Visual Comfort and Self-Perception of Productivity in an Office Building in Raleigh, North Carolina

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Decision-making in architectural design is a complex process that includes various factors such as aesthetics, user needs, and environmental considerations etc. (Gercek and Arsan, 2019). Creating a visually comfortable space is one of the main goals for architects in the decision-making process (Konstantzos and Tzempelikos, 2017). ASHRAE Guideline 10P (2014) states four conditions which contribute to create a comfortable space for occupants: thermal, visual, indoor air quality and acoustics. Based on United Nations statistics (2017), the urban population is increasing and will become 60% of the total world population by 2030. The majority of employees will work in office environments (ASHRAE, 1993), and the time spent by employees in the workplace and related stress is increasing (Evans, G.W. and McCoy, J.M., 1998; Poursafar, et al., 2019). This elevates the importance of designing comfortable office space for employees. Since staff (labor) costs are one of the primary costs of an organization, improvements that affect overall comfort have the potential to improve productivity, retention and benefit employers. Studies show that visual comfort can improve productivity in space (Boyss et al. 2003; Heschong, 2003; Aries et al., 2015).

The goals of the study are to explore the relationship between visual comfort and the employees perception of their own productivity. The methods used in this study include survey and environmental monitoring. The participants, designer/occupants in a design firm in Raleigh, North Carolina, USA, participated in an online subjective survey asking about their perceived productivity and visual comfort in the space from Aug 19 - Sept 6, 2019. The illuminance was measured by sensors and serve as empirical data for reference. A correlational analysis was conducted between the results of the survey questions (visual comfort and productivity). The results show that there is no statistically significant relationship between visual comfort and employees' perception of their productivity for the study period. Furthermore, the data collected from sensors showed that the daylight distribution in the open office is unequal.

1.0 INTRODUCTION

The fact that people spend 90% of their time indoors (Leech et al., 2000) illustrates the importance of the built environment on people's comfort, satisfaction, and well-being. Statistics show approximately 60% of the world's population will live in urban areas by 2030 (United Nations, 2017). Most people in urban areas will spend their time in office buildings (ASHRAE, 1993); the time that people are spending in their workplaces is increasing, along with the stress levels of employees while at work (Evans, G.W. and McCoy, J.M., 1998; Poursafar, et al., 2019). The main cost of business expenses is operational costs which is 90% of the building's costs over its lifetime (Clements-Croome, 2000; World Green Building Council, 2014). Romm and Browning (1998) believe that one percent increase in the office workers' productivity can be equal to the company's annual energy cost. These numbers illustrate how small changes in office workers' productivity have a significant impact on the company's overall bottom line (Al Horr et al., 2017).

ASHRAE Guideline 10P (2014) establishes four comfort conditions which contribute to a comfortable environment for humans: thermal, visual, acoustics, and indoor air quality. Creating a comfortable visual environment for occupants is one of the main considerations in designing working and living spaces (Konstantzos and Tzempelikos, 2017). Konstantzos and Tzempelikos (2017) state that in the past few years, visual comfort in office buildings has been the main focus of façade design. By creating comfortable and desirable conditions in office spaces, employees will be more productive and healthier, tending to spend more time at their workstations. People prefer to sit and work beside or close to a window, but there are no studies showing the main reasons behind that preference (Aries, 2005; Aries et al., 2015). Aries et al. (2015) mentioned some potential reasons which include: (i) the view to outside, (ii) the amount of daylight, (iii) full continuous spectrum of color, and (iv) the change in seasons and day.

Several studies show that the access to daylight impacts the reduction of stress and the increase of productivity (Boyss et al. 2003; Heschong, 2003; Aries et al., 2015). Since the intensity of daylight is variable during the daylight hours, it can cause discomfort in the workspace at some periods of the day through glare or heat gain (Osterhaus, 2005; Velds, 2002; Aries et al., 2015). Thus, when daylight causes the visual or

ZONE NAME	DAYLIGHT EXPOSURE	ZONE TYPE	# OF SENSORS IN THE ZONE	HEIGHT OF SENSOR FROM THE FLOOR
A	DIRECT SOUTH	OPEN OFFICE	4	3
B	INDIRECT NORTH	OPEN OFFICE	4	3
C	DIRECT SOUTH AND WEST	DESIGN LAB	1	7
D	DIRECT NORTH	MATERIAL LIBRARY	1	5.5
E	DIRECT NORTH	CLOSE OFFICE	2	3
F	DIRECT NORTH	CONFERENCE ROOM	1	6
G	DIRECT NORTH	RECEPTION	1	2.5
H	INDIRECT NORTH	CONFERENCE ROOM	1	2.5
I	NO DAYLIGHT	SERVER ROOM	1	4.5

Table 1. Zone properties in the office. Image credit: Author.

thermal discomfort, the occupants wish to have less daylight in the space (Aries et al., 2015). This situation is one example illustrating the importance of the building design and daylight ing effectiveness. Building design projects have many variables influencing the decision-making process to meet the requirements for different aspects of the projects such as physical needs, environmental concerns, user needs, aesthetics, and budget etc. (Gercek and Arsan, 2019). The architects must deal with layout, form, materials, colors, methods of construction, and many other factors to meet the needs of stakeholders including users, developer, company, etc. (Cooper et al., 2004). A successful design project relies on the ability of the designer to find a solution to the complex problems specific to the project (Poursafar et al., 2019). The U.S. Energy Information Administration (2011) emphasizes that decisions made in the early design stages are more impactful for reaching the established performance goals of the project, significantly influencing the results of the final space.

2.0 METHODOLOGY

This study includes two data collection methods: occupant survey and environmental monitoring. The data gathered from these methods will be used to understand two main goals of this study: the relationship between visual comfort and employees' perception of their productivity; and understanding of the daylight distribution across the open office.

2.1 SAMPLE SIZE AND PARTICIPANTS

The participants of this study are 18 full-time employees in an architecture and design firm in Raleigh, NC. The office is on the third floor of an eight-story building in the central business district. There are two glass-enclosed offices, an open office workplace with bench-style desking, an open-floor kitchen and common area (design lab), two glass-walled conference rooms, a reception space, and a server room on this floor. This location was selected through an existing relationship with the office and willing participants. To mitigate the potential risks of a power dynamic, participation was voluntary, and the survey was confidential. A meeting with potential participants was held at the beginning of the study to clarify the goals and methods of this research. The meeting helped the participants to understand the goals of the study and allowed the group to engage in a question and answer discussion. The researchers were available in the office to answer participants' questions confidentially. Also, the presence of the researchers during the study helped the team to access participant insights about the process to improve research designs for future similar studies.

2.2 RESEARCH DESIGN

The research design of this study includes Institutional Review Board (IRB) application and approval, meetings with the participants, participant surveys, and environmental monitoring (Figure 1). IRB approval was sought through NC State University, and was found exempt due to the minimal risk to participants. In a 30-minute participant meeting at the beginning of the study, the researchers reviewed the goals, process, and benefits of this study, confidential surveys, environmental monitoring, and participation requirements. During the initial meeting, a written consent form was distributed among the employees which they reviewed. Occupants were given one week to decide whether they want to participate before the study began. 18 employees were willing to participate in this study. After signing the consent, the study started and the link to the online confidential survey was distributed among the employees via email.

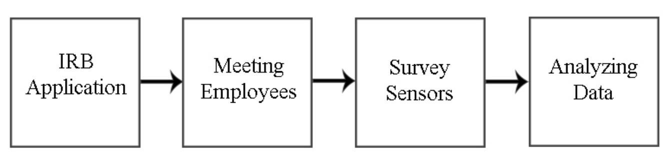


Figure 1. Research Design Diagram. Image credit: Author.

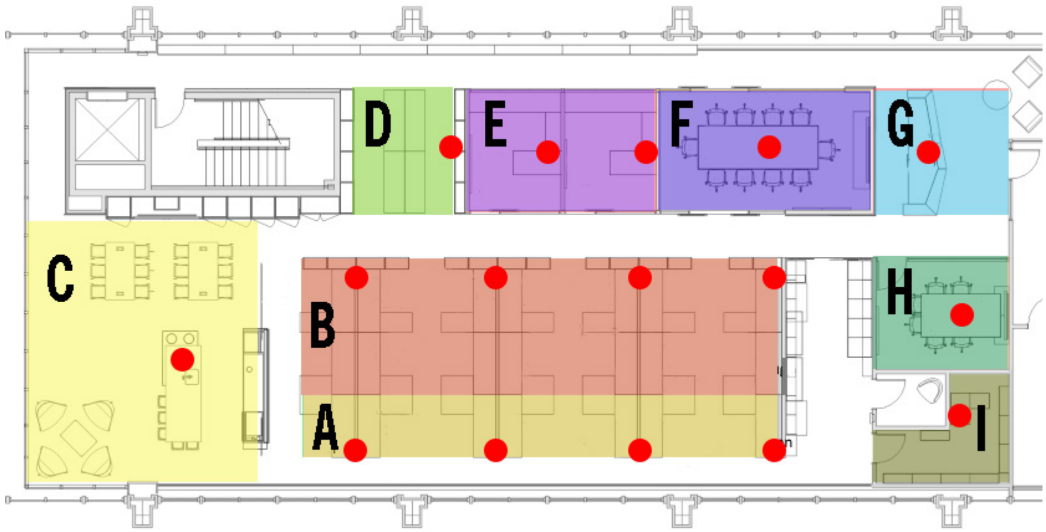


Figure 2. Zones and the locations of sensors. Image credit: Author.

conditions. Table 1 shows the properties of each zone. In the survey, the participants had to choose where they were located within the office for the preceeding time period and answer questions based on personal experience within the space. The locations of the sensors are shown by red circles in Figure 2.

Wireless Omron 2JCIE-BL01 battery-operated and Bluetooth-enabled environmental monitoring sensors were used. These sensors measure some environmental conditions such as dry bulb temperature, relative humidity, illuminance level, sound level, pressure and UV level. The sensors are very small, located at eye-level, and have remote connectivity, so they did not affect the employee's everyday tasks.

2.3.1 DATA COLLECTION: SURVEY

A confidential online survey was distributed among the participants four times a week (one survey per day) over three consecutive weeks between August 19th and September 6th, 2019. During the first half of the study, the surveys were sent to participants at 2:30pm and during the second half, they were sent out at 9:30am. This provides participants' perceptions of daylight in both morning and afternoon lighting conditions. The Roast Survey[1], developed by KieranTimberlake, KT Innovations, was used in this study. This survey contains questions about thermal, acoustics, visual comfort, and indoor air quality as well as addressing the perceptions of the impact of the environment on productivity[2]. Each question uses a standard 7-point scale (Figure 3). For example, the visual comfort question has answers ranging from "much too dim (-3)" to "much too bright (3)" with a neutral option in the middle. The productivity question has a 5-point scale with answers ranging from "the environment greatly interferes with productivity (-2)" to "the environment greatly enhances the productivity (2)". In this survey, participants indicated (i) their location in the office when completing the survey; (ii) their activity in the past 20 minutes; and (iii) their clothing (clothing type- clo). This survey plots the data to a visualization method on the floor plan, using a separate graph for each of the questions. It also allows for exporting a .csv file for further analysis, which was exported for visual analysis in Tableau and statistical analysis in SPSS software.

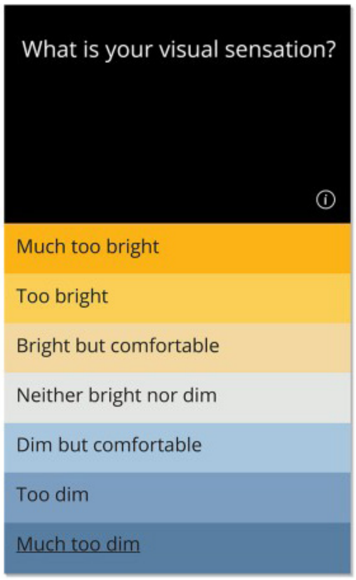
2.3.2 DATA COLLECTION: ENVIRONMENTAL MONITORING

The illuminance level was measured by Omron 2JCIE-BL01 sensors located in sixteen places within the office area. The locations of the sensors are shown by red circles in Figure 3. Sensors were located in the places with the most use in the office. The sensors were wirelessly connected via bluetooth and physically small (1.9in x 1.5in x 0.6in), so they do not interfere with the employees' everyday tasks. The sensors which are located in Zones A, B, E, G and H were placed by 3M adhesive strips on the walls between 2.5 and 3 ft height from the floor; in these zones, people are mostly seated and working. In the design lab (Zone C) and one of the conference rooms (Zone F), the sensor was hung from the ceiling to be central in the space, and because there were no appropriate locations to adhere the sensor. It also allowed the team to explore how to gather data differently. In Zone D, the sensors were placed with 3M adhesive strips at 5.5 ft height above the finished floor to understand the comfort level at an approximate standing height, because in this zone employees mostly work while standing.

3.0 RESULTS

In this study, survey and environmental monitoring were conducted in an office building in Raleigh Aug 19 - Sept 6, 2019 to understand the daylight distribution across the office

[1] https://roastsurvey.com/
[2] Whether the environment enhances or interferes with productivity



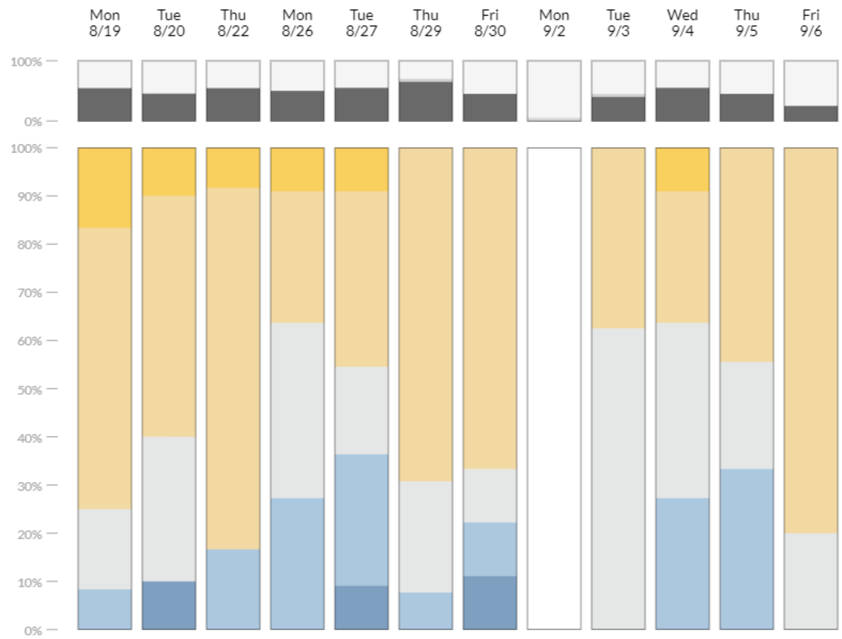


Figure 3 and Figure 4. Visual comfort survey and summary of responses. Image credit: KT Innovations: ROAST.

			PRODUCTIVITY VALUE	VISUAL COMFORT VALUE
KENDALL'S TAU-B	PRODUCTIVITY VALUE	CORRELATION COEFFICIENT	1.000	-.007
		SIG. (2-TAILED)		.924
		N	123	123
	VISUAL COMFORT VALUE	CORRELATION COEFFICIENT	-.007	1.000
		SIG. (2-TAILED)	.924	
		N	123	123

Table 2. Kendall's Tau-b Statistical Correlation Analysis. Image credit:Author.

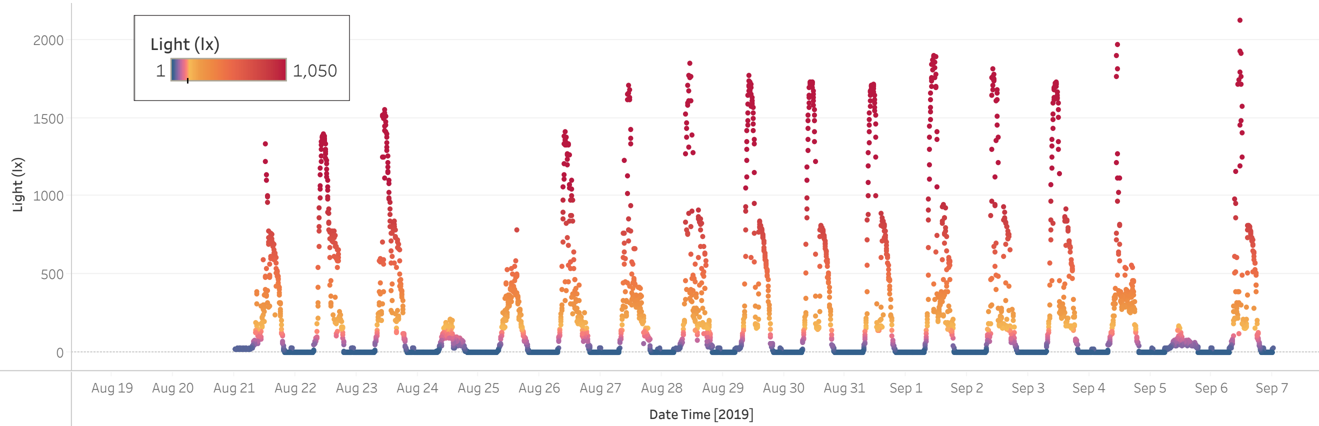
and the relationship between visual comfort and employees' perception of their productivity. The results shown in this section are divided into two sections: (i) survey results, and (ii) environmental monitoring results.

3.1 SURVEY RESULTS

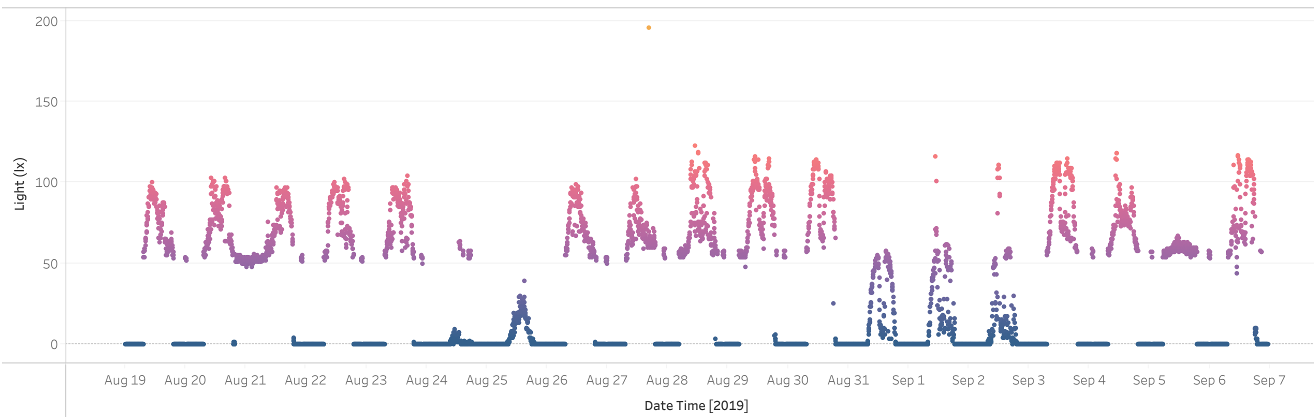
Figure 4 shows the results for the question relating to visual comfort. The responses show that most people feel "bright but comfortable" for the duration of the study. The results of the survey[3] also indicate that most of the participants who responded "too dim" or " dim but comfortable" are located on Zones F, G and H. All these zones are located on the north side of the building or having indirect north sunlight. Therefore to improve the visual comfort of Zones F, G and H, the spaces require additional lighting to achieve equal light levels across the space.

The responses to the series of surveys were analyzed for correlation analysis in SPSS. To understand the relationship between visual comfort and the employees' perception of their productivity. To analyze the correlation between these two factors, Kendall's Tau-b test has been chosen. The analysis in Table 2 shows that there is no statistically significant correlation between visual comfort and the employees' perception of their productivity ($p = .924$). This means that during the study period, visual comfort did not play an important role in enhancing or decreasing the employees' productivity in the office space.

[3] Because of confidentiality of the results, the data visualization of the floor plan cannot be shared.



Date Time and Date1 vs. Visual Comfort Value and Light (lx). For pane Light (lx): Color shows sum of Light (lx). For pane Visual Comfort Value: Color shows details about Productivity Description1. Shape shows details about X & Y 1 (group). The view is filtered on Date1 and Date Time. The Date1 filter ranges from 8/19/2019 12:00:00 AM to 9/6/2019 11:59:59 PM and keeps Null values. The Date Time filter ranges from 8/19/2019 1:16:00 PM to 9/6/2019 4:31:00 PM and keeps Null values.



Date Time and Date1 vs. Visual Comfort Value and Light (lx). For pane Light (lx): Color shows sum of Light (lx). For pane Visual Comfort Value: Color shows details about Productivity Description1. Shape shows details about User Id, X, Y (group) B2. The view is filtered on Date1 and Date Time. The Date1 filter ranges from 8/19/2019 12:00:00 AM to 9/6/2019 11:59:59 PM and keeps Null values. The Date Time filter ranges from 8/19/2019 1:16:00 PM to 9/6/2019 4:31:00 PM and keeps Null values.

Figure 5. Illuminance (lux) levels in Zone A (top image). Illuminance (lux) levels in Zone B (bottom image). Image credit: Author.

3.2 ENVIRONMENTAL MONITORING RESULTS

Figure 5 shows the results of sensor readings of the daylight values nearest the exterior window (Zone A, direct south daylight) were compared with the levels away from the window (Zone B, indirect south daylight) as indicated in the floor plan in Figure 3. As shown, at some points, the light levels in Zone A are more than 1500 lux, while in Zone B, the highest illuminance level is 100 lux. Studies show that the standard light level for an office building should be between 300-400 lux (Richman, 2015). The results show the unequal distribution of lighting across the office space. The work spaces close to the south windows are very bright while there are some dim areas in the spaces further from south windows.

4.0 DISCUSSION

One percent improvement in productivity in office workers can be equal to the company's annual energy cost. (Romm and Browning, 1998). ASHRAE Guideline 10P (2014) states that there are four comfort conditions caused human comfort in buildings which are: (i) thermal, (ii) visual, (iii) indoor air quality, and (iv) acoustics. Visual comfort is one of the most important factors in designing living and working spaces (Konstantzos and Tzempelikos, 2017), and access to daylight enhances people's productivity (Boyss et al. 2003; Heschong, 2003; Aries et al., 2015). In this paper, visual comfort, daylight level and employee comfort are being studied with two different methods: survey and environmental monitoring. The goal of this study is to understand the relationship between visual comfort and the employees' perception of their productivity, and also the quality of daylight distribution across the open office.

The results of this study show that there is no statistically significant correlation between visual comfort and the employees' perception of their productivity. The results of the survey show that most participants who answered "too dim" or " dim but comfortable" are located in the north part of the office, while most of the participants in the south side feel "bright but comfortable". This results along with the sensor results show that there is an extreme disparity in lighting distribution across the office. The results of this study are in contrast with several studies in the literature review. Considerations for this contrast is the duration of the study which was in July and August when the altitude of the sun is high. In the summer, visual comfort and employees' perception of their productivity are not related with each other, but additional study is necessary to understand the sun angle and perception in the fall, winter and spring months. Additional data collection and surveys are necessary for comparison.

Limitations of this study include sensor data loss at the period of the study (because of the unpredictable sensors' technical issues). The term productivity is difficult to quantify. In this study, we used the question "How does your environment affect your productivity?". An alternative way to study productivity is to measure distractions from the work especially the distractions that disengage a worker from a task to correct the environment to make it more comfortable to work, i.e. turing on the desk fan/heater, wearing a sweater, closing the window shades, etc. Future studies consider measuring distractions as a value.

The sensors are small, inexpensive and can measure a variety of environmental factors such as dry bulb temperature, relative humidity, illuminance, acoustics level, pressure, and UV level. Their data collection frequency was set to gather one data point every five minutes. After researching the sensors available in the market, these sensors were decided to be the most versatile and appropriate for the goals of the study. There were several issues with the sensors which negatively impacted the study, and some important data was lost during the data gathering process. Only one device such as an iPad was only able to connect to up to five sensors, so at least four devices were needed to gather the data from all sixteen sensors. This then, necessitated pulling the data from different devices into one location for further analysis and synthesis. Second, because the sensors use Bluetooth connectivity, sometimes the devices were unable to find the sensors, and sometimes the process of connecting was time consuming. This hindered the flow and efficiency of the data collection. Third, some of the sensors stopped gathering data at some point in the study, causing gaps in monitoring and lost data.

In our future studies, data will be collected in different seasons to see how these two factors are correlated throughout the year. Additional aspects of a future study include the addition of building daylight simulation to the methodology. The goal of the future study is to improve the designers understanding of the quantitative results of building daylight simulation and sensor data through their experience in space. It also helps to build a common language between the analyst and designers in the design team to understand the daylight results better. The results of the current study will be input data for the future study.

5.0 CONCLUSION

The goal of this paper is to understand the daylight quality in space, and the relationship between visual comfort and employees' perception of their productivity in the Raleigh office. The results show that there is no statistically significant relationship between visual comfort and employees' perception about their productivity in the workspace in the summer. Daylight distribution is unequal, ranging from 100-1500 lux across the open office area. The next step will be continuing the study in different seasons to see how the relationship between visual comfort and employees perception of their productivity changes. Also, additional questions about productivity will help to improve the study and the results. Furthermore, adding building daylight simulation to the methodology may help designers to understand the quantitative results of daylight simulation and sensors and gain awareness in the decision making process.

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