Measuring the Impact of Indoor Environmental Quality Data on Perceived Comfort

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1. Introduction

IoT (internet of things) devices have become integrated into our everyday lives from smartwatches monitoring our health to voice controlled power outlets turning on our appliances. The integration of sensors into mundane objects allows for people to be informed of their surroundings and themselves in ways that would not be possible for them to be fully aware of otherwise. Many studies dealing with this topic have focused on how to better present the information rather than whether the information should be presented at all. The placebo effect, which is most often associated with positive medical effects despite no actual treatment, could also be taking affect in a negative way when it comes to informing occupants of room conditions. There is a known negative correlation between increased levels of CO_2 and cognitive performance (Scully et al., 2019), but humans are not typically able to perceive these changes (Zhong, 2022). Therefore, it is still important that factors such as these should be monitored, but it is still a question as to whether humans need to be informed of it. When making decisions about their level of comfort in the space, occupants could potentially be influenced by the information of room conditions such as light levels, temperature, and gases present . Values that are outside of an occupant's understanding of acceptable ranges or a lack of knowledge of what is the acceptable range could cause a placebo effect on their perceived comfort.

1.1 Background

The placebo effect is a well-established phenomenon that occurs when people experience benefits from an intervention even though the intervention does not have any true effect (Beecher, 1955). This effect has long been studied in medicine revealing that the power of suggestion in control trials has resulted in patients seeing improvements (Beecher, 1955). Placebos have also been studied in the field of human computer interaction by showing improved performance and/or mood based on interactions with dummy computer applications (Fogg, 2002; Kosch et al., 2023; Villa et al., 2023). Villa et al. (2023) found that the belief in the effectiveness of human augmentation technologies succeeded in changing behaviors. In this study, participants were told that a device would emit an inaudible sound that would improve their visual processing allowing them to better select “winning” cards. As a result, participants displayed increased risk taking demonstrating that the placebo technology influenced them to partake in behaviors and make decision that they might not do normally (Villa et al., 2023).

Additionally, as IoT devices controlling aspects of our environment become more prevalent in people’s homes and lives, focus has turned to how to better display data and keep humans in the loop (Tomat et al., 2020). The idea of Crowdsensing is based on the assumption that humans are always correct in their comfort evaluations since their opinion is the only thing that matters when determining their own comfort (Tomat et al., 2020). Crowdsensing utilizes IoT and the opinions of occupants to converge on environmental conditions that best suit everyone (Tomat et al., 2020). While individuals are the best evaluators of their own comfort, what we know about placebo effects suggests the possibility that individuals could undergo false experiences based on the power of suggestion.

With the prevalence of IoT, there is also the threat of information overload. Though there is still debate on what constitutes overload and whether it is truly possible, it is supported by evidence and theories from multiple fields (Bawden et al., 1999; Gobet et al., 2001; Jacoby, 1984). Fan and Smith (2021) found that people who perceived an overload of information on COVID-19 also experienced negative wellbeing. The overload of information available to people with the internet and social media has been shown to have negative effects on mental states and wellbeing. Too much information about data relating to health such as COVID-19 or indoor air quality (IAQ) can cause people to panic and develop negative effects on their lives (Fan & Smith, 2021).

With the emergence of COVID-19 and concerns over climate disruption, there has also been an increased interest in indoor air quality. Concerns over sick building syndrome, poor air quality, and pollutants has led to an increase of sensors to monitor these types of data and therefore more information has become available to people but often not with the necessary knowledge to interpret that data. An increase in data that is not familiar to the average person has the high risk of being interpreted incorrectly and overwhelming the interpreter. This combination of information overload and not understanding the information presented could possibly lead people to assume that the information is negative. Being presented with an abundance of assumed negative information could potentially lead to a placebo effect occurring where occupants' perceived comfort matches their interpretation of the indoor environmental quality (IEQ) data presented to them. Therefore, though we know that IEQ is important to heath, cognitive function, and overall comfort, it is possible that it is better for humans to be out of the loop to maximize the benefits of IEQ monitoring and control.

1.2 Research Questions and Hypotheses

This study will focus on the effect of sensor information on occupants' perceived comfort rather than on objective data of indoor environmental quality (IEQ). The two research questions for this study are *R1)* to what extent does being informed of room conditions impact occupants' perceived comfort compared to baseline occupants' perceived comfort when not informed of conditions, and *R2)* How does information seeking in the context of IEQ relate to perceived comfort in the space.

We hypothesize that occupants will report a decrease in comfort when informed of conditions compared to the reported comfort of occupants when uninformed. We predict that the reported comfort will be significantly lower when informed of unfavorable room conditions compared to the reported comfort of those not informed. Additionally, we expect that an increase in IEQ information seeking will have a negative relationship with perceived comfort reports.

2. Method

2.1 Inclusion and Exclusion Criteria

The experiment will take place in person at the University of Central Florida. Therefore, participants will only be able to take part in the study if they are able to travel to the University of Central Florida. Participants must be 18 years or older since this study is not directly about children and there is no need for their inclusion. In order to avoid practice effects or biasing of the participants, participants who have taken part in prior research from our lab will be excluded from participation. Lastly, participants must have normal or corrected to normal vision since the independent variable involves seeing the current room conditions on a display. Though accommodations for blind participants could be made by verbally conveying the values, it would be exceedingly likely that receiving the information in a different way or even the inflection in the researcher's voice could unduly bias the results.

2.2 Demographics

Participants will be recruited from the University of Central Florida since there is an ample number of people who would be available to participate in an in-person study. A random sample will be selected from the university population based on the people who choose to volunteer. The only stipulation on demographic recruitment is that an even distribution of sexes will be targeted since some studies suggest that there is a difference in temperature sensitivities based on sex

(Chang & Kajackaite, 2019; Parkinson et al., 2021). Participants who choose not to disclose their sex will not be excluded from the study.

2.3 Materials

Data collection will be conducted through a Qualtrics survey presented on an iPad. The measures will be gathered through 7-point Likert-scale responses and semantic differential scale responses with multiple questions addressing the same measures to control for random selections. The Likert-scale questions will be presented in a random order to account for ordering effects. However, for the purposes of this paper, the questions will be grouped together based on what they are measuring. The questionnaire will be a modified version of the CBE Occupant Satisfaction survey that was developed by the Center for the Built Environment at University of California Berkeley (Frontczak et al., 2012; Zagreus et al., 2004). This survey is used for many occupant comfort studies due to its simplicity and flexibility (Frontczak et al., 2012; Zagreus et al., 2004). The survey is intended for long term use studies, but it is also capable of being used for right-now evaluations which is how it will be utilized for this study (Peretti & Schiavon, n.d.). The survey will collect measures of thermal comfort, air quality, and lighting excluding questions that indicate long term occupancy (Frontczak et al., 2012). Additionally, questions will be added to address CO_2 levels separate from IAQ measures along with supplementary semantic differential scale questions where each question addressing one of the dependent variables being studied. Lastly, a Likert scale response question asking how frequently the participant viewed the IEQ stimuli will conclude the survey. The additionally questions with the response type indicated are listed below.

I. *(Likert scale) Select the level to which you agree with the following statements.*

   A. *I am concerned about the CO_2 levels in this room.*

B. The CO_2 levels in this room are not something I am worried about.

C. The CO_2 levels are impacting my comfort level.

II. (Semantic Differential Scale) On a scale of 0 being this room is too cold to 7 being this room is too hot, please indicate your assessment of the current room temperature.

III. (Semantic Differential Scale) On a scale of 0 being the light is too dark to 7 being the light is too bright, please indicate your assessment of the current room lighting conditions.

IV. (Semantic Differential Scale) On a scale of 0 being this room has no CO_2 to 7 being this room has a dangerous level of CO_2, please indicate your assessment of the current room CO_2 levels.

V. (Semantic Differential Scale) On a scale of 0 being this room has optimum air quality to 7 being this room has terrible air quality, please indicate your assessment of the current room air quality.

VI. (Semantic Differential Scale) On a scale of 0 being this room is very uncomfortable to 7 being this room is very comfortable, please indicate your current physical comfort level.

VII. (Likert Scale) How often did you look at the room data during this study?

In addition to the questionnaire, a visual stimulus will be used to convey information about the room conditions to the participants. A 20 by 4 liquid crystal display controlled by an Arduino Mega 2560 will be used to display simulated room conditions. Two sets of simulated room conditions will be programmed to be displayed during the study. The first set will contain normal values for an average room, and the second set will contain abnormal but plausible values for an average room.

Additionally, sensors will be set up in the room to monitor the room conditions of interest and ensure that no unexpected changes occur. One BME680 sensor, one SCD30 sensor, and one

SGP41 sensor will be sufficient to monitor indoor air quality, CO_2 levels, temperature, and humidity. The sensor data will be used for quality control purposes to ensure that conditions do not vary outside of an acceptable range.

2.4 Procedure

Stratified Randomization will be used to ensure a random sample for each group while also controlling for sex. Participants will be split into three groups: a control group, a moderate experimental group, and an intensified experimental group. The experiment will be a 1 by 3 design with the one independent variable being the level of stimulus presented. The choice was made to not physically alter the conditions of the room for two reasons. The first reason is that some of the conditions that we are examining, such as an abundance of CO_2, could pose potential harm to participants. In order to minimize harm, we opted for a deceit study where participants will be presented with fake data about the room conditions that would be more concerning than typical room conditions. Secondly, one of the motivating factors of this study is that many of these room conditions are not perceivable in most situations (Pei et al., 2024; Zhong, 2022).

Participants will be given an informed consent form before the study begins. The informed consent will omit that the study is to see if the presence of IEQ data causes a placebo effect in occupants. Instead, participants will be informed that the study is to examine IEQ preferences across demographics.

Once participants have completed the informed consent, they will be directed to the study room. The study room will be kept at constant conditions throughout the experiment with a room temperature of 22 degrees Celsius since that temperature has been indicated as a comfort temperature associated with better performance (Abbasi et al., 2019). Other conditions such as lighting, CO_2 levels, and overall air quality will be monitored and kept at the levels standard to the room. Participants will be directed to sit at a table so that they will be in direct view of the IEQ stimuli or where it would be in the case of the control group. For the control group, the IEQ stimuli will be completely removed. For the other two experimental groups, the IEQ stimuli will be in the same position and close enough to the participant where they can view the information on the screen with ease. Before the participant arrives, the program for the corresponding experimental group will be uploaded to the Arduino so that it is already displaying information when the participant first sees it. The device will display information about the temperature in Fahrenheit, CO_2 in parts per million (ppm), air quality in Air Quality Index (AQI), and light in lux. The expectation is that most participants will not be familiar with the ideal values for the information except Fahrenheit and it may lead to confusion that causes them to develop incorrect and potentially negative feelings about the room conditions. Since participants will most likely be familiar with Fahrenheit due to the fact that it is the standard system in the United States where the study will be conducted, the difference in the moderate case and the intensified group will be relatively small with a difference of 2 degrees Fahrenheit. The moderate group will be shown "Temperature: 71.6 °F", and the intensified group will be shown "Temperature: 73.6 °F" as the first field on the screen.

The second field will display the CO_2 levels and increase slowly to simulate the behavior of CO_2 concentrating in rooms that are occupied (Franco & Leccese, 2020). For the moderate group, values will start at 290 ppm and increase on a varied rate from 1 ppm per 40 seconds to 2 ppm per 5 seconds with the quantity and time interval being randomly selected from this range to simulate the chaos of natural patterns. The moderate group reading will be capped at 400, and if this point is reached, the value will decrease by 6 ppm in a random time interval from the range detailed above. The intensified group values will start at 990 ppm and increase with the same pattern as the moderate group. The intensified group values will not be capped.

The third field will display the air quality using the Air Quality Index which uses the accumulated values over specified time frame to calculate a value from 0 to 500 (*AQI Basics | AirNow.Gov*, n.d.; Khreis et al., 2022). Since the smallest time interval used to calculate the AQI value is one hour of readings, the true value would likely not change during the short duration of this experiment. Therefore, a static value will be shown to each experimental group with "Air Quality: 34" being shown to the moderate group and "Air Quality: 76" being shown to the intensified group (*AQI Basics | AirNow.Gov*, n.d.).

Lastly, the lighting information will be displayed in lux and vary randomly every 5 to 10 seconds in a set range of 50 lux for each experimental group. The moderate group will vary in the range of 500 lux to 550 lux (*1926.56 - Illumination. | Occupational Safety and Health Administration*, n.d.). The intensified group will vary on the range of 900 lux to 950 lux.

Once seated, an iPad will then be given to the participant so that they can complete the Qualtrics questionnaire. The questionnaire will be the same for all groups except for the last question about how often participants looked at the room information. This question will not be present on the control groups questionnaire since their answer will be "not at all" by default. The first section will include demographic information such as age, weight, sex, ethnicity, and race. The second section will be the modified version of the CBE Occupant Satisfaction survey described in section 2.3. The third section will be the original semantic differential questions and the question about frequency of information seeking described in section 2.3.

Since this study will include deception, participants will be debriefed after the experiment to ensure that their autonomy is not violated. They will be informed of the deception that they received and why it was necessary for the experiment. Additionally, participants will be informed of the goals of the study and given the opportunity to revoke their consent and have their responses destroyed.

3. Potential Data Source

Data will be mock data generated from Mockaroo (*Mockaroo - Random Data Generator and API Mocking Tool | JSON / CSV / SQL / Excel*, n.d.). The data will be stored as a CSV file with each row representing a single participant. Mockaroo allows for up to 1,000 rows at no charge. However, I will use only ninety rows meaning that there will be thirty participants per group.

In order to reduce redundancy and extensive post processing of data, I will simplify the number of fields by using a single field for each measure. Instead of including a field for each question for the same measure, one field will represent the individual's average score for the measure. The intuition behind this is that taking the average score of the questions addressing a single measure will make the data easier to interpret and will control for outlier responses at the individual level.

The fields included in the dataset will cover the demographic information, dependent variables, the independent variables, and the control variable. For the first independent variable, the groups will be categorical with 0 representing the control group and 2 representing the intensified group. Sex will also be coded with 0 representing intersex, 1 representing female, and 2 representing male. The fields for dependent variables will be represented by a number between 0 and 7 inclusive to represent the number of response options on the Likert scale. The fields will be temperature satisfaction, CO_2 satisfaction, air quality satisfaction, lighting satisfaction, and overall satisfaction. Additionally, one of the two independent variables, frequency of engagement with stimuli, will be another field that is represented by a number between 0 and 7 inclusive.

4. Proposed Analyses

For this research question, a one way between subjects MANCOVA is the best fit without first knowing what the data looks like. First, I would need to test the data to make sure it meets the assumptions of homogeneity of variance and homoscedasticity (Amon, 2023a). Since there is only one covariate being tested, we do not have to test for collinearity. Assuming that the data meets the assumptions, the test will be run using sex as a control, experimental group as the independent variable, and temperature satisfaction, CO_2 satisfaction, air quality satisfaction, lighting satisfaction, and overall satisfaction as the dependent variables. This analysis will aim to answer the research question of whether the intensity of the IEQ values impacts occupant satisfaction. Since it is a one-way MANCOVA, there will be no significant interactions between independent variables. Therefore, Tukey pairwise comparisons can be run.

Additionally, a simultaneous multivariate regression will be run with frequency of engagement with stimuli as an independent variable and temperature satisfaction, CO_2 satisfaction, air quality satisfaction, lighting satisfaction, and overall satisfaction as the dependent variables. The data would need to be checked that it meets the assumptions for a regression model beforehand. The data will need to be relatively normally distributed and have heterogeneity of variance in order to continue (Amon, 2023b). Additionally, the variables will need to be tested for multicollinearity using tolerance and variance inflation factor (Amon, 2023b). Cooke's Distance will also be used to see if there are any extreme and influential values that are impacting the model. If there are any, the values will be removed and a new model will be created and compared to the old one. This will help to ensure the accuracy and generality of the model. This analysis will aim to answer the research question of whether the frequency of IEQ information seeking impacts occupant satisfaction.

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