# Analysis of the Indoor Environmental Quality's Impacts on Human Performance

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***Abstract*—Indoor Environmental Quality (IEQ) has been known for decades to has strong influence towards productivity. A poor IEQ will bring negative impact on workforce health. However, until now IEQ factors have not been taken into consideration by office management or building contractor. Especially in Indonesia, attention is only put to selling price, size, location, and facilities. Hence, this research aims to discover the effect of IEQ (thermal, lighting, and colour layout) on human performance and discover the optimal combinations of those. This research found out that those factors have significant impact on human performance and discovered that temperature of 23.5 ℃, lighting of 500 lux and blue colour as the layout is the optimal combination. The increase of office management and interior designers' awareness to consider IEQ factors in designing a productive workplace environment is expected in regards to this result.**

***Index Terms*—colour layout; human performance; indoor environmental quality, lighting; thermal comfort**

## I. Introduction

One of the basic human needs at work is a working environment that enable employee to work optimally and supported with comfortable conditions [1]. Performance of an employee can be increased by more than 10% with the quality improvement of their office environment [2]. Developments in IEQ can increase productivity between 0.5% to 5% (e.g. [3], [4]). Instead, if not good enough, it can decrease productivity, cause illness and reduces users' wellbeing (e.g. [5]-[7], [4], [8], [9]).

Estimated increase in productivity itself is usually considered through changes in performance related to the overall productivity and is usually in the form of direct actions such as speed and time needed to complete a task [10]. The calculation of the productivity becomes an important component in the explanation of the relationship between IEQ and productivity. Performance is often used as a reflection of productivity where accuracy and speed as the most common parameters used [2].

In research on the effect of air temperature in the room, discomfort caused by too high or too low temperature have a bad influence for employee's productivity. Thermal discomfort increases workload, make employees work harder to maintain performance, and lower their motivation [2].

Besides room temperature, IEQ factors that often considered is lighting. One of the key factors to determine employee productivity is the aspect of quantitative and qualitative of the room lighting, so the speed and quality of the job completion is affected by the lighting conditions (e.g. [11]-[13]). Another IEQ factor to consider is the room colour. Previous studies found that room colour has a significant effect on psychomotor activity and a person's emotional state [14].

Theories regarding IEQ importance has been studied and are already widespread, but the fact apparently not in line with the theory. During this time, office design only considering the sale value, location, size, and facilities without considering the factors previously described [15].

Previous studies have concluded that IEQ factors, especially room temperature, lighting, and room colour have an influence on people. Employees is always associated with the office as a place they spend the most time to work. The study aims to optimize these factors so employee can improve its performance which resulted in increased productivity and profit for the company. While studies prove these factors individually have an effect on humans, this research is intended to study the interactions and optimal condition between the three factors.

## II. Literature Review

Performance is often associated with achievement of results and always related to standards, objectives, and expectations. There are six factors that can affect performance: Data and information; resources, tools, environment support; consequences, incentives and rewards; individual abilities; and motives [16]. Each objective of the performance should be adjusted according to some standards. Two common standard is quality and quantity. Human performance is the completion of the work performed by a human operator or a team. Job can be in different level from simple to complex one. Whether do the work manually or monitor the automated system, human performance can be measured [17]. In general, it can be measured by speed or time, accuracy or error, workload or demand capacity, and preference. Measurement selection of these four categories must be adapted to the type of work to be measured and its environment [18].

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Work with the needs of high precision requires a high level of lighting, but too high lighting can cause glare from the work object, place where the work took place, or lighting source itself. But if the lighting level is too low, employees cannot see clearly enough to meet the requirements of work and to avoid error. Therefore, it is necessary to ensure that the light falling on the working surface (illuminance) should be sufficient and the light received by the eyes of the workers (luminance) is not excessive. This requirement also depends on the reflection of the work area and various types of materials used in the working surface, such as walls, ceilings, equipment, flooring furniture, clothing, and others [19].

Thermal Comfort has been a debate among employees who worked at the same place and eventually become a serious conflict between them. One of the reasons is a different combination of several variables that have a different effect on each employee [19].

Colour can affect human behavior in ways that can be measured [20]. According to [21], almost all workers spend time in front of a computer every day, look at the bright colours on the screen continuously create the need for smoother colours and soft that produces quieter environment. So the purpose of the selection of colour schemes is to get better quality of the job. If the colours do not match, workers can get negative influences such as stress, depression, and boredom [22].

## III. Method

This Research using Design of Experiments (DOE) with 3 factors and each factor has 2 levels of factors, therefore factorial design of 23 is used which will produce 8 treatment combined with 18 replications. Details on the factors and standard factors used were as follows:

- Room temperature factor has two levels: the level of 23,5$^{o}$C and 27,5$^{o}$C. 23,5$^{o}$C temperature selection is based on [26] mentioning 23,5$^{o}$C as the neutral temperature, proofing that participants gave better results than the higher temperatures in the research, which is 29,5$^{o}$C. While the selection of 27,5$^{o}$C temperature taken from The Minister of Manpower and Transmigration Republic of Indonesia.
- Room light factor has two levels: the level of 300 lux and 500 lux. Setting lighting to 300 lux and 500 lux is based on a review of literature that shows good lighting levels for an office job or in the room is 300 lux and 500 lux (e.g. [23]-[25]).
- Room colour factor had two levels: the level of green and blue. The colour selection is based on previous research saying that cool colour cause workers make fewer mistakes than the warm or neutral colours.

This study has a dependent factor that will be affected by the above three factors, that is human performance. Human performance measurement used a measuring instrument of verbal ability and numerical ability tests with accuracy or the numbers of correct answers and the speed of test execution as parameters. Verbal ability tests consists of 25 questions containing a set of problems of seeking synonym words, antonyms words, the analogy of the word, group of words, and comprehension of discourse. Numerical ability tests consist of 20 questions consisting type of sequence of numbers, basic math and word problems.

Besides through human performance, this study also measured subjectively the respondent's perspective. Subjective measurements include measuring the level of comfort and satisfaction of the respondents as well as performance of each condition. Comfort and satisfaction of respondents were measured using a questionnaire modified from Indoor Background Survey Question.

TABLE I. Design of Experiment's Combination

| Combination | Temperature (°C) | Lighting (Lux) | Room Colour | Exam Type |
|---|---|---|---|---|
| 1 | 23,5 | 500 | Green | A |
| 2 | 23,5 | 300 | Green | B |
| 3 | 27,5 | 300 | Green | C |
| 4 | 27,5 | 500 | Green | D |
| 5 | 23,5 | 500 | Blue | E |
| 6 | 23,5 | 300 | Blue | F |
| 7 | 27,5 | 500 | Blue | G |
| 8 | 27,5 | 300 | Blue | H |

## IV. Result

ANOVA processing of verbal accuracy showed that the three factors have significant effect on the accuracy of verbal matter. This is due to three factors has a value smaller than the α (0.05). The temperature factor (P value 0.000), light factor (P value of 0.042), and room colour factor (P value of 0.000). As for the interaction between the factors there are no significant effect on the accuracy of verbal matter, it has a P value greater than α (0.05). Optimal combination to get the right amount or maximum average accuracy in 18.33 is with a temperature of 23.5 ℃, 500 lux of lighting, and room colour of blue. Equation of prediction model for verbal accuracy is as follows:

Accuracy = 15,3472 + 1,6389 x temperature - 0,4444 x lighting - 1,0972 x room colour - 0,1250 x temperature x lighting + 0,3889 x temperature x room colour - 0,0556 x lighting x room colour + 0,1250 x temperature x lighting x room colour. The R2 value for verbal accuracy is about 0.4015.

ANOVA processing of numeric accuracy showed that three factors have significant effect on the accuracy of numeric matter. This is due to three factors has a value smaller than α (0.05). The temperature factor (P value of 0.000), a light factor (P value of 0.042), and room colour factor (P value of 0.000). For the interaction between the factors there are no significant effect on the accuracy of numeric matter, it has a P value greater than α (0.05). Optimal combination to get the right amount or maximum average in 18.28 is with a temperature of 23.5 ℃, 500 lux of lighting, and blue colour room. Equation of prediction models for numeric accuracy is as follows:

Accuracy = 15,3056 + 1,6528 x temperature - 0,4167 x lighting - 1,0694 x room colour - 0,1528 x temperature x lighting + 0,3611 x temperature x room colour - 0,0972 x lighting x room colour + 0,1389 x temperature x lighting x room colour. The R2 value for verbal accuracy is about 0.4295

ANOVA processing showed that the three factors have significant effect on the processing time of verbal matter. This is due to three factors has a value smaller than α (0.05). The temperature factor has a P value of 0.002, a light factor has a P value of 0.000, and room colour factor has a P value of 0.029. As for the interaction between the factors there is only a significant effect on the processing time is a matter of verbal interaction between temperature and light because it has a P value smaller than α (0.05) that is 0,000. The rest did not significantly influence verbal matter processing time because P value is greater than α (0.05). Optimal combination to obtain an average processing time of verbal maximum of 18.67 is at a temperature of 23.5 ℃, 500 lux of lighting, and the room colour of blue. Equation of prediction models for verbal processing time is as follows:

Processing Time = 21,3971 - 1,0058 x temperature + 1,7911 x lighting + 0,7178 x room colour - 1,1969 x temperature x lighting + 0,0724 x temperature x room colour - 0,1858 x lighting x room colour - 0,1495 x temperature x lighting x room colour. The R2 value for verbal processing time is about 0.3022.

Processing ANOVA of the processing time in numeric matter showed that three factors have significant effect on the processing time of verbal matter. This is due to three factors has a value smaller than α (0.05). The temperature factor has a P value of 0.029, a light factor has a P value of 0.003, and room colour factor has a P value of 0.045. As for the interaction between the factors no significant effect on the accuracy of numeric matter because P value is greater than α (0.05). Optimal combination to obtain an average processing time about verbal maximum of 51.58 is at a temperature of 27.5 ℃, 500 lux of lighting, and the room colour of blue. Equation of prediction models for verbal processing time is as follows:

Processing Time = 59,519 + 2,679 x temperature + 3,649 x lighting + 2,454 x room colour + 0,296 x temperature x lighting - 0,559 x temperature x room colour - 0,103 x lighting x room colour – 1,212 x temperature x lighting x room colour. The R2 for numeric processing time is about 0.1242

TABLE II. SUMMARY OF RESPONDENT'S SATISFACTION

| Combination | Answer | | | | | | Total Value |
|---|---|---|---|---|---|---|---|
| | VuS (1) | Us (2) | SuS (3) | SS (4) | S (5) | VS (6) | |
| 5 | 0 | 0 | 0 | 5 | 8 | 5 | 90 |
| 1 | 1 | 0 | 1 | 3 | 10 | 3 | 84 |
| 4 | 0 | 0 | 3 | 5 | 8 | 2 | 81 |
| 2 | 0 | 1 | 2 | 5 | 9 | 1 | 79 |
| 6 | 0 | 0 | 4 | 5 | 7 | 2 | 79 |
| 7 | 0 | 1 | 3 | 6 | 7 | 1 | 76 |
| 8 | 0 | 1 | 5 | 9 | 2 | 1 | 69 |
| 3 | 0 | 2 | 6 | 5 | 5 | 0 | 67 |

TABLE III. SUMMARY OF RESPONDENT'S COMFORT

| Combination | Answer | | | | | | Total Value |
|---|---|---|---|---|---|---|---|
| | VuC (1) | uC (2) | SuC (3) | SC (4) | C (5) | VC (6) | |
| 5 | 0 | 0 | 0 | 6 | 8 | 4 | 88 |
| 1 | 1 | 0 | 1 | 4 | 10 | 2 | 82 |
| 2 | 0 | 1 | 3 | 4 | 9 | 1 | 78 |
| 6 | 0 | 0 | 4 | 6 | 6 | 2 | 78 |
| 4 | 0 | 2 | 3 | 6 | 6 | 1 | 73 |
| 7 | 0 | 2 | 2 | 8 | 5 | 1 | 73 |
| 8 | 0 | 3 | 4 | 6 | 4 | 1 | 68 |
| 3 | 0 | 4 | 4 | 5 | 4 | 1 | 66 |

Referred to Table II above, the highest weight value of comfort is in combination 5 with temperature of 23.5 ℃, 500 lux lighting, and blue colour room. While the combination with the lowest weight value is combination 3 with temperature of 27.5 ℃, 300 lux light, and green colour room.

Processing Time = 21,3971 - 1,0058 x temperature + 1,7911 x lighting + 0,7178 x room colour - 1,1969 x temperature x lighting + 0,0724 x temperature x room colour - 0,1858 x lighting x room colour - 0,1495 x temperature x lighting x room colour. The R2 value for verbal processing time is about 0.3022.

## V. Discussion

Confirming previous research, thermal factor has significant effect on human performance. Regardless the thermal level variation, those researches have shown the effect of room temperature on human performance. Also, this confirmed that lighting as well as room colour has significant impact on human performance. The results of work environment satisfaction questionnaire are divided into four parts, that are temperature, lighting, room colour, and overall condition. Each factors is covered with two predetermined level and the overall condition is discussed with each combination of existing situation.

The first is room temperature factor. Most respondents are more satisfied with the temperature of 23.5℃ compared to room temperature of 27.5$^{o}$C. It was derived from satisfaction responses; "Very Satisfied", "Satisfied", and "Little Satisfied" at room temperature of 23.5$^{o}$C with 65 responses which outweigh room temperature of 27.5$^{o}$C with 41 responses. Accordingly, dissatisfaction statement of "Extremely Dissatisfied", "Not Satisfied", and "Slightly Not Satisfied" got more responses at room temperature of 27.5$^{o}$C with 31 responses compared to 23.5$^{o}$C with 7 responses.

The second factor is lighting. Respondents in general are more satisfied with the lighting level of 500 lux compared with the lighting level of 300 lux. It was derived from satisfaction responses; "Very Satisfied", "Satisfied", and "Little Satisfied" of 500 lux with 58 responses which outweigh 300 lux with 46 responses. Accordingly, the dissatisfaction statement; "Extremely Dissatisfied", "Not Satisfied", and "Slightly Not Satisfied" got more responses in lighting level of 300 lux with 26 responses compared to of 500 lux with only 14 responses of "Slightly Not Satisfied".

The last factor is the room colour. Most respondents are more satisfied with the blue colour room than the green colour room. Based on satisfaction responses of "Very Satisfied", "Satisfied", and "Little Satisfied" blue colour got more responses with 69 compared to the green colour with 54. Accordingly, dissatisfaction responses as "Extremely Dissatisfied", "Not Satisfied", and "Slightly Not Satisfied" for green colour got more responses with 18 compared to blue colour with only 3 responses of "Slightly Not Satisfied".

Taking everything into account, most satisfied respondents fell on combination 5 due to respondents' responses that all fell on "Very Satisfied", "Satisfied", and "Little Satisfied" without any response of "Extremely Dissatisfied" "Not Satisfied", and "Slightly Not Satisfied". Basis weight value that has previously shown in Table III shows that the highest weight value is in combination 5 with weight value of 90. This has a combination of room temperature 23.5 $^{o}$C, 500 lux lighting and blue colour room. This combination confirmed satisfaction results of respondents in each factor.

In contrast to the overall conditions, respondents are not satisfied on combination 3 because most response indicates dissatisfaction of "Slightly Not Satisfied" and "Not Satisfied" compared to other 8 responses. Of basis weight value has previously shown in chapter Table III, it appears that the lowest weight value is 67, which fell on combination 3. This combination has a combination of room temperature 27.5 $^{o}$C, 300 lux lighting and green colour room. This combination confirmed the satisfaction results of respondents in each factor.

Ordering combination based on weight value of respondent satisfaction shows a pattern that respondents are strongly influenced by light and temperature. This was shown by three combinations with the highest value, all have the same lighting level of 500 lux but with different room temperature and colours. It can be concluded that respondents' satisfaction subjectively triggered by the lighting conditions of the room. While three combinations with the lowest value have the same room temperature that is 27.5 $^{o}$C, but differ in lighting and room colours. It can be concluded that respondents' dissatisfaction subjectively triggered by room temperature.

Room colour that did not seems affect respondents' subjective satisfaction was presumed to be caused by short experimental time frame, that is 80 minutes. Working time in both numerical and verbal problems are quite short that caused respondents to dedicate most time to answer question and less time to observe the surrounding environment, includes room colour. Room colour factor is perceived to be more subtle compared to room temperature and lighting that was directly felt by the respondents. Nonetheless, room colour remains a proven effect due to similar weight of highest and lowest values to the preferences of respondents in each factor. The results of the comfort working environment questionnaire can be divided into four parts, namely temperature, lighting, room colour, and overall condition. Each covered with two factors predetermined level and the overall condition is discussed with each combination of the existing situation.

The first factor is room temperature. Most respondents found that temperature of 23.5$^{o}$C is cold for a total of 70 responses, while temperature of 27.5oC was hot for a total of 46 responses. Cold response itself is divided into "A Little Cold", "Cold", and "Very Cold", while hot response divided into "Less Hot", "Hot", and "Very Hot".

The second factor is lighting. A total of 63 respondents found that 500 lux of lighting is light, whereas for the 300 lux of lighting respondents almost evenly split between light and dim with the distribution of the 42 and 30 responses respectively. Response light itself is divided into "A Little Light", "Light", and "Very Light", while dim divided into "Little Dim", "Dim", and "Very Dim".

The last factor is the room colour. Most responses expressed comfort, that consists of "Very Comfortable", "Comfortable", and "A Little Comfortable" in the blue colour with 68 responses compared to green with only 55 responses. In contrast, expression of discomfort that consists of "Not Comfortable" and "Slightly Not Comfortable" dominates the green colour with 17 responses compared to the blue colour with just 4 responses.

After viewing each of the factors, then we will see comfortable preference of respondents to the overall

condition of the combination. Respondents seem comfortable on combinations 5 because all responses to combination 5 are all referring to "Very Comfortable", "Comfortable", and "A Little Comfortable" and there was no response of inconvenience from "Very Not Comfortable", "Not Comfortable", and "Slightly Not Comfortable". Of basis weight value has previously shown in table 3, it appears that the weight of the highest value is in combination 5 with weight value of 88. This combination has a combination of room temperature 23.5$^{o}$C, 500 lux lighting and blue colour room. When viewed from this combination, it can be concluded that the respondent was comfortable with the room temperature conditions which they consider cold and lighting conditions that they consider light, while for the room colour had been appropriate when respondents were asked to rate the room colour factor alone.

In contrast to the overall conditions, respondents are not satisfied on a combination 3 because it has a response that indicates dissatisfaction that the statement "Slightly Not Comfortable" and "Not Comfortable" at most compared to others as many as 8 answers. Of basis weight value has previously shown in Table III, it appears that the weight of the lowest value is in combination 3 with the weight value 66. This combination has a combination of room temperature 27.5$^{o}$C, 300 lux lighting and green colour room. When viewed from this combination means that respondents are not comfortable with the room temperature conditions which they consider heat and lighting conditions that they consider dim lighting, while for the room colour had been appropriate when respondents were asked to rate the room colour factor alone.

Ordering combination base on weight value of respondent comforts shows a pattern that is the comfort of the respondents were first determined by the room temperature and the room temperature they deem convenient is that they think is cool. This is because the four highest-ranked in the sorting combination is a combination of room temperature 23.5$^{o}$C. Then is that makes them comfortable is the lighting and lighting that they deem convenient is that they think is light. This is because the second highest rank in the sorting combination is the combination with 300 lux of lighting. For the colour of the room that did not make a specific pattern can be caused by the same thing on the satisfaction questionnaire respondents.

A p value less than 0.05 which indicates that the dependent factors significantly influence the independent factor, but in this study the p values obtained some still approaching 0.05, which indicates that the influence of these factors are not absolute, still there is the influence of individual preferences respondents to the existing factors. It can also be seen from the values of R2 which is still far from 1.

The results are not too good on this study due to the time and place have not been fully qualified as a condition of the office. The artificial office cannot fully represent the atmosphere of the office and less conducive to maintain the state of the factors corresponding to the desired conditions. Also limited time of only 1 hour does not represent the usual office hours of 8 hours per day. These things in particular should be considered for future research.

Analysis of IEQ impacts to human performance and analysis of questionnaires, satisfaction and comfort to the working environment basically gives the same result for the best possible condition, that is combination 5 with temperature of 23.5 ℃, lighting of 500 lux, and the blue colour room except in the numerical processing time at a temperature optimum conditions 27.5 ℃, 500 lux of lighting, and the blue colour room. The results are likely to be similar between the experiment results and subjective ratings or between qualitative and quantitative ratings. This proves that if the respondents were satisfied and comfortable with IEQ in the workplace, it will increase their human performance as well.

## VI. Conclusion

As mentioned previously, this journal is aimed to discover two outcomes, which are to discover the effect of IEQ (thermal, lighting, and colour layout) on human performance and discover the optimal combinations of those three factors. The human performance parameters used in this experiment are accuracy and duration, which are calculated using verbal question and numerical question.

The three factors that are analysed in this research, which are temperature, lighting and room colour; has been discovered to have significant impact on human performance, measuring accuracy and speed using verbal and numerical questions. However, the interaction between each factor, has not been proven to have significant effect on human performance. The optimal combination for verbal and numerical accuracy, as well as for verbal and speed is at temperature 23.5 ℃, lighting 500 lux and room colour blue. Meanwhile, the optimal combination for numerical speed is temperature 27.5 ℃, lighting 500 lux, and room colour blue.

The optimal combination is also parallel with result of subjective measurement which is through the satisfaction level and comfort level of the respondent. Respondent feel the most satisfied and comfortable at room condition (temperature 23.5 ℃, lighting 500 lux and room coloured blue). Respondent is unsatisfied and uncomfort at the temperature 27.5 ℃. This result is suspected to be reason, explaining the result of numerical speed. We are assuming that respondents feel not unease at the temperature 27.5 ℃, leading them to finish their task quickly ignoring the accuracy or the outcome the test given.

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