controlling Volatile Organic Compounds and the specific composition of particulate matter  
35 is costly in money and time, which may expose why these methods are usually reserved  
36 for controlled environment studies and sensitive occupancies.  
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47 Ensuring good indoor air quality in an indoor environment is done by providing access to  
48 outdoor air. However, it is a challenge when the outside environment also contains  
49 contaminants (Clements-Croome *et al.*, 2008). Occupants may complain about odours and  
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3 CO<sub>2</sub> concentration. However, they are less likely to complain about either high organic  
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5 pollutants or low ventilation level in a condition with less odour. It means that building  
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7 users may present discomfort, health symptoms, and behavioural changes without linking  
8  
9 these subjects to poor air (Heinsohn and Cimbala, 2003).  
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13 Many previous studies have specified that the concentration of CO<sub>2</sub> inside buildings is a  
14  
15 suitable indicator of indoor air quality (Lai *et al.*, 2009; Wong, Mui and Hui, 2008;  
16  
17 Seppänen, Fisk and Mendell, 1999). Similarly, a study also supported that the  
18  
19 concentration of CO<sub>2</sub> in buildings can be used as an accurate indicator of pollutant  
20  
21 concentration. The study presented that CO<sub>2</sub> values above 1000 ppm in classrooms were  
22  
23 related to a 10-20% increase in absenteeism (Shendell, 2012). It is also debated that  
24  
25 absence from school reveals poor IAQ amongst other indoor variables, and those  
26  
27 respiratory illnesses are more common in classrooms with inadequate ventilation. Many  
28  
29 studies show that higher ventilation level improves performance because poor indoor air  
30  
31 quality negatively affects teachers' comfort and health, thus reducing motivation to teach,  
32  
33 increasing absenteeism, and ultimately impairing student outcomes (Wargoeki, 2017;  
34  
35 Schneider, 2003; Kielb *et al.*, 2015; Toftum *et al.*, 2015). Another study found that higher  
36  
37 airflow level considered variance in students and teachers' performance for some tasks.  
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39 They also reported that when the fresh air rate increased, students felt less hungry  
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41 (Wargoeki and Wyon, 2006). The study suggested mechanism for this relationship is that  
42  
43 fresh air reduces stress, of which hunger has proposed a proxy. It analysed thermal and air  
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45 quality studies highlighting the importance of these factors for student performance  
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47 (Mendell and Heath, 2005).  
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3 Moreover, higher humidity and organic pollutants are associated with augmented  
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5 respiratory illness and asthma, leading to reduced attendance and performance (Smedje *et*  
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7 *al.*, 2017; Hou *et al.*, 2021; Wang, J. *et al.*, 2013; Zhong, Yuan and Fleck, 2019; Hameen  
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9 *et al.*, 2020). Another study has indicated that CO<sub>2</sub> concentration is a reliable parameter for  
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11 bio-effluents from occupants. It is consequently a good indicator of the occupants' numbers  
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13 in an architecture space and can forecast user's complaints about odour. However, CO<sub>2</sub>  
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15 concentration in spaces is not an accurate indicator to measure the quantity of outdoor air  
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17 supplied (Lan *et al.*, 2014).  
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22 There are several studies on IAQ that focus on determining the sources of contaminants.  
23  
24 The material of the flooring surface affects IAQ and leads to respiratory illness in schools.  
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26 It measured 80 carpeted floor classrooms that load organic pollutants, finding that 30% of  
27  
28 them contained unacceptable values of fungal and insect allergens (Tortolero *et al.*, 2002).  
29  
30 Foarde and Berry compared classrooms with mostly carpeted floors to one that mainly was  
31  
32 tiled, finding that the carpeting illustrated as a contaminant sink, giving higher surface  
33  
34 loadings (Foarde and Berry, 2004). However, hard flooring was correlated with higher  
35  
36 aerosol particulate concentrations. The psychological and acoustic variances between  
37  
38 carpeting and hard flooring complicate the association of student and teacher performance  
39  
40 with IAQ. Bullock also reports that students' scores in mathematics with tiled floors  
41  
42 classrooms were higher than those with carpeted floors. However, the study's validity was  
43  
44 limited because only 5% of the total schools surveyed had carpeted classrooms (Bullock,  
45  
46 2007). A significant flooring-related finding of a study by Fisk was that the removal of  
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48 carpeting from buildings was associated with enhanced performance. It also showed  
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3 reduced levels of physical contaminants, better air quality and less intense symptoms of  
4 sick building syndrome (SBS) and reduced levels of physical contaminants. The absence  
5 of carpets improved performance by 2.5% and 3.8% on a logical reasoning test, by 6.5%  
6 in the amount of text typed, and by 3.1% on a timed test. Self-assessments of performance  
7 show that improved performance may have been a consequence of the reduced incidence  
8 of headache (Fisk, 2000).  
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18 Poor IAQ may lead to building-related illness and SBS, a condition in certain buildings  
19 where users feel uncomfortable, sleepy, suffer headaches, or lose concentration (Heinsohn  
20 and Cimbala, 2003; Sateri, 2004). Studies also conclude that SBS is increased by the  
21 presence of high concentrations of indoor air pollutants, particularly biological  
22 components, such as volatile organic compounds and formaldehyde (Takigawa *et al.*,  
23 2009; Yang *et al.*, 2020; Jiang *et al.*, 2017).  
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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

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3 symptom such as throat irritation, headache and allergies connected with buildings  
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5 conditions. Most of the poor classroom conditions identified were associated with one or  
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7 more symptoms, the strongest correlations being the incidence of paint odours, dust, and  
8  
9 mould (Kielb *et al.*, 2015).  
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13 ASHRAE (2013): *Ventilation for Acceptable Indoor Air Quality*, published by the  
14  
15 American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE),  
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17 specify a minimum level of the supply of outdoor air to buildings based on a reduction  
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19 approach to controlling pollutants. A typical classroom designed the minimum ventilation  
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21 requirement to be approximately 3 litres of outdoor air per second per person,  
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23 corresponding to 0.47 cubic feet per minute (cfm). In contrast, a ventilation rate of less  
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25 than 0.152 m<sup>3</sup>/s is classified as 'still air'. Such stagnation is adverse to IAQ because particles  
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27 of contaminants are static in the air that occupants breathe, affecting their health and  
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29 comfort.  
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34 The Occupational Safety and Health Administration (OSHA) and the National Institute for  
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36 Occupational Safety and Health (NIOSH) have indicated limits for safe exposure to  
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38 contaminants. NIOSH uses a ten-hour exposure period for establishing concentration  
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40 limits, while OSHA uses eight hours (Heinsohn and Cimbala, 2003). The OSHA 8-hour  
41  
42 maximum average for "particulates not otherwise designated" is 10,000 µg/m<sup>3</sup> of PM10  
43  
44 and 5000 µg/m<sup>3</sup> for PM2.5, although these are higher than the IAQ suggestions above.  
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3 The IAQ Tools for Schools action kit addresses the school administrators and teachers.

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5 This resource includes simple yes/no checklists to classify sources of air quality problems  
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7  
8 and makes suggestions for indicating items of concern tools (Roy, 2012).  
9

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11 A review of several studies concludes that increasing the natural air ventilation rate would  
12  
13 enhance the performance and speed of classroom works by about 14%. The interventions  
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15 reported that performance on classroom tasks was significantly affected. The results  
16  
17 demonstrate that classroom air quality is a significant factor in the learning process and  
18  
19 should be considered the highest educational priority, together with teaching material and  
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21 resources. Furthermore, classroom air quality was much worse than in offices because this  
22  
23 context was neglected (Daisey, Angell and Apte, 2003).  
24  
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26  
27 In common with other workers, teachers should exercise some control over temperature  
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29 and ventilation conditions in classrooms because this would lead to improved performance,  
30  
31 fewer symptoms of illness and less absenteeism. Employees' performance improved by  
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33 6.5% in a controlled environment. However, while providing adequate ventilation and  
34  
35 removing sources of pollutants are associated with improved health and performance (Yu  
36  
37 *et al.*, 2011). There are indoor air quality studies that uses deep neural network and IOT  
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39 sensors (Chen *et al.*, 2020; Woo *et al.*, 2011).  
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44 Teachers prefer to be able to open classroom windows. A comparison study of schools  
45  
46 found that operable windows in classrooms improve students' achievement of 7% better  
47  
48 results in maths and reading than those in classrooms with fixed windows (Heschong,  
49  
50 Wright and Okura, 2002). Another study found that topics in a controlled study in a test  
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3 chamber had higher skin temperature and drank more water when windows were not open,  
4  
5 possibly due to worse air pollution (Schweiker *et al.*, 2013). A study recommends that  
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7 shading devices, orientation, the size, and the position of windows should be considered at  
8  
9 the design phase to avoid overheating, glare and poor air quality (Barrett *et al.*, 2015).  
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13 The literature review has highlighted the importance of indoor air quality in educational  
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15 buildings and its need to study in the middle eastern climate.  
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## 18 **Methodology**

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21 This study investigated the relationship between Indoor Air Quality (IAQ) and teacher  
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23 performance (Alzahrani, 2018). The approach adopted was constructed evidence of the  
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25 association between IAQ and teacher performance using the following hypothesis:  
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29  $H_0$ : There is a link between indoor air quality and teacher performance in classrooms.  
30

31  
32 In order to evaluate this hypothesis, a mixed-methods approach used questionnaire surveys  
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34 and physical measurements of IAQ parameters to figure out the correlation and inference  
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36 (Holt and Goulding, 2014). The outcome of this study is based on the assumption that when  
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38 teachers are more comfortable with indoor air quality, they will perform better in the  
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40 classroom.  
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43  
44 Figure 1 outlines the research process in the form of a flowchart. It outlines five stages of  
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46 the research study through three phases: Input, Process, and Output phases. The first stage,  
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48 Preliminary Literature Review, involved identifying the main gap in the literature that  
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50 serves as the input to the study. The second stage focused on identifying the purpose of the  
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52

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.

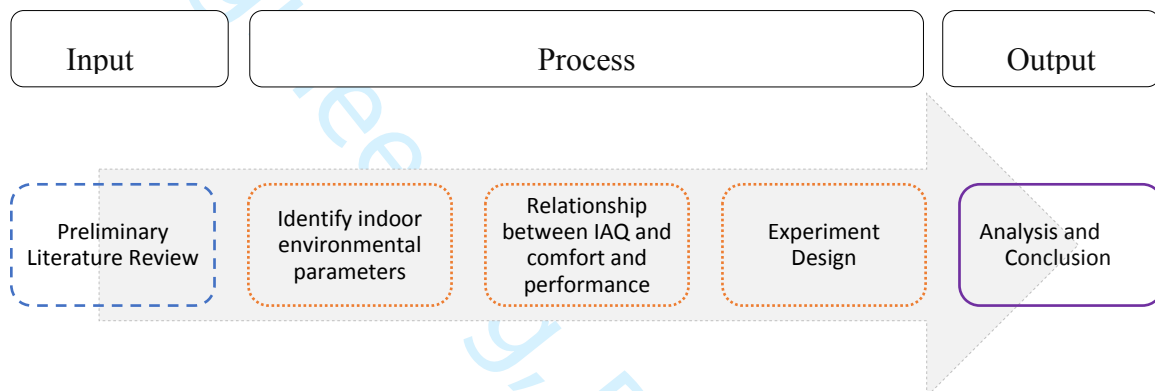


Figure 1: Methodology flowchart

### 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 21°42' N latitude and 39°10'E longitude. The city of Jeddah has an approximate population of 4.4 million inhabitants, 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).

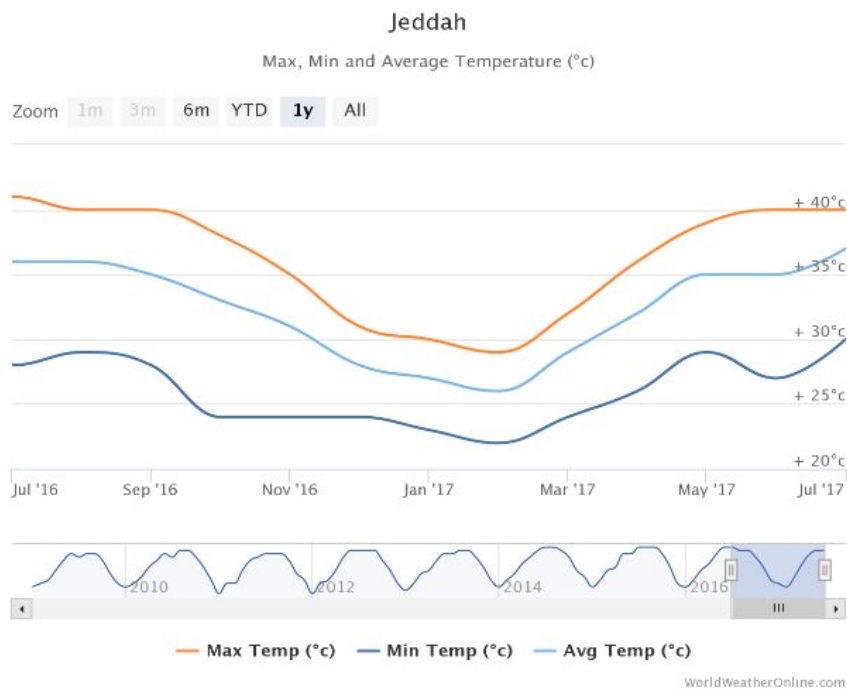


Figure 2: Temperature variations in Jeddah

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.

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3 Questionnaires used a five-point Likert scale (1= Strongly disagree to 5 = Strongly agree)  
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5 examining indoor air conditions. It also included one multiple-choice item on thermal  
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7 sensation and five Likert scale items on air movement and mechanical ventilation,  
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9 humidity, CO2 concentration and accessibility of a thermostat and overall acceptability of  
10  
11 indoor air quality. Teachers' response to indoor air conditions reflects their comfort.  
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13 Literature on indoor air comfort suggests that teachers' performance is highly affected by  
14  
15 their perception of indoor air quality (Gou and Lau, 2013; Frontczak *et al.*, 2012; Al Horr  
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17 *et al.*, 2016; Lan, Wargoeki and Lian, 2011; Akimoto *et al.*, 2010; Djongyang, Tchinda and  
18  
19 Njomo, 2010). The measurement of indoor air variables used standard instruments, the  
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21 parameters of which were recorded at three places (front, centre and back) in each  
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23 classroom. From this, the average was calculated, following the method used by Awang  
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25 (Awang, Mahyuddin and Kamaruzzaman, 2015). The measurements were recorded 'live'  
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27 in the presence of students and teachers, interrupting classroom activities as little as  
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29 possible to capture the actual classroom environment.  
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### 36 Data Analysis

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39 This study used Artificial Neural Network (ANN) to develop an assessment model and  
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41 validate findings. MATLAB was used to develop and assess the ANN model. The data  
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43 were quantitatively analysed to determine general trends regarding the statistical data  
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45 associated with the model. The data analysis stage also involved testing the hypotheses to  
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47 determine the causal link (or not) between IAQ and performance. ANN data was divided  
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49 into three segments of algorithm learning: 70% of the data for training the model, 15% for  
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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.

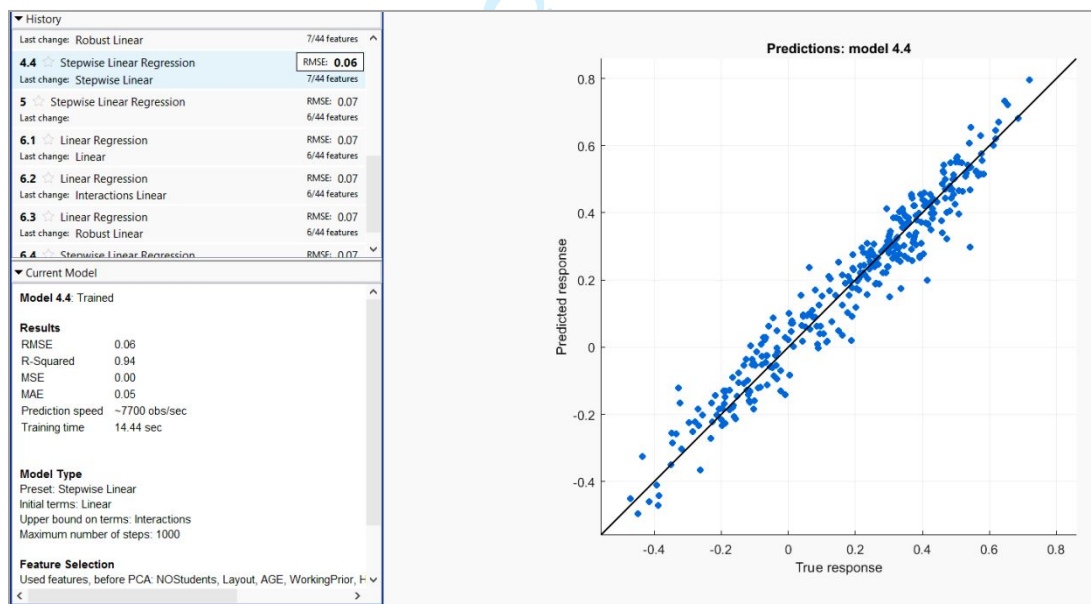


Figure 3: Relationship between indoor air quality and performance

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%.

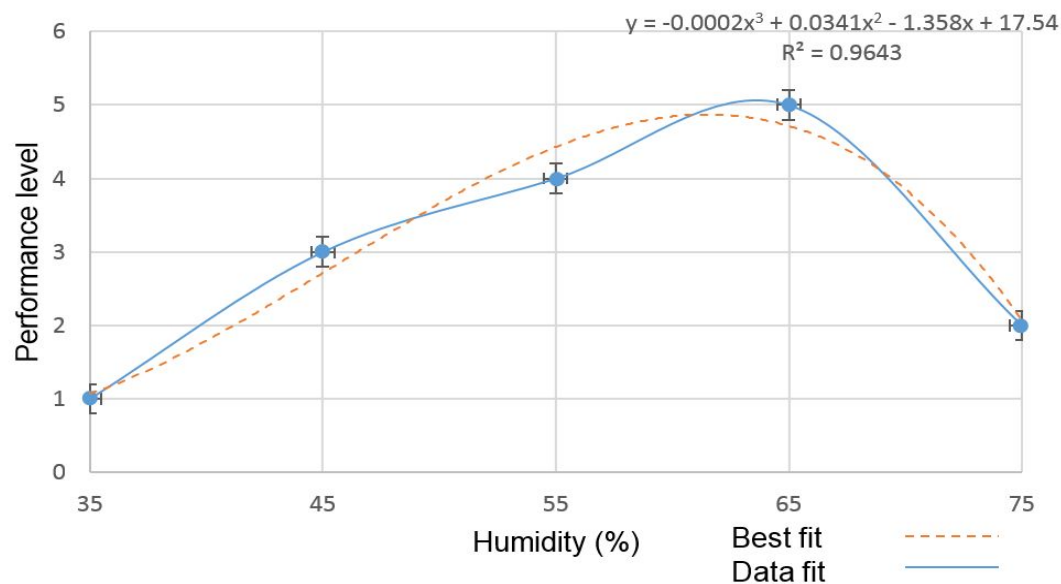


Figure 4: The relationship of humidity level with performance

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



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3 industry were most productive when relative humidity was 59.5%. Likewise, it was noted  
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5 that maximum performance linked to a relative humidity of approximately 60% (Sarbu and  
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7 Pacurar, 2015). Contrastingly, another study found increased relative humidity rate from  
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9 30% to 70% significantly augmented the complaints among employees and consequently  
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11 affected performance (Tsutsumi *et al.*, 2007).  
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### 14 15 Sensitivity Analysis: Ventilation Rate and Teacher Performance 16

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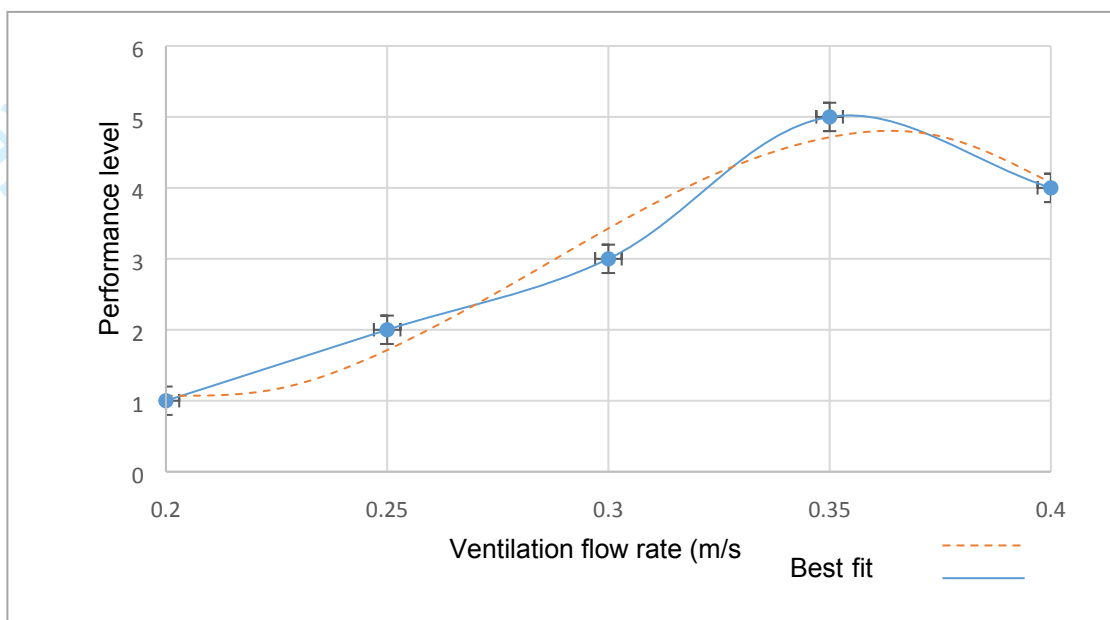


Figure 5: The relationship of ventilation rate with performance

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<sub>2</sub> concentration and Teacher Performance

Carbon dioxide concentration is the third parameter of IAQ, which considered the primary indicator of indoor air quality. CO<sub>2</sub> 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<sub>2</sub> concentration,  $R^2 = 0.9753$ . Performance was maximum when the air contained less than 650 ppm of CO<sub>2</sub> and fell gradually up to 1050 ppm. No difference in performance was detected when CO<sub>2</sub>

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<sub>2</sub> noted above.

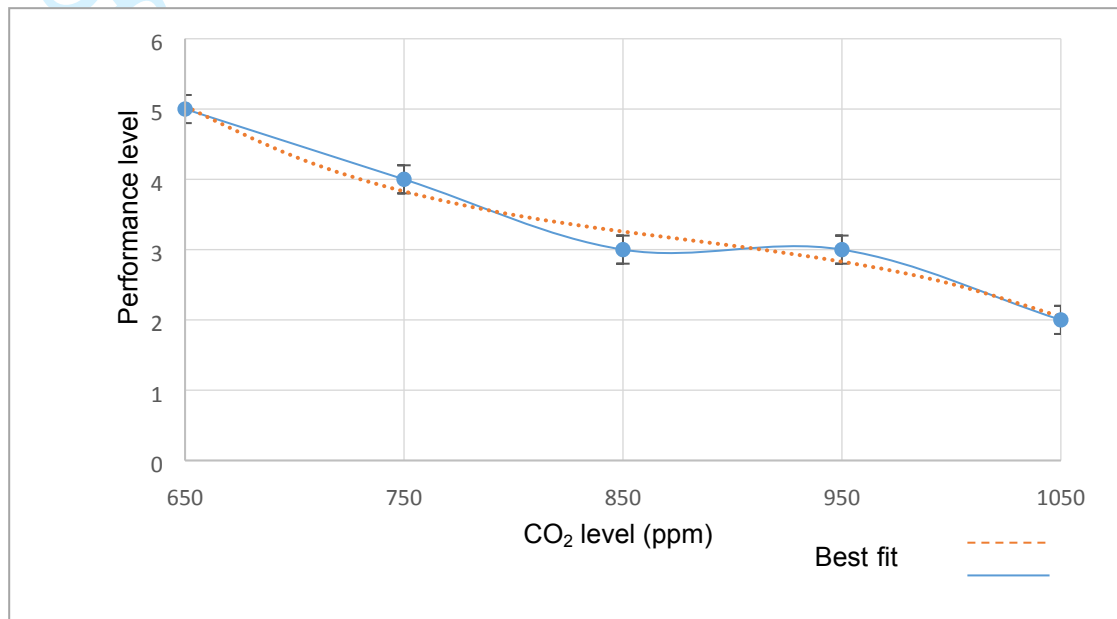


Figure 6: The relationship of CO<sub>2</sub> level with performance

The findings of this study indicate the relationship between CO<sub>2</sub> as an indicator of IAQ and performance, which is that performance improves when CO<sub>2</sub> concentration decreases; the optimal CO<sub>2</sub> 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<sub>2</sub>, the performance level was almost steady, and no significant decreases of less than 1%, even if CO<sub>2</sub> 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<sub>2</sub> concentrations above 1000 ppm are related to a 10-20% increase in absenteeism and recommend that reducing CO<sub>2</sub> 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 CO<sub>2</sub> 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<sub>0</sub>: 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<sub>2</sub> 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<sub>2</sub> level as an inverse indicator of ventilation rate and fresh air delivery to occupants. Higher levels of CO<sub>2</sub> and indoor air pollutants, caused by insufficient ventilation in classrooms, may

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2  
3 impair teaching processes and outcomes by losing attention and increasing tiredness.

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5 Conversely, higher ventilation rates indirectly improve performance and learning outcomes  
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7 because fresh air improves teachers' comfort and health, strengthening motivation to learn  
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9 and reduce absenteeism.

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13 Optimal levels for IAQ and performance for relative humidity range between 55% and  
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15 65%, with an optimum ventilation rate between 0.32m/s and 0.4m/s and an optimum level  
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17 of CO<sub>2</sub> between 600ppm and 700ppm. It proves the null hypothesis for the existing link  
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19 between indoor air quality and teacher performance.

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23 Generally, this study only focused on IAQ in mechanical system ventilated buildings, with  
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25 three measurement periods (autumn, winter and spring), within the context of Jeddah,  
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27 Saudi Arabia. Therefore, results may be assessed within these factors. Though similar  
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29 studies have been included in this study, it would be valuable to extend further case study  
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31 with different climatic areas and building types. It would not only advance data reliability  
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33 but would also be able to assess variables and their interventions. This study would also  
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35 help improve the design guidelines for the indoor environmental quality of office buildings  
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37 in the middle east.  
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42 Finally, this study was limited to teacher performance only and did not consider student  
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44 performance. However, as students typically represent a significant proportion of the  
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46 college population, it is recommended that additional work is undertaken to capture a  
47  
48 representative sample frame of this demographic to supplement these findings.  
49  
50 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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S.No.	Comment	Response
1	It would have been better to use newer methods such as deep learning instead of neural networks.	<p>Thank you for the comment. Deep learning is a newer method. We would take this comment on board in the following experiment. ANN is still an acceptable and solid method for predictive analysis. ANN is still being used, and below is a list of recent ANN publications:</p> <ol style="list-style-type: none"> <li>1) <a href="#">Alzahrani, H., Arif, M., Kaushik, A., Goulding, J. and Heesom, D. (2021), "Artificial neural network analysis of teachers' performance against thermal comfort", <i>International Journal of Building Pathology and Adaptation</i>, Vol. 39 No. 1, pp. 20-32. <a href="https://doi.org/10.1108/IJBPA-11-2019-0098">https://doi.org/10.1108/IJBPA-11-2019-0098</a></a></li> <li>2) Al Horr, Y., Arif, M., Kaushik, A., Tumula, P., Elsarrag, E. and Mazroei, A., 2017. APPLICATION OF ARTIFICIAL NEURAL NETWORK ANALYSIS IN DEFINING THE RELATIONSHIP BETWEEN INDOOR ENVIRONMENT QUALITY AND OCCUPANT PRODUCTIVITY. <i>WELCOME TO DELEGATES IRC 2017</i>, p.940</li> <li>3) Xu, A., Li, R., Chang, H., Xu, Y., Li, X., Lin, G. and Zhao, Y., 2022. Artificial neural network (ANN) modelling for the prediction of odour emission rates from landfill working surfaces. <i>Waste Management</i>, 138, pp.158-171</li> <li>4) Gheziel, A., Hanini, S. and Mohamedi, B., 2021. Artificial neural network (ANN) for prediction indoor airborne particle concentration. <i>International Journal of Ventilation</i>, pp.1-14.</li> </ol>
2	Of the best, taking students reactions of IAQ performance, not of the teachers only	Thank you for the comment. We focused on teachers' performance because there are plenty of studies on students, and comparatively, there are more minor studies on teachers' performance.
3	The research did not address the method of taking measurements in practice	Thank you for the comment. The context and data collection measurement are mentioned in the sub-section – Case study location and context



4	The abstract must be changed to journal form.	Thank you for the comment. We have updated the abstract and structure as per journal requirements.
5	need to unify references (author name, "paper name", Journal, vol., No., Pp., year)	Thank you for the comment. We have updated the references as per the Harvard system (as mentioned in the author guidelines)
6	Added table title above the table.	Thank you for the comment. We have updated the caption above the table.
8	Of the best, taking students' reactions to IAQ performance, not the teachers only.	Thank you for the comment. We focused on teachers' performance because there are plenty of studies on students, and comparatively, there are more minor studies on teachers' performance.
9	The research did not address the method of taking measurements in practice.	Thank you for the comment. The context and data collection measurement are mentioned in the sub-section – Case study location and context
10	there are a lot of newer IAQ papers(with deep learning)+_(IoT sensors).	Thank you for the comment. We have added the following studies on deep learning and IoT <ul style="list-style-type: none"> <li>• Heo, S., Nam, K., Loy-Benitez, J., Li, Q., Lee, S. and Yoo, C., 2019. A deep reinforcement learning-based autonomous ventilation control system for smart indoor air quality management in a subway station. <i>Energy and Buildings</i>, 202, p.109440.</li> <li>• Chen, Y., Tong, Z., Zheng, Y., Samuelson, H. and Norford, L., 2020. Transfer learning with deep neural networks for model predictive control of HVAC and natural ventilation in smart buildings. <i>Journal of Cleaner Production</i>, 254, p.119866.</li> </ul>
11	Need to add who to measure: Humidity, ventilation, Co2 level.	The first author set up the sensors on the site and used to maintain the set-up and collect data regularly.
12	Not verify the performance levels(1-6).	Thank you for the comment. The study used a Likert scale from 1 to 5. The figure shows 6, but there are no responses on 6.
13	Need to enlarge Figure	Thank you, we have enlarged figures.
14	And added the same Figure for each parameter, not temperature only	Thank you. We have added the external temperature of Jeddah to show the variation of weather across the year.

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