VISUAL QUALITIES AND PERCEIVED THERMAL COMFORT- RESULTS OF SURVEY STUDIES IN A LEED PLATINUM OFFICE BUILDING

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ABSTRACT: Occupants are exposed to various interlinked environmental factors in office spaces. Office spaces have visual qualities, spatial characteristics, and building features that can have a significant impact on their overall perceived comfort and perceived thermal comfort. The analysis used subjective responses from 500 occupants collected from an energy efficient LEED platinum building in Charlotte, North Carolina. The survey addressed visual qualities of IEQ factors (View satisfaction, Natural daylighting, Quality of lighting, and. Based on the occupant survey, empirical analyses have examined the effects and interactions of Indoor Environmental factors (such as thermal, visual and the ability of control) on occupant perceptions. This evaluation was executed in different personal attributions, spatial locations, and configurations (classified by different floors, office layouts, distance to windows and cardinal directions) of their workspace. The results indicated that the pleasant visual qualities could positively impact the perception of thermal comfort, even when other measured visual or thermal comfort problems existed. Enhancing visual comfort (lighting and view) can improve occupants' perception of thermal satisfaction indirectly and may provide better indoor conditions in office buildings. The study implies that occupant surveys can offer a systematic measure for evaluating office spaces to enhance the perceived comfort.

KEYWORDS: Thermal comfort, Thermal perception, Visual qualities, View, Quality of lighting

INTRODUCTION

Office employees spend a considerable amount of time in their workplace. Not only they are influenced by the thermal qualities of their environment, but also their perception of comfort over time (Schweizer et al., 2006).Thermal comfort is derived from a complex interaction between the occupant and their environment. The American society of heating, refrigerating and air conditioning engineers (ASHRAE) defined it as "the condition of the mind in which satisfaction is expressed with the thermal environment". In accordance with this definition, thermal comfort is a state of mind rather than a state condition that can be influenced by personal differences and the individual perception of other environmental factors (Lin & Deng, 2008).The physical parameters play significant role in thermal perception and parameters such as visual comfort, activities, clothing, and psychological factors (Nikolopoulou & Steemers, 2003). Recently, the experiment of virtual reality has been employed as a tool to measure and assess the qualitative and quantitative aspect of human perceptions and their interactions. As the study shows, the lab experiment regarding the ten variations of the climatic context in urban spaces shows that the thermal perceptions of humans can be altered by visual qualities. For example, processing only sky, shadow and lighting effects(Vigier, Moreau, & Siret, 2015). Previous studies addressed the comfort factors that focused on the effects of a single human satisfaction. Their influences on occupant comfort remain the primary measure for predicting productivity and satisfaction within the workplace. The goal of this paper is to investigate if enhancing visual comfort (lighting and view) can improve occupants' perception of thermal satisfaction indirectly to provide better indoor office building conditions.

This paper chose a LEED platinum office building to evaluate the statistical correspondence of visual and thermal perception of people through a survey to address the following questions:

(1) Does occupant satisfaction with thermal and visual qualities change depending on different occupant locations in the building (floor, cardinal direction, distance to window, and office layout)?
(2) Does the priority of visual and thermal quality change among different groups of occupants (groups in terms of gender, age, and work duration)?

2.0 METHOD

2.1 Research design

This study is based on a survey of occupants in an office building in Charlotte, North Carolina. The inhabitants were asked by email to complete a questionnaire concerning their experience in the office with a focus on indoor environment conditions. The survey was done in August, 2016. During the study, the building's performance was

undergoing measurements and verification studies.

2.2 Site
The office building is 51 stories high on a one-million-square-foot city block in Charlotte, North Carolina. The building contains private, semi-private, and open-plan office spaces. The building was awarded an ENERGY STAR certification by the Environmental Protection Agency for its overall energy efficiency.

2.3 Survey participants
Random Occupants of the sample floors were selected and invited to complete a questionnaire on paper. Approximately 21% of people who received the email agreed to participate. The participants were equally distributed over the office building.

Table 1: List of personal attribution:

Personal characteristics	**Description**	**Sample size (n)**	**Percentage (%)**
Gender	Female	281	56.7
	Male	212	42.7
	Unknown	3	0.6
Age	20 or below	4	0.8
	21-30	86	17.3
	31-40	168	33.9
	41-50	136	27.4
	51 or above	93	18.8
	I prefer not to answer	9	1.8
Time of working in the building where you currently work	Less than 1 year	176	35.5
	1-5 years	306	61.7
	5+ years	14	2.8

2.4 Measures
2.4.1. Questionnaire
Participants received a 25-item questionnaire. As the employees were informed, the intention of the questionnaire was to understand how office users perceive the office environments and how they rank the important factors. The table 1 indicates the personal attributions of occupant that include age, gender, and duration of time of working in the workspace. In addition to the demographic questions), the questions concerned perception of the office environment and overall occupant satisfaction into three main categories: Thermal, Visual qualities and General qualities that indirectly affect the other two major categories. These groups of items represent the satisfaction level of respondents with each questionnaire item on the seven-point scale ranging from 'very dissatisfied' (coded as 1) to 'very satisfied' (coded as 7). Table1 summarizes the questionnaire items used in the analysis for this study.
Since this study focuses on the influence of visual qualities on occupant thermal perception, the analysis is based on the workspace attributions such as cardinal direction, floor (as external factors), different office layouts, and distance to windows (as internal factors) that are described in table 2. Basically, work space attributions consider the occupant's position in the horizontal and vertical axis as average quantities to assess the qualitative perceptions of human.

Table 2: List of questionnaire items

Category	Items	Survey questions	Rating scale
Thermal comfort	Thermal condition	I am satisfied with the thermal conditions in my office workspace.	1=Strongly disagree 7=Strongly agree
	Temperature	In general, how satisfied are you with the temperature in the workspace where you spend the most time?	1=Very Dissatisfied 7=Very Satisfied
Visual qualities	Quality of light	I am satisfied with the QUALITY of light in my office workspace.	1=Strongly disagree 7=Strongly agree
	Access to daylight	I am satisfied with ACCESS to natural daylight in my office workspace.	1=Strongly disagree 7=Strongly agree
	View	I am satisfied with the VIEW from my office.	1=Strongly disagree 7=Strongly agree
Control	ABILITY to alter the temperature	I am satisfied with the ABILITY to alter the temperature in my office workspace.	1=Strongly disagree 7=Strongly agree
	ABILITY to alter the electric lighting	I am satisfied with the ABILITY to alter the electric lighting to meet my needs.	1=Strongly disagree 7=Strongly agree
	ABILITY to alter the blinds	I am satisfied with the ABILITY to alter the blinds and daylight source to meet my needs.	1=Strongly disagree 7=Strongly agree

Table 3: List of Work space attributions

Work space attributions		Description	N	(%)
Internal	Office Layout	Enclosed private	76	15.3
		Enclosed shared	82	16.5
		Open-plan	169	34.1
		Open Office: cubicles with high partitions	160	32.3
		Open Office: cubicles with low partitions (lower than 5 feet)	9	1.8
		Open Office: workspace in open office with no partitions	76	15.3
		Other	128	25.8
	Distance to Window	0-5 feet	62	12.5
		6-10 feet	75	15.1
		11-15 feet	231	46.6
		16 feet or more	128	25.8

External	Cardinal Direction	Facing north (or northeast or northwest)	118	23.8
		Facing south (or southeast or southwest)	158	31.9
		Facing west	84	16.9
		Facing east	60	12.1
		I don't know	76	15.3
	Floor	1 to 4	85	17.1
		5 to 9	205	41.3
		10 or above	206	41.5

The internal work space attribution classifies the office layouts into five categories, depending on the level of personal enclosure: (1) Enclosed private office, (2) Enclosed shared office, (3) Cubicles with high partitions (about five or more feet high), (4) Cubicles with low partitions (lower than five feet high), and (5) Open office with no partitions or limited partitions. Another internal variable is the distance to the window that considers how close the primary workspace is to the nearest exterior window. In this internal category, the distance of work space to windows is divided to three types: 0-5 feet, 6-10 feet, 11-15 feet, and 16 feet or more. Cardinal direction related to external work space attributions is defined by the closest cardinal direction of the nearest exterior window. The four major orientations are used along with (North, South, West and East) the uncertain response (I don't know). The Floor is the other external work space attribution that influences the occupant's overall satisfaction. The floor is grouped in three main groups: 1 to 4, 5 to 9 and 10 or above.

3.0 RESULTS

The radar charts are derived from regression coefficients to study the correlation of the visual,thermal and controls factors regarding the overall satisfaction of the occupant. In order to estimate impacts of different factors (visual, thermal and control) on occupant overall satisfaction, multiple regression analysis is concluded in the survey responses into two sub-groups (personal and work space attributions) for two major purposes. First specify the relation of different factors (visual, thermal and control) to each other. Second, the evaluate the impact of each factor to overall occupant satisfaction. Hence the increase or decrease in overall satisfaction, depending on whether an occupant is satisfied or dissatisfied with particular factors. The multiple regression analysis produces the coefficients for the significant factors of variables. :(Kim & de Dear, 2013).

3.1 Personal characteristics and attributions

Based on the regression coefficients displayed in figure 1.a, the satisfaction of quality of light declines as the duration of working increases from 'less than 1 year' (0.25) to '1 to 5 years' (0.16). However, the satisfaction of natural light increases respectively as the working duration of occupants '1-5 years' (0.13) to '5+ years' (0.23) increases. The 'view satisfaction' item follows this pattern as well meaning that occupants with less than 1 year of living in the building are less satisfied (0.16) in comparison to '1– 5 years' (0.17). The 'thermal satisfaction' is increased from 'less than 1 year' to '1-5 years' or 0.18 to 0.21 correspondingly. Control items follow the same pattern This means that as the working duration in the building increases, the satisfaction of control items would also increase too, i.e. 'Less than 1 year' (0.02) to 5+ years (-0.16).

As Figure 1.b shows, there are two variables of visual factors for male and female that impact on occupant satisfaction. On the contrary of males, females are more satisfied with 'quality of light' (0.25) rather than 'View' (0.11). Males are more satisfied with 'view satisfaction' (0.22) and are less satisfied with 'quality of light.' The thermal satisfaction is more pleasant for males (0.22) than females (0.20). The control items are not significant for both groups except the 'ability to alter the blind' for males is 0.1. As the graph shows, the View satisfaction for man and quality of light for female are the visual factors that have the directional relationship with thermal satisfaction.

According to figure 1.c The higher age of occupant causes their satisfaction are more depend on the quality of light. The age groups: 21 to 30, 31 to 40 and 51 or above correspond to 0.13, 0.16, and 0.20 respectively. The view satisfaction is quite similar between ages '21 to 30' (0.20) and '51 or above' (0.21). The group age of '31-40' (0.13) ranked second in all of the satisfaction factors. However, thermal comfort among the age groups does not follow the same pattern. The thermal satisfactions of the age groups are almost the same (0.20, 0.19, and 0.20) except for '20 or below' because it is higher than the others (0.25). The 'ability to Control' ranked the third factor that influences overall satisfaction. Only the occupants who are in the '21 – 30' group are the most satisfied with the ability to alter the temperature and blinds (0.11), but they are less satisfied with the 'control' factor in comparison to others. In summary, the people in the age range of "21 – 30" are the most satisfied (0.1).

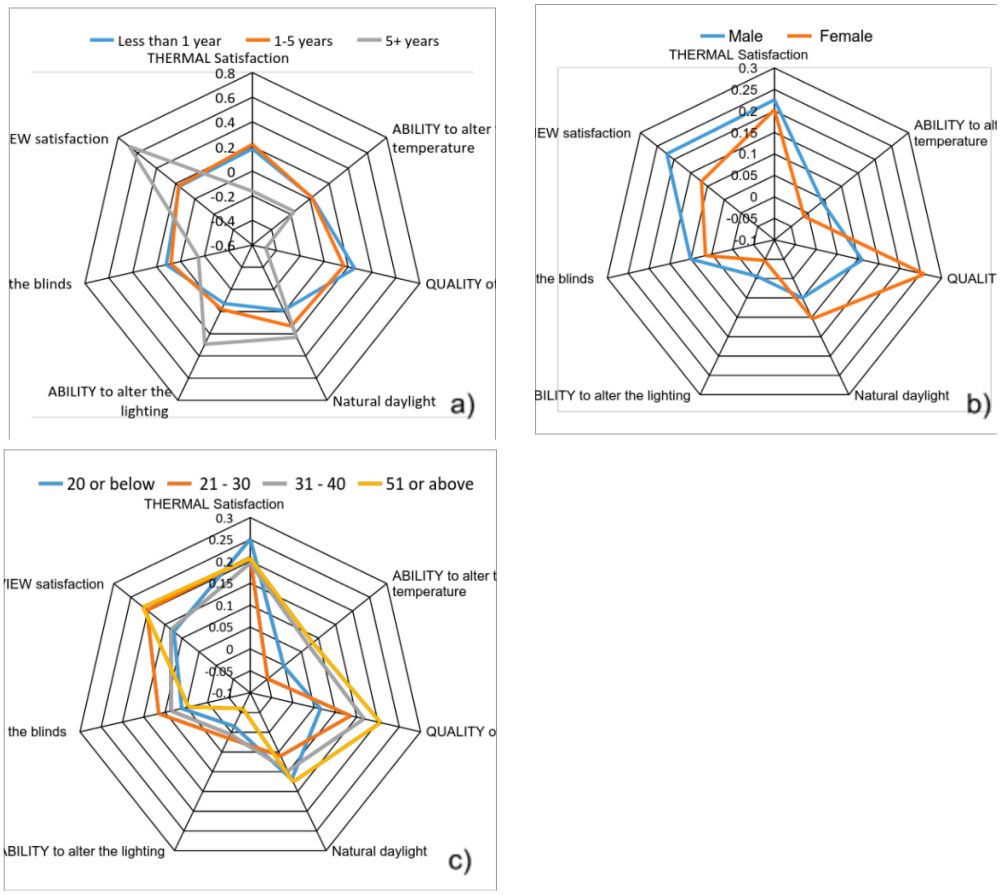

Figure 1: The impact of visual, thermal, control factors in overall satisfaction estimated by regression coefficients for a) Work duration, b) Gender, c) Ages

3.2. Cardinal directions

As figure 2.a indicates, all occupants from different orientations of the building have a significant 'view' satisfaction except the East orientation. From the East to West side, satisfaction with the quality of light and natural daylighting declines but 'view satisfaction' does not show any correspondence with them. Apart from the East side, all of the other sides were significant in 'view satisfaction, ' and the West was the highest ranked among other sides (0.283). Satisfaction with 'thermal conditions' that were facing the South significantly outscored the other cardinal directions (0.307). The rank of the West was as significant of a number for the North (0.192, 0.212). Thermal satisfaction for the East side was the second most influenced factor in overall satisfaction. Nevertheless, thermal satisfaction was the lowest among other cardinal directions. None of the control factors had significant numbers in all cardinal directions.

3.3. Floor groups:

As figure 2.b indicates, all occupants from floor groups had a similar overall satisfaction rate but with different factors that played different roles in their perception. Although the 'quality of light' and 'view satisfaction' in '10 floor or above' have a higher rank (0.25, 0.247), the pattern is not followed when it compares to the floor group of '5-9' since it has the lowest rank (0.12). The 'natural daylighting' satisfaction (0.124) plays a notable role in the visual perception of people which resulted because of the pattern change. In floors 1 to 4, the 'view satisfaction' (0.20) and 'quality of light' (0.16) are in second place among other floor groups. Thermal satisfaction is the first item that influences overall satisfaction of '5 to 9' floors (0.24) while the visual factor ranked as second in compare to other floors and the 'ability to alter the temperature' on the same floor is notably high (0.24).

3.4. Office layouts

Regardless of office layouts, the 'view' satisfaction was identified as the most significant quality determinant of occupant workspace satisfaction. On the other hand, the relative importance of factors is varied between different office layouts. The 'quality of light' satisfaction is the main factor that most clearly differentiates them. The quality of light (0.31) is significantly different in enclosed offices (public and private) because the quality of light was one of the least important factors for those in open offices.

In open offices, its comparative importance to 'view satisfaction' (0.29) increased as the degree of the enclosure (partition) decreased among open offices. As a result, It ranked as the second most important factor for enclosed offices (0.248), low partitioned offices (0.162) and no limited partitioned offices (b 0.29).It was the most important factor for high partitioned offices (0.11). However, thermal satisfaction does not follow the same pattern; it becomes the third most important factor in enclosed offices since it is, relatively higher than other office layouts. Also, as the degree of enclosure was reduced, the thermal satisfaction decreased in open offices.(Figure 2.c)

3.5. Distance to the window.

Visual factors of the 'distance to window' are varied. The highest rank in quality of light belongs to occupants who work in '1-6 feet' of a window (0.38), and the lowest belongs to those who work in '16 feet or above'. The highest number in satisfaction of 'natural daylight is lower (0.202). This shows that the trend decreased as the distance of the occupants to a window increased. The thermal satisfaction has a directional relation with distance. In other words, as the distance to window increases, the occupant is more satisfied except for those who are in '16 feet or above' (0.276) This is slightly less than 11-15 feet (0.283). All satisfaction with visual control abilities increases as the distance of the occupant to the windows declines. As the graph indicates, the occupants are more satisfied with 'ability to alter blinds' (0.20) in '0-5 feet' and the 'ability to alter the lighting' (0.14) in '6-10 feet' of distance. This has the highest rank among other distance groups.

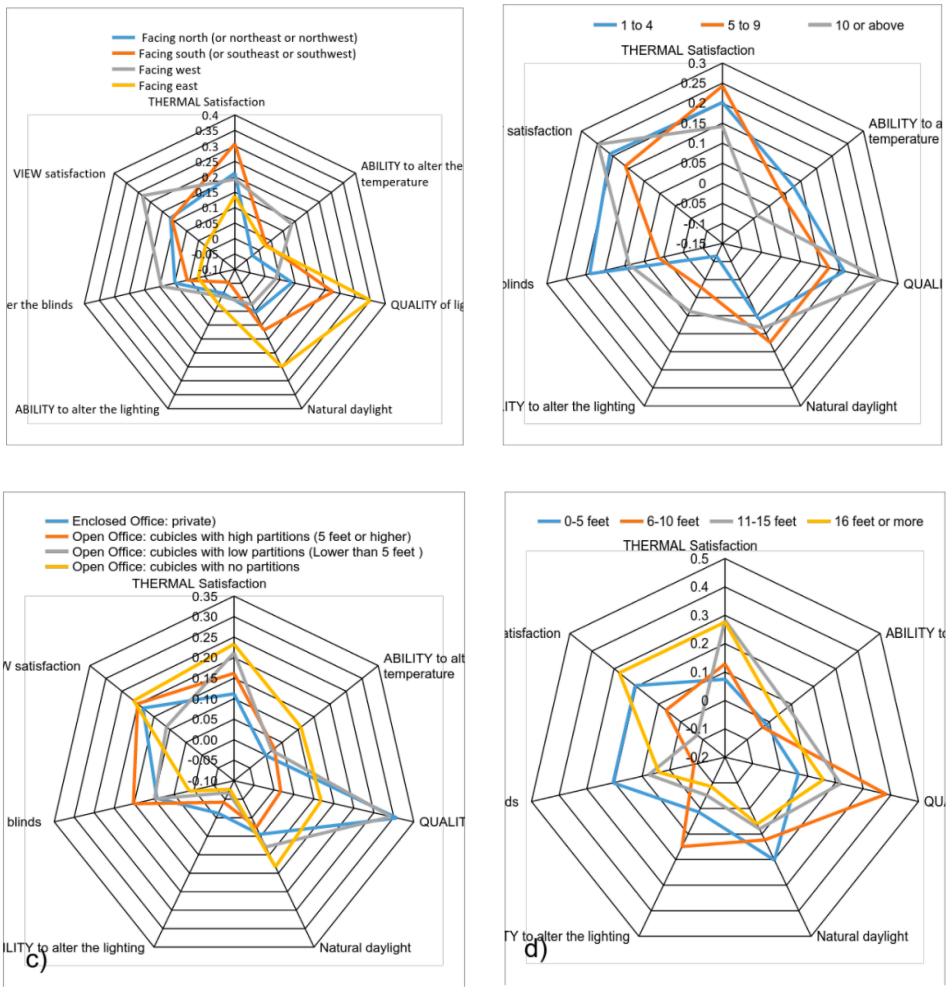

Figure 2: The impact of visual, thermal, control factors in overall satisfaction estimated by regression coefficients for a) Cardinal direction, b) Floor, c) Office layout, d) Distance to window

4.0 DISCUSSION AND CONCLUSION

According to regression coefficients of personal characteristics, (Fig. 1) individual attributions play a significant role in human perceptions. According to our hypothesis, the pleasant view and quality of lighting have a larger effect on overall satisfaction and can reduce the perception of dissatisfaction in thermal factors. Because of the adaptation process between occupant and environment, the work duration increases the satisfaction between visual qualities and thermal

comfort can potentially influence each other and alter the perception regarding cooler or warmer indoor environments. The assessment of age groups shows that the higher the age group is, the more satisfied they are with visual and thermal comfort even though they are more likely spend more time in the building. All of these individual factors imply how thermal and visual qualities are subjective and can be vary among other groups of people. It also emphasizes how flexible our perception of the environment is and that it can be easily altered by external factors such as the quality of lighting or view satisfaction.

Results show that the different workspace attributions can influence the occupant's perception. However all of those influences are not direct, and because of the qualitative aspect of the data, concrete conclusions to of the hypothesis cannot be determined. The results do not explicitly show how much the thermal perceptions of an occupant are influenced by visual qualities. However, the assessment of cardinal directions shows how much the qualitative variables such as 'view' can strongly influence occupant perception. The West side can potentially be considered as an undesirable side of the building since it can be exposed to excessive amounts of light in the afternoon that cause glare while being deprived from natural daylighting. However, because of a pleasant view (as the occupant defined) it could influence the overall satisfaction. These findings highly support the qualitative results of virtual reality lab too, as their results shows, simple visual cues (sky, sun, shadows, light post-process effects) impact on thermal impressions during the virtual experience that can lead to change the person thermal comfort too(Kim & de Dear, 2013).
It is expected as the levels of the floors increase, the level of visual qualities increase as well. Although the 'quality of light' increases in accordance with expectation, the view in floor '1 to 4' was perceived as more pleasant by the occupant of that floor. This reason might be derived from the connection of occupants and urban context. More importantly, the coefficient b of thermal satisfaction was higher in floors that emphasized the indirect relation of thermal satisfaction and view. As view satisfaction increases, thermal satisfaction can increase too(Vigier et al., 2015).
As the analysis and results of the office layout shows, increasing the visual qualities for both view and lighting can potentially increase thermal perception. Therefore, the open office layout with partitions had better performance and as the partitions became lower the satisfaction enhanced. In some cases, the high partition has a better view satisfaction in comparison to low office partition. These numbers are also influenced with by categories such as the distance from the windows. The distance to window shows that the closer occupants are to the window, the more the view and visual qualities increase. This In result, this could influence thermal perception and thermal satisfaction.

Because of the qualitative nature of data and analysis, the direct relation of visual qualities and thermal perception cannot be proved completely. However, the results from the virtual reality assessment can reinforce the hypothesis about the relation and domination of visual effect on thermal comfort.

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