A Correlation Studies of Indoor Environmental Quality(IEQ) Towards Productive Workplace

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Abstract—**Productivity is one of the major contributions to build the economic growth in every country. Human performance and working environment is related to each other and have a major impact on the work efficiency and production output. Nowadays, most of the offices are fully equipped with** mechanical **ventilation and fully air-conditioned. Office building occupants spend almost 12 hours daily indoor and that makes good indoor environment very important due to achieve workers satisfaction and more comfortable. The objective of this paper is to observe the correlation of IEQ and productivity in working place. It is believed that this study have been able to provide a better understanding. It is hoped that this useful findings would serve as a reference in the future to the building industry, academicians and also public in sustaining better indoor environmental quality.**

Keywords- Building performance, Indoor Environmental Quality, Occupants' Satisfaction, Office Building

I. INTRODUCTION

People always talk and want to build cost effective building but at the same time neglected about how important indoor environmental quality in a building. In Malaysia research about indoor environmental quality in work place is restrictive compare to other country. Employees' performance and competence are very dependent on indoor environmental surrounding. Traditionally people spent more time outdoors than indoors but people in industrialized countries spend more than 90% of their lifetimes indoors [1]. Previous literature review investigate for instance in United State of America the total time staying indoors for an average working person is 23 hours and 15 minutes per day or 97.7% of his or her lifetime [1].

Unhealthy building can occur a lot of illnesses to the occupants. "Building-Related Illness" (BRI) or "Specific Building-Related Illness" (SBRI) has been defined as illness that the causal factor can be identified clinically [2]. The illnesses are usually characterized by a unique set of symptoms which may be accompanied by clinical signs, laboratory findings, and identifiable pollutants such as hypersensitivity pneumonitis, humidifier fever, asthma, and allergic rhinitis [2].

"Sick building syndrome" (SBS) is used to portray conditions of discomfort and severe health outcome symptoms [3] and the causal factor can't be identified. The usual symptoms are headache; loss of concentration; itchy, runny or stuffy nose; itching, watering or dry eyes; dry skin; lethargy; and dryness or irritation of the throat [4].

The objective of this paper is to explain the correlation between Indoor Environmental Quality (IEQ) and the productivity.

II. INDOOR ENVIRONMENTAL QUALITY (IEQ) AND PRODUCTIVITY

Concentration and alertness is vital for a good work performance but still there are personal and external factors that can disturb depending on the physical and mental health of an individual [8].

Generally productivity is all about speed and accuracy [8] of certain task but specifically it actually can be measured or subjectively estimated [12]. Personal, social, organizational and environment are the core elements that can affect the output efficiency in the office building [9]. Previous studies have reported somehow until now there is no standard procedure or system to determine productivity or performance measurement [9].

Thermal comfort, lighting quality, acoustical quality and air quality are the important factors of IEQ [5] [17]. Below are the short explanations of the four elements.

A. 1. Indoor Air Quality (IAQ)

IAQ is the major contribution factor in determine IEQ level. This is because there are several of pollutant gaseous (Table 1) concentrations which is the main office environment pollutants [18].

TABLE I. GASEOUS POLLUTANTS IN INDOOR AIR (EXCEPT VOC)

Pollutant	WHO concentration of concern	Source
Carbon Monoxide	5	Combustion products, tobacco smoke
Radon and daughters	79Bq/m3	Building materials
Formaldehyde	0.12	Furniture,fittings,insulation,paper
Ozone	0.08	Photocopiers,laser printers, ionisers
Carbon dioxide	12000	Occupants, smoking
Sulphur dioxide	1.35	External environment

Source : [18]

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Previous literature reviews scrutinize the quality of air may be defined in two approaches [16]:

- Qualitatively-describe by the individual response such as odor
- Quantitatively-determined by chemical or physical measurements

Other than gaseous pollutants, pollen and spore allergens, viable microbial allergens, pathogenic microbes, toxigenic microbes, volatile organic compounds (VOCs), mold volatile organic compounds and dust also can contribute to poor IAQ [19].

In addition other researchers found that temperature [12], outdoor air quality and room air ventilation as well effected to IAQ [16].

Poor IAQ can cause the building occupants experience health effects such as flu like symptoms, dermatitis, irritation, systemic toxicity, headache, fatigue, chest tightness [19] and etc that of course will slow down the efficiency and productivity of the workers. Additionally previous studies proved that productivity loss 6-10 percent in SBS buildings [7] [12] due to unhealthy IAQ.

B. Thermal comfort

Thermal comfort can be described according to air temperature, air velocity, relative humidity [17] and can be express by building user perception [18] whether they want it to be cooler or warmer to be comfortable [5]. Human factor also contribute to achieve comfortable environment such as clothing and activity [5].

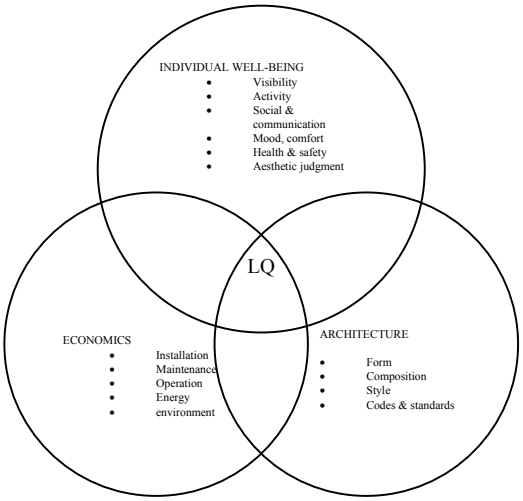
Many researchers has accepted that a high percentage of people are comfortable in sedentary (office) occupations, where the effective draught temperature is between -1.5 and +1K and the air velocity is less than 0.35m/s [18].

Staffs that are not comfortable will take more breaks and loss of concentration in doing their task. Previous study claims was as much as 30 percent of sick leave due to SBS can be reduced if the workers could control their own thermal environment [7].

C. Lighting Quality

Light can influenced building occupants' comfort level in several ways [2] through vision [18] and it's really important towards the productivity. Poor quality in lighting can cause fatigue, drowsy, nausea, eye irritation etc. Poor lighting can be because of excessive lighting or inadequate of lights [2].

Figure 1 shows the integration of individual well-being, architecture and economics [10]



Source : [10]

Figure 1. Lighting quality (LQ): the integration of individual well-being, architecture and economics

Previous literature review [10] provides summarized simple principles for suitable lighting conditions in office buildings.

TABLE II. LIGHTING PRINCIPLES FOR PRODUCTIVE WORKPLACE, BASED ON OFFICE RESEARCH

Mediating process	Guidelines/Principles
Visibility	• appropriate horizontal vertical illuminances for tasks and viewers • control unwanted light (glare), both direct and reflected • use high-frequency ballasts for fluorescent lights
Activation	• investigate light exposure schedules for aiding night-shift workers • enable increased light exposure for some part of the day • avoid creating stressors : direct glare, excessive luminance contrast • use high-frequency ballasts for fluorescent lights
Meaning	• learn end-users' expectations beliefs about lighting • design to allow users' preferred range of illuminances (in offices, average between 300 and 500 horizontal illuminance) • keep vertical surfaces bright, above 30cd/m^2(200lx vertical) • provide individual controls • keep controls simple and responsive • maximise access to daylighting and windows, but protect against thermal and glare problems • create interest by integrating luminance variability with architecture • use lighting designs with both direct and indirect

Source : [10]

D. Acoustical Quality

Noise and vibration is in a wave motion [5][18] that can be annoyed in terms of psychological and can come from outdoor, engineering services [18] or from person to person itself.

Noise pollution can create stressful feeling and health effect such as dizziness.

III. METHODOLOGY

The fundamental of this study is to show the correlation between IEQ and productivity in workplace. A literature search was embarking upon articles, books and journals discussing on how IAQ, thermal comfort, noise pollution and lighting quality related to each other.

IEQ, IAQ, productivity, SBS, BRI and relevant articles were searched electronically in major databases: Google Scholar, Science Direct, Emerald and in Building and Environments conferences.

IV. FINDINGS & ANALYSIS

Five case studies have been concluded as a table below:-

Case study	Building type	Objective of study	Procedure	Results	Remarks/Comments
[11]	6 residents, 6 offices & 6 restaurants	1)To provide quantitative information on the levels of potentially important pollutants 2)to compare indoor and ambient pollutants levels 3)to investigate the extent to which certain indoor pollution sources influence the quality of IAQ	Ambient air samples were collected	As a result, the author found that VOCs level were more variables in offices than in the restaurants and residential building. The relationship of Environmental Tobacco Smoke (ETS) and indoor VOC levels were not strongly correlated to each other. But a very strong correlation was found between indoor and outdoor levels of vehicle related pollutants.	The relationship was based on the summary of statistics for indoor & outdoor concentration. So smoking is not a major factor in determining VOC or CO levels in the indoor environment.
[13]	2 offices	1)to investigate the connection between SBS and indoor air pollutants between old and new building	Measurement of IAQ and questionnaires were performed	As a result ventilation rate was higher in new building (21.1cfm/person) compare to an old building (18.6cfm/person). But in terms of indoor air pollutant (IAP), an old building has a higher reading for CO2, CO, TVOC, PM10, and PM2.5 while new building showed higher concentration of Ultrafine Particle (UP) and Temperature Humidity Index (THI) value. CO2 is approximately correlated with other indoor pollutants. Temperature and humidity have a direct and strong correlation factors that can influenced SBS.	SBS can be detected from the level of CO2 and THI value. Even though the results of CO2 and THI were higher in both buildings but it were still under benchmark of Malaysia Indoor Air Quality Code of Practice (IAQ-COP)
[14]	1 office	1)to determine occupants' satisfaction and perception level in their office buildings; in terms of indoor environment i.e. thermal comfort, air movement, visual comfort, noise pollution and cleanliness 2)to suggest and recommend ways to improve office indoor environment	Questionnaires	As a result from the findings, building cleanliness and noise pollution were in comfort level. On the other hand there were sign indicated uncomfortable in terms of cooling system (73%), natural day lighting (53%), air movement (40%) and also quality of indoor ventilation (47%). Visual comfort, indoor air movement and ventilation have a direct correlation with occupants' comfortability.47% out of total respondents indicated that their work productivity is decreased due to poor indoor environment	Maintenance of heating, ventilation and air-conditioning (HVAC) in an office building is a must to keep and sustain good IAQ. So can be concluded that IAQ have a direct correlation with productivity.
[17]	1 hospital (operating room)	1)to do assessment on indoor conditions	Questionnaires	The highest reporting rates were headache (31%), exhaustion (30.3%), dry skin, dry throat and dry eyes. Overall men suffer an average of 1.68 symptoms per person, which is significantly lower than the 2.70 symptoms for women. Noise levels were reported high by resulting noise complaints range from simple annoyance (26%) to headaches (32%) and more serious problems like concentration (25%).	Genders factor give an impact to determine whether the IEQ is good or poor.

[31] [32]	Office building	1)to assess the effect of perceived indoor air quality on productivity loss	Measurement of IAQ, questionnaires and simulation were performed. Text-typing, proof-reading and addition were used (typical office tasks). Firstly, pollution load have been decreased or secondly, increased the outdoor air supply rate while the pollution load was constant.	As a result the researcher stated that a direct and positive correlation was found between the acceptability of air quality and productivity. Perceived air quality, pollution load and ventilation efficiency impact have been touched in this study to prove that IAQ affected working performance. From the simulation the author also verify that production loss due in thinking is more severe than productivity loss in typing. So the conclusion is the usage of minimum-airflow-rate design principles affects 5-13% on productivity.	Poor IAQ have a direct correlation to productivity loss.

V. DISSCUSSION

There is a large volume of published studies describing that poor IEQ can easily be affected on the productivity in a workplace. Based on the outcome of the present survey, good maintenance of HVAC system can enhance the quality of indoor air. Outdoor air has continuity with indoor air in term of levels of vehicle related pollutants that can get in through opening doors or windows.

Present surveys prove IAQ play an important role and has a strong and direct correlation with work efficiency output. Earlier scientific studies indicate that 15% of work performance can be increased when the building occupants are comfortable with their environment [9]. This statement is strongly supported by other studies that also mentioned productivity can be improve by decreasing emissions, outdoor airflow rate and ventilation effectiveness [31].

Poor quality of indoor air will affect individual wellbeing that can make workers take a long break, increase sick leave, increase complaints, risk of accidents at a work place and increase in mistakes. Previous literature review documented that productivity can drop from 2 to 100 percent in SBS buildings and the evidence by one building in Washington DC has been shut down to investigate the indoor pollutant [12].

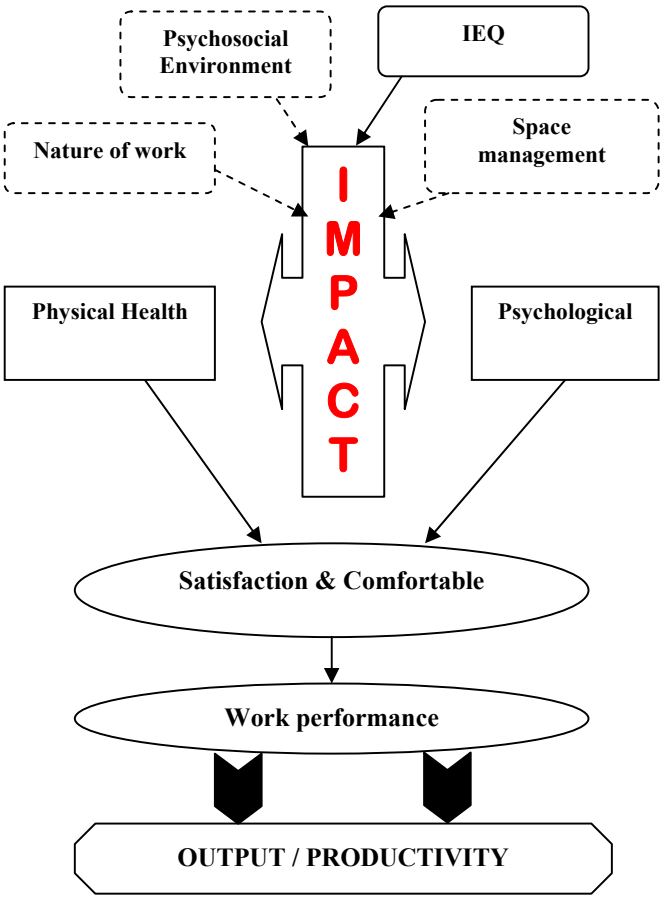
Poor IEQ will not only affected physical health of the building occupants but also psychological health. Workers will be more stressful if their feel uncomfortable with the atmosphere and environment in the office despite of the nature of work itself.

In order to determine thermal comfort level in workplace, individual factor such as gender, activity before they enter the building and age are the important roles that will contribute to environment satisfaction.

Present surveys show acoustic and lighting stand in the lowest ranking of IEQ parameters, compare to IAQ and thermal comfort. This is because less complaint were made regarding these two elements.

VI. CONCLUSION

Relationship of work performance or well known as productivity with indoor environment can be concluded in the diagram below:-



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