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TESTING THE CORRELATION BETWEEN INDOOR ENVIRONMENTAL QUALITY AND PRODUCTIVE TIME

Wissam G. Khoury[1], Issam M. Srour[2,4] and Ali A. Yassine[3]
[1] Graduate Student, The American University of Beirut, Lebanon
[2] Assistant Professor, The American University of Beirut, Lebanon
[3] Professor, The American University of Beirut, Lebanon
[4] corresponding_author_is04@aub.edu.lb

Abstract: Indoor Environmental Quality (IEQ), being one of the main pillars of sustainability, stretches its effect far beyond ensuring a pleasant environment for the occupants to live in. In fact, IEQ plays a major role in defining the level of productivity within organizations. Recent studies acknowledge the link between IEQ and employees' overall satisfaction at work, and in turn, productivity. The ultimate goal of an ongoing research project is to propose and validate a decision making tool that optimizes office buildings renovation projects based on maximizing occupants' satisfaction with the IEQ conditions at their workplace, and in turn, maximizing their productive time. The first step in this direction requires an understanding of the relationship between IEQ and productivity. This is achieved in this paper through a survey of corporate employees, which provides a correlation between the level of IEQ in an office setting and the overall level of satisfaction with the workplace. The latter is, in turn, correlated with the level of occupant productivity at work, as measured by the amount of productive time. The paper concludes with an empirical model based on statistical regression analysis, depicting the relationship between IEQ satisfaction and productive time.

1 INTRODUCTION

The overarching objective of any for-profit firm is to maximize profitability. The cost of employees is considerably larger than any other cost incurred in running most businesses. In fact, the cost of employees is more than 130 times the cost of energy in a typical workplace, and is 85% of the total costs incurred in a typical office building (Annika et al. 2013). Hence, to ensure a profitable operation, the benefits associated with the employees' productivity must outweigh the associated costs. In fact, a slight increase of 0.1% in employee productivity - by enhancing Indoor Environmental Quality (IEQ) factors such as occupant comfort and satisfaction - can yield a dramatic increase in profitability (Singhvi et al. 2005).

IEQ is defined as "*a generic term used to describe the physical and perceptual attributes of indoor spaces. These include the indoor air quality and the thermal, acoustic and visual properties of the environment, as well as various characteristics of the furnishings, facilities and fitouts" (Newton et al. 2009).* Fifteen different IEQ factors define the indoor environmental quality of a workplace; these are: thermal comfort, air quality and ventilation, amount of light, visual comfort, noise level, sound privacy, amount of space, visual privacy, ease of interaction, comfort furnishing, adjustability of furniture, colors

and textures, building cleanliness, workspace cleanliness, and building maintenance (Kim and de Dear 2012). Each of these factors has a unique impact on the physical and mental well-being of the occupants.

The main hypothesis tested in this study is the existence of a relationship between productive time and occupants' satisfaction with IEQ conditions at the workspace. The relationship is said to exist due to the proven influence of the different IEQ factors on the well-being of the occupants, which, in turn, influences the level of productivity. The level of performance of the IEQ factors at the workplace is indicated via the self-assessed satisfaction levels reported by the occupants, and the level of productivity is estimated by measuring the productive time. Accordingly, the first *null hypothesis* tested in this study is:

[1] $H_0^1 =$ *The level of productive time does not correlate with the level of satisfaction with the IEQ conditions at the workplace.*

The literature includes several studies that offer quantitative post-occupancy evaluation of the correlation between employee productivity and satisfaction with the workplace. However, the results of these studies differ widely due to the different approaches used for measuring satisfaction and productivity. The purpose of this study is to redevelop this relationship using a new method that targets the possible gaps spotted in previous studies. This method includes estimating productivity through measuring productive time, a more quantifiable parameter to assess. Satisfaction with IEQ is measured by self-assessing the level of satisfaction with each of the factors of IEQ, and then aggregating the assessments to estimate the level of overall satisfaction with the IEQ at the workplace, while taking into consideration the different level of influence of each IEQ factor on the over satisfaction at the workplace.

In the next section, a literature review on IEQ is presented and related to the well-being, satisfaction, and productivity of building occupants. The third section presents the objective and the methodology adopted in this paper to test the existing relationship between productive time and occupant satisfaction, taking into consideration the spotted gaps in the literature. The fourth section begins with testing the hypothesis of this relation, and ends with a regression curve that raises a concern regarding extremely low satisfaction levels. The paper concludes by comparing the results with those of previous studies.

2 LITERATURE REVIEW

This section presents a literature review on the correlation between post-occupancy IEQ and the following three conditions: Occupants' well-being, overall satisfaction, and level of productivity at the workplace. Based on the reviewed literature described in this section, the relationship among the three mentioned conditions can be depicted as schematized in Figure 1.

The four factors of IEQ, nature of work, psychological environment and space management, do not equally influence physical and psychological status; however, all four play a role in influencing occupants' satisfaction level, which, in turn, influences their level of productivity. It is important to note that the direct causality between all these factors as presented is only a simplified representation that is yet to be ascertained and validated, since the existing relationship among these factors is of high complexity.

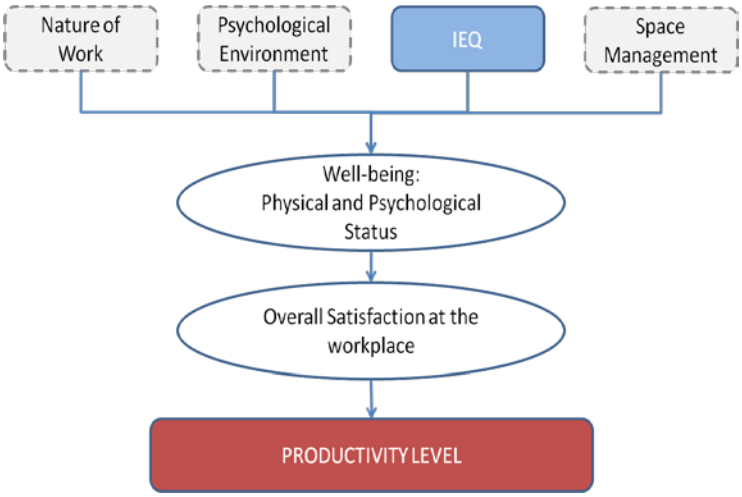

Figure 1: The hypothesized relationship between IEQ conditions, well-being, overall satisfaction, and productivity at the workplace – Adapted from (Mahbob et al. 2011).

2.1 IEQ Conditions and Occupants' Well-Being

IEQ conditions at the workplace can have physical and psychological implications on the employees. Many studies examined the health implications of each of the 15 IEQ factors on occupants' well-being (Singh 2009, McGrory 2012). As summarized in Table 1, many of the implications are common across several IEQ factors. This shows the complexity of the relationship between IEQ conditions and occupants well-being.

Table 1: IEQ and well-being (Kumar and Fisk 2002, Balazova et al. 2008, Mardex 2004)

IEQ Factor	Health Impact (Physical and Psychological)
Thermal Comfort[a]	Fever, chills, fatigue, attention drift, dizziness and nausea
Air Quality and Ventilation[b]	Asthma/chest tightness, respiratory allergy, fever/chills, dizziness, nausea, headache, eye/nose/throat irritation, fatigue, dry or itchy skin, lowered cognitive performance
Amount of light	Depression, dizziness, nausea, fatigue, headache
Visual comfort	Depression, Stress, headache, fatigue
Noise level	Stress, headache, fatigue, lowered cognitive performance
Sound privacy	Attention drift, lowered cognitive performance
Amount of space	Stress, fatigue, headache
Visual privacy	Attention drift, lowered cognitive performance
Ease of interaction & IT	Stress, tension, attention drift, misconception and miscommunication
Comfort furnishing	Muscle aches, de-motivation
Adjustability of furniture	Muscle aches, de-motivation, stress
Colors and textures	Depression, fatigue, stress, headache
Building cleanliness	Stress, de-motivation
Workspace cleanliness[b]	Eye/nose/throat irritation, dry or itchy skin, respiratory allergy, lowered cognitive performance, stress, de-motivation, headache
Building maintenance	Can lead to any of the above

[a] Canadian Centre for Occupational Health and Safety (http://www.ccohs.ca)

[b]EPA – Indoor Air Facts No. 4 (revised) (http://www.epa.gov/iaq/pdfs/sick_building_factsheet.pdf)

2.2 IEQ Conditions and Occupants' Overall Satisfaction with the Workplace

Several studies examined the relationship directly between IEQ factors and occupants' overall satisfaction at the workplace (Agha-Hossein et al. 2013, Frontczak et al. 2012). Of particular interest is Kim and de Dear's work, which goes a step further in relating IEQ to satisfaction by giving weights to the IEQ factors. Kim and de Dear (2012) present a tool that allows for quantifying the level of occupant satisfaction with the IEQ conditions in the workplace by breaking it down into its 15 factors and applying the weighted effect of each factor on the overall resulting satisfaction level. Some of these 15 factors, named *Proportional Factors* – such as air quality, amount of light and sound privacy, have a direct relation with the overall satisfaction; i.e. as the level of perceived satisfaction with these IEQ factors increases or decreases, the level of overall satisfaction increases or decreases respectively, each with a different magnitude. Other IEQ factors, named *Basic Factors* – such as temperature, noise level and amount of work space, have a non-direct relation with the overall satisfaction. When such factors are perceived negatively, they inflict a negative effect on the overall satisfaction, while perceiving them positively barely adds to the overall satisfaction; quoting, "it is not easy to impress occupants with IEQ". This classification indicates that every IEQ factor affects the overall satisfaction of the occupants differently, depending on their type and on how well they perform at the workplace. Some have linear relation with the overall satisfaction, while others do not. For this reason, it is highly important to include the weights of the IEQ factors while quantifying the overall satisfaction at the workplace.

2.3 IEQ Conditions and Occupants' Productivity

Productivity, being the essential organizational outcome, forms the main indirect economical benefit of IEQ enhancements. As shown in Figure 1, IEQ is among the four main factors that describe the overall satisfaction and comfort of employees at their workplace, which in turn affects their level of performance and productivity at work. Enhanced indoor environments in office buildings have a positive correlation with occupants' satisfaction, yielding higher levels of well-being, which, in turn, positively correlates to productivity. The approaches followed in analyzing the relationship between productivity and IEQ can be categorized into three methods. The first method consists of qualitatively analyzing IEQ investments and yielding benefits. A detailed conceptual relation presented by Seppanen and Fisk (2003) show that health and productivity are highly improved when proper measures are taken to enhance IEQ conditions. The second method, such as the one used by Wyon (2004), relies on statistical techniques to examine the effect of IEQ conditions on productivity. This method analyzes the effect of each IEQ factor independently. For example, air quality is among the IEQ factors that could highly affect office work performance by up to 9%. Despite the fact that segregating the many IEQ factors simplifies the analysis, the sum of their individual effects on performance would not be equal to the combined effect of all factors acting together. The third method looks at IEQ as a whole as opposed to analyzing the effect of individual IEQ factors on productivity independently. Oseland (2004) found a linear relation between productivity and both, environmental and facility factors at the workplace. However, Oseland's measuring of productivity was based on two self-assessed questions which ask the respondents about the effect of the facility and the environment on their productivity, along with several other questions of which are concerned with downtime such as waiting for lifts, walking between buildings, and other similar questions that might not link to IEQ conditions specifically. Moreover, the IEQ factors were not weighted while calculating the overall satisfaction, such as the case with Kim and de Dear's study.

Contrarily, Somers and Casal (2009) proposed a nonlinear U-shaped relation between productivity and satisfaction. No explanation was reported regarding this unexpected relation: as satisfaction increases, productivity decreases for the lower levels of satisfaction. Artificial Neural Networks were used to model nonlinearity. Job performance measurements of the employees were taken from the organization's formal performance appraisal process and reflected supervisor ratings of employee job performance. Beside the possible inaccuracy and bias associated with such productivity measuring techniques, the sample was limited to nurses and psychiatric technicians drawn from a university medical center. Despite the limited sample of this study, it presented the possibility of having nonlinear relationships between IEQ and performance, and hence productivity, which could negate the generalization of Oseland (2004)'s findings.

It is important to note that all of the three methods described in this section use similar means for measuring job performance and productivity level. Productivity is measured by either self-assessments or by simulating office activities (typing, proof-reading, addition, etc.) Self-assessments are not quite accurate primarily due to the lack of reliable benchmarks. Moreover, being aware of the fact that they are being studied, occupants' might report biased self-assessments of productivity. Simulating office works, on the other hand, includes uncountable tasks to be properly measured. In addition, some tasks might not always be affected by the level of IEQ satisfaction, depending on the difficulty of the task at hand. This makes it challenging to quantify job performance and productivity, and highly lowers the accuracy of the results. Moreover, simulating office work would inevitably include bias since, again, the studied sample is aware of being observed. Another important point is the fact that adding or averaging productivity measures for the sampled employees might be misleading. The level of output for the same state of satisfaction might significantly vary from one employee to another, depending on their nature of work, experience, psychological or physical status, etc.; thus employees with low satisfaction might have outputs equal to or higher than that of satisfied employees.

The best way to attain valid measures is by studying employees' productivity level at their own offices, while performing their routinely tasks, and without being aware of a direct assessment of their abilities (Haynes 2008). Such a technique has rarely been used in a job performance versus job satisfaction study due to being practically infeasible. This fact is due to the complexity of controlling the many possible combinations of IEQ conditions if analyzed as a whole, difficulty of measuring irregular day-to-day tasks, and difficulty in studying the productivity of employees while at work without having biased results. Due to the complexity in objectively measuring the level of productivity on all its aspects, this paper focuses on productive time related to IEQ conditions. Non-productive time, in this context, is defined as the working time wasted by not being productive due to poor IEQ conditions specifically, subtracted from the total working time of an employee. Measuring productive time rather than productivity could give lower estimates since IEQ conditions might have an effect on productivity parameters other than productive time, such as task productivity: the amount of work done during productive time. However, the level of influence of IEQ per se on task productivity is very difficult to quantify due to the complexity of other influencing factors, and could include biasness since it directly assesses the performance of the individuals who are aware of being tested. Instead, and by asking the employees about the time lost due to external factors or due to causes out of their control, all related to IEQ, they are more likely to reply with objective and more accurate estimates, since erring seem to have neutral influence on their benefit. Moreover, measuring time rather than productive work is a much easier task to do. Several peer-reviewed questionnaires present in the literature measure productivity by focusing on quantifying productive time, such as the Migraine Work and Productivity Loss Questionnaire (MWPLQ), and the Health and Performance Questionnaire (HPQ).

3 METHODS

In order to examine the null hypothesis [1] and further investigate the potential relationship between occupant satisfaction with the IEQ and productive time, a survey questionnaire consisting of three sections was proposed. The first section gathers demographic information related to the respondent. The second section measures time lost during working hours due to poor IEQ conditions as self-assessed by the occupants via expressing their level of satisfaction with IEQ conditions. The aim is to quantify the working-hours lost without performing productive work due to IEQ related causes. Productive time is measured by a set of questions adopted in part from previous productivity-related questionnaires, such as *Work Productivity, Work Productivity and Activity Impairment General Health Questionnaire, QQ Instrument*, etc. The questions were modified to portray IEQ-related lost time at work. This section directs respondents towards estimating their time lost due to poorly performing IEQ factors or related physical and mental problems faced at work. The third section of the questionnaire directs the respondents into self-assessing their level of overall satisfaction towards their workplace using the same questioning and scaling technique used in Kim and de Dear (2012)'s study, including the weighted parameters presented for the different IEQ factors to estimate an accurate level of overall IEQ satisfaction. Table 2 discloses a few sample questions from the questionnaire, as shown in their related sections.

Table 2: Sample questions from survey questionnaire

Section	Question	Measure/Scale
Section I	How long have you been working at your current workplace?	Years & Months
Section I	Your job description includes occupying your office for an average of:	Days a week & Hours a day
Section II	During the past week, how many days have you left work early due to being tired or depressed, and not feeling like dealing with the poor environmental conditions at your workplace as indicated in Questions 1 and 2?	Days
Section II	During the past 12 months, how many times have you felt that your workplace environment made you sick or too tired to work that you took a sick-leave (allergic, migraine, prolonged nausea, etc.)?	Times
Section III	How satisfied are you with the noise level in your workspace?	Scale 1 to 7
Section III	How satisfied are you with the temperature in your workspace?	Scale 1 to 7

The responses of the survey were used to compute three parameters out of each questionnaire: *Longevity*, *Percent Productive Time and Percent IEQ Satisfaction.*

- *Longevity:* Question 1 of Section I asks participants about their time spent at their current workplace. Longevity in this context does not imply the number of years of employment, but merely the number of years spent at the currently occupied office, which might be much less than the total years of employment.

- *Percent Productive Time*: Question 2 of Section I through Question 15 of Section II of the questionnaire are used to calculate the respondent's percentage of utility of their potential productivity. For example, a *Percent Productive Time* of 70% means that the respondent is, on average, wasting 30% of their working time. This is calculated by summing up the time lost due to the several IEQ-related impediments at the workplace that hinder the respondent from being productive. The lost time due to each of the impediments is self-assessed by the respondents by responding to Section II of the questionnaire. The summed lost time is subtracted from the total working-time supposed to be spent at the workplace; yielding *Productive Time*.

- *Percent IEQ Satisfaction*: Section III of the survey questionnaire is used to calculate the percentage of satisfaction of the respondent with the IEQ conditions, which influences their level of overall satisfaction with the workplace. In total, 15 questions, each relating to one of the 15 IEQ factors, ask the respondent to self-assess their perceived level of satisfaction towards the related IEQ factor on a scale of 1 to 7, similar to that used in Kim and de Dear's study (2012). The responses are then accumulated after being factored by the weighted influence effect of each IEQ factor, as proposed by Kim and de Dear, to yield the overall IEQ satisfaction at the workplace. A *Percent IEQ Satisfaction* of 80% means that the respondent is 20% short of being completely satisfied with the IEQ conditions at the workplace. This also means that the IEQ conditions are contributing to the overall satisfaction 80% of what they could at an ideal situation.

The total sample size included 102 participants divided among offices of six organizations of different types: engineering, pharmaceutical, banking, industrial, governmental, and educational; each of which completed between 15 and 20 questionnaires. The aim behind selecting different types of organizations

was to include a various combination of white-collar employees working on different types of office-work tasks, to generalize the validity of the tested relationship. A total of 20 hard copies of the questionnaire were kept at the lobbies of each of the consenting organizations, and the employees were invited to fill them in; voluntarily and anonymously. The gathered data were then checked against random responses and any outliers using the ROUT method. The ROUT method in brief attempts to fit the regression model to the data where outliers have little impact. Then, it detects the points that are far enough from the predicted model, basing its prediction on a predefined false discovery rate. The remaining data is then statistically analyzed to reveal the descriptive statistics of the three parameters, longevity, percent productive time and percent IEQ satisfaction, of the studied sample. To study the null hypothesis, a bivariate (Pearson) correlation is carried out on the resulting data, testing the proposed relationship between productive time and overall satisfaction with IEQ conditions at the workplace. The next natural step after testing the null hypothesis is to further investigate this relationship by trying to infer a statistical regression model that relates the two parameters. The obtained regression curve is then validated by comparing the results of this survey with those of Oseland (2004)'s and Somers and Casal (2009)'s statistical regression models, since these two models address the same problem, yet yield possibly contradicting results; the latter claims a linear relation, while the former presents a nonlinear U-Shaped regression curve.

4 RESULTS

4.1 Data Analysis

One response out of the 102 was eliminated since it was found to have been filled arbitrarily; the calculated lost time was greater than the reported total working hours per day. For the remaining responses, and using the previously described calculations, each questionnaire was reduced to a coordinate point (Percent IEQ Satisfaction; Percent Productive Time). Two outliers were filtered out of the data set using maximum *False Discovery Rat*e of 1% (Motulsky and Brown 2006). For the remaining responses (total of 99), the three variables are statistically summarized in Table 3.

Table 3: Descriptive statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Percent Productive Time	99	68.6	30.8	99.4	72.6	14.9
Percent IEQ Satisfaction	99	97.8	2.2	100	54.3	23.9
Longevity	99	11.9	0.1	12	3.1	2.9

- *Percent Productive Time:* The percent productive time mean of the sampled employees is 72.6% with a standard deviation of 15.0%; i.e. on average, employees are performing their jobs at 72.6% of their ability. The minimum recorded time productivity is 31%, while the highest is about 99%. This suggests that employees tend to utilize their productive time at a wide range of levels, depending on several parameters, among which, the level of IEQ satisfaction.

- *Percent IEQ Satisfaction:* The percentage of satisfaction with the IEQ conditions averages to 54.3%, with a standard deviation of 23.9%. The levels of satisfaction with the IEQ seem to range across the whole 100% scale, with a minimum of 2.3%, and a maximum of full satisfaction.

- *Longevity:* The longevity mean of the sample is approximately three years. The logical explanation for this apparently low number goes back to the first question of the survey, which states: "How long have you been working at your current workplace?" The aim of this study is to measure the level of satisfaction of the employees with the IEQ conditions of their *currently* occupied office. Since many employees throughout their employment tend to get transferred from one workplace to another due to

several reasons; getting promoted, moving to a new office building, department switching, etc., the average longevity is as low as three years.

Table 4: 2-Tailed Pearson correlation test

		Percent Productive Time	Percent IEQ Satisfaction
Percent Productive Time	Pearson	1	.56**
	Sig.		0
	N	99	99
Percent IEQ Satisfaction	Pearson	.56**	1
	Sig.	0	
	N	99	99

** Correlation is significant at the 0.01 level (2-tailed).

As summarized in Table 4, the bivariate (Pearson) correlation test shows that there is a statistically significant correlation between the two parameters, thereby enough evidence to reject the null hypothesis H_0^1. This result further confirms the findings of Somers and Casal (2009) and Oseland (2004).

4.2 Best-Fit Regression Curve

After performing the regression analysis on the collected data to find the best fit curve that would model the relationship between *Percent Productive Time* and *Percent IEQ Satisfaction,* the three regressions with the highest R-Square values are found to be the linear, quadratic and cubic curves. In addition to featuring the highest R-Square value, the cubic model offers a more logical fit especially for cases of high levels of satisfaction, since 100% productive time is practically infeasible as shown by the quadratic fit in Figure 2. Similar to the finding of Somers et Casal (2009), the relation between Productive time and Satisfaction with IEQ thus appears to be non-monotonic with a U-shaped cubic regression curve. As the satisfaction increases to 25%, the productive time drops from 70% to 60%. This value then increases at a slower rate to 95% as satisfaction increase until 100%.

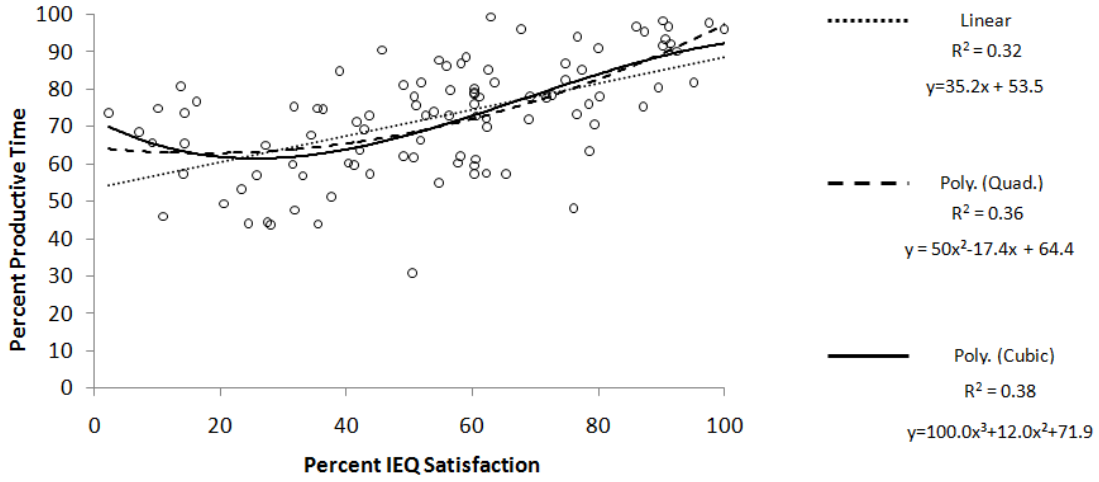

Figure 2: U-Shape cubic relation between productive time and IEQ satisfaction.

4.3 Discussion

Despite the approach used in measuring satisfaction and productivity, which is validated by previous literature to have more accurate results in comparison to other approaches used in other studies, all three regression curves show relatively low R-Squared values. A possible cause behind this outcome is the fact that productive time and satisfaction level with the different IEQ factors had been self-assessed by the respondents, who could have estimated their lost time inaccurately, or reported their level of satisfaction based on the momentarily situation they were in at the moment of assessment, rather than responding in a general manner. Another cause could be due to the complexity of the relationship between IEQ conditions and occupants' comfort, well-being, satisfaction and productivity. This complex relation stretches far beyond the frame of this study, which relies on several assumptions that simplify this relationship to a quantifiable dimension. For example, feeling dizzy at work and not being able to be productive could be due to reasons that have nothing to do with IEQ, such as feeling ill or pregnancy. A third important observation spotted in Figure 2 that could be associated with the low correlation factors attained is the scatter plot for low values of IEQ Satisfaction (below 20%). The scatter plot at that region of the graph seems to lie randomly above all three regression curves, which could influence the best-fit curves into falsely depicting the relationship between very low IEQ satisfaction levels and productive time. Unlike the first two causes presented, this is not an error in estimation or bias in assessment, but could be a phenomenon that needs to be looked at more closely. If there is no correlation between Percent Productive Time and Percent Satisfaction for such low satisfaction levels, then the proposed model is not applicable for extremely low satisfaction levels, which should be excluded from its domain.

5 CONCLUSIONS

In this paper, the relationship between post-occupancy perceived satisfaction with the indoor environmental quality of office buildings and the self-assessed level of productive time of the occupants is tested. To the contrary of most reviewed studies, productive time rather than productivity per se is measured, linking it solely to poorly performing IEQ or related health problems. The level of IEQ satisfaction, on the other hand, is based on Kim and de Dear (2012)'s regression model, which takes into consideration the weighted influence of the IEQ factors on the overall satisfaction. A survey questionnaire was used to gather the sample data that links the level of productive time to the level of IEQ satisfaction at the workplace. Running a Pearson Correlation test on the gathered data shows a significant relationship. After the initial plotting of responses, a cubic U-shaped behaviour of the studied relationship is observed, similar to what Somers and Casal (2009) concluded. However, and after analyzing the causes behind this unexpected increase in productive time at lower levels of satisfaction, it appears that there might be no correlation between the two. This leads to the conclusion that the curve might not hold valid for such cases; an observation that calls for further studying the hypothesized relationship. The significance of this study is that it validates the existence of the relationship between occupant productivity and satisfaction at the workplace, presents a quantitative empirical model for the relation between productive time and IEQ satisfaction specifically, and presents a possible explanation to the counter-intuitive U-Shaped regression curve attained. Possible future work on this subject could focus on the relation between productive time and extremely low IEQ satisfaction levels. Future work could also address one of the limitations of this paper, i.e. its reliance on self-assessment methods of productive time as proxy for productivity. More direct measurements of productivity are needed to confirm the relationship between IEQ conditions and productivity.

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