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Comparison of mood and task performance in naturally-lit and artificially-lit environments

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Abstract

The article presents the results of a laboratory study conducted at Shanghai Tongji University. The study compares participants' mood and task performance between naturally-lit and artificially-lit environments, with a view to identify negative impacts, such as lighting variation and temperature asymmetry caused by dynamic natural light. It was observed that the mood change in the naturally-lit environment was more significant, especially the decrease of positive mood, than in the artificially-lit environment. For the subjects in the naturally-lit environment, performance scores decreased with increase in the light intensity and temperature asymmetry. Based on the study results, suitable daylighting design was recommended for classrooms or offices.

Keywords

Artificial light, Comparison, Mood, Natural light, Task performance

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Introduction

Literature reviews[1–4] show a strong preference for natural light in workplaces and classrooms because of the belief that natural light supports better health and productivity. Several surveys[1–5] report of people's belief that natural light is superior to electric light, and office workers and university students prefer daylight for psychological comfort and general health. However, as natural light comprises two distinct components, namely diffuse light and direct sunlight coming from the sun, the real natural light environment is dynamic and complicated. When sunlight is present, illuminance levels generally tend to be higher than the minimum level recommended for performing almost any given task.[6] Also, when sunlight is admitted, local temperature will be much higher.[7] The unwanted local heating of the indoor space gives rise to abnormal vertical temperature differences (also called temperature asymmetry), which in turn cause thermal discomfort. Particularly, the people engaged in light sedentary activities, like office workers or students, are sensitive to temperature asymmetry.[8]

Natural light in indoor space has both positive and negative impacts. Positive impacts include enhancement of visual, emotional, and psychological well-being of occupants,[9,10] and negative impacts include such factors as glare, overheating, or general dissatisfaction of occupants.[5,11–17] People like natural light, provided that no associated discomfort disturbs their activities. Therefore, people's preference to natural light is not unconditional. To fully understand the benefits of natural light, it is necessary to study the effects of variations in lighting and local temperature caused by the dynamics of natural light. This study, therefore, is aimed at exploring beyond the extant knowledge on daylighting-behaviour by comparing subjects' mood and performance between naturally-lit and artificially-lit environments. Besides, the potential negative

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impacts of a naturally-lit environment, because of its instability and variance, would be identified and suitable high quality daylighting design recommended for workplaces and classrooms.

Literature review

Previous research by Commission International de l'Eclairage (CIE) or Illuminating Engineering Society of North America (IESNA) on lighting-behaviour was focused on generating designs that could satisfy the requirements of visual tasks without causing extreme discomfort.[18] However, in that endeavour, the research obviously ignored the possibility that lighting conditions could become positive contributors to employee performance and well-being. Recent studies started laying more emphasis on the quality of daylight environment.

Mohamed Boubekri et al.[19] attempted to assess the effects of window size and sunlight penetration on a person's emotional response and satisfaction by studying a sample of 40 office workers in an office. Each subject was asked to proofread one page of text and fill in a questionnaire conveying his or her mood and satisfaction level at that time. The results of study suggested that control over sunlight penetration could be used to promote or facilitate certain activities that were desirable in office settings. Moderate amount of sunlight penetration seemed to be optimal for tasks requiring relaxation. Further, it was found that very large sunlight penetration causes negative feelings. More recently, Wang and Boubekri[20] conducted an experiment in a sunlit multifunctional seminar room to measure the occupants' mood, preference, and task performance. Ten different seating locations in the room, which had different levels of exposure to sunlight and access to outdoor view, were examined. Each experimental session lasted about 50 min. The subjects were asked to rate their mood and to complete two cognitive tasks. It emerged that the optimal zone with a sense of privacy and control was located close to a sun patch. The two above cited studies indicate that other characteristics of the room where daylight is defined are as important as the lighting elements. Without evaluating the room environment as a whole, assessing the benefits of daylighting, sunlight, or a window view would not be meaningful.

To study the interactive effects of indoor environmental parameters, a survey was conducted in the campus office at Tsinghua University.[21] The subjects and measurement points were located symmetrically in the room where, during the survey, the temperature, noise, and lighting were controlled mechanically. The subjects were asked to express their satisfaction at different combinations of the three parameters. The survey results revealed that indoor environmental factors offset the effect of each other to a certain extent, and that the subjects were less sensitive to changes in luminance. Other studies[22,23] also show that physical environmental parameters are interrelated and that the feeling of comfort is a composite one involving the occupant's sensations to all the parameters. However, occupants' preferences to different environmental parameters may not reveal the real impact of lighting environment, because in a short-term study, the occupants may not always correctly perceive the stimuli and hence their immediate judgments may not be correct. Nonetheless, these studies stress the need to consider other environmental aspects, such as changes in local thermal environment with variations in natural light.

This study compares the variations in subjects' mood and task performance between naturally-lit and artificially-lit environments. The objective of this research is to ascertain whether the variations and asymmetry caused by dynamic natural light can significantly affect work performance and mood.

Method

Settings

The experiment was conducted in a 5.0 m (length) × 3.0 m (width) × 2.7 m (height) chamber, located next to windows on the second floor of a laboratory building at Tongji University, Shanghai. The experiment was conducted in mornings (09:00–12:00) of October 2011, during which the chamber was not in the shadow of surrounding buildings (Figure 1). The chamber was divided into two subrooms by an opaque screen (Figure 2): one room had windows for natural light and outdoor view (one residential building and lawns in front); the other room had its windows opened to the indoor area and was lit by artificial lights only. The artificial lights consisted of 64 efficient light bulbs, each of them with power 9 W, luminous flux 495 lm and colour temperature more than 4000 K. The artificial lights could be moved up and down to control the light intensity on the desk. Two different environments (a naturally-lit environment and an artificially-lit environment) were thus created. To control glare, blinds were installed on the two windows towards indoor and outdoor, respectively, and they were adjusted before each session to make sure that there was no direct glare from sun or lights within the sight of the seated participants.

Participants

Fifty-two participants (26 pairs) – 12 females and 40 males – were recruited for this experiment.

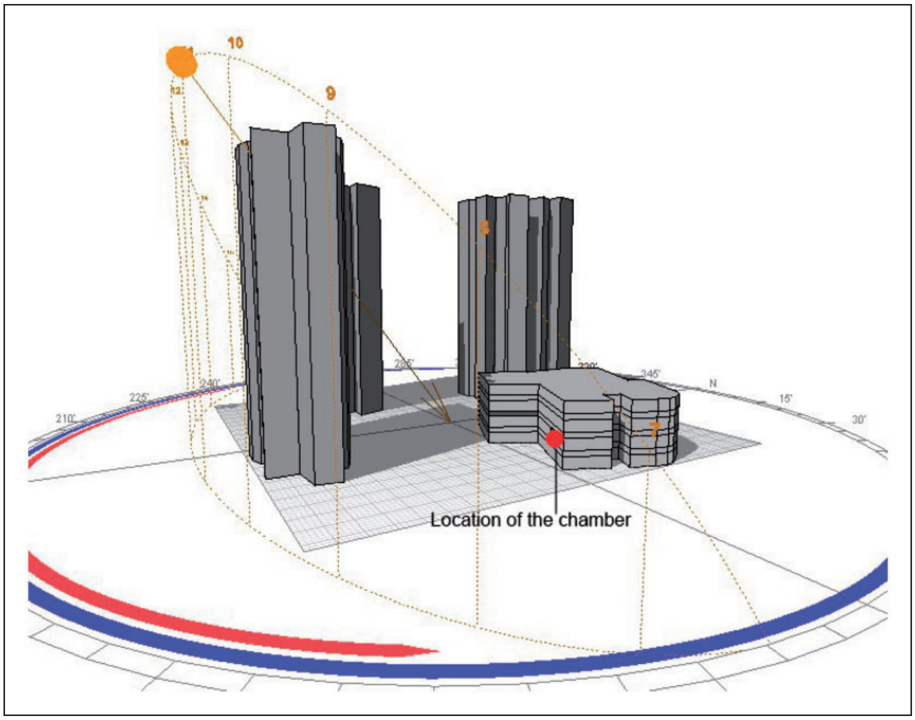

Figure 1. Site and sun path analyses (15 October).

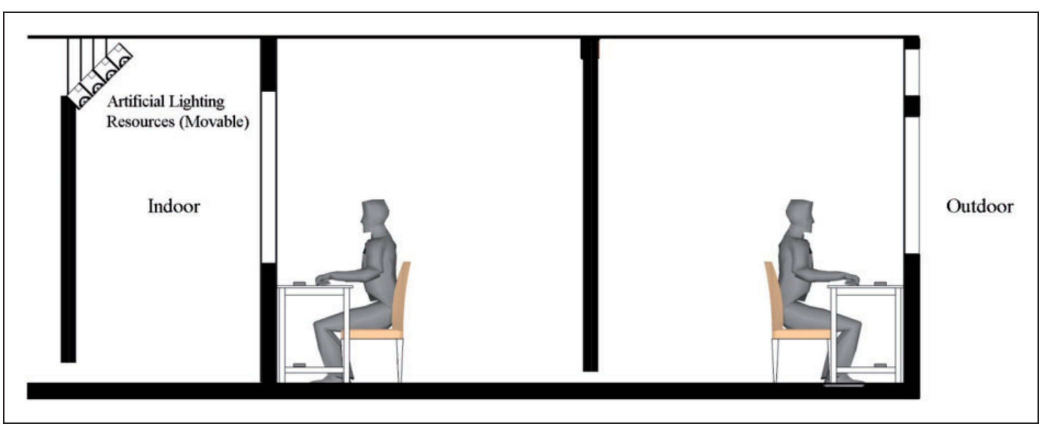

Figure 2. The chamber's setting.

The recruitment of each pair was based on two key criteria: First, the participants must be of the same gender and belong to the same class, preferably the same dormitory room; second, they must be free from chronic diseases, such as asthma, allergy, hay-fever, and colour-blindness. The participants were all university students, aged 20–26 years. They were required to wear long-sleeved sweater, long and thick trousers, long top and bottom (underwear), and socks and shoes, all with an estimated insulation value of 1.20 Clo, including the insulation of the chair. They were also asked to have good rest on the night before the experiment. All the participants completed their experimental sessions successfully. Verbal and written informed consent was obtained from all the participants before they participated in the experiment. All protocols were approved by the university's ethics committee.

Procedure

Each experimental session lasted about 40 min. To start with, an instructor explained the participants about the process of this experiment and asked them to sign the consent form for participating in this study (5 min). After that, the participants were required to first rate their mood according to a questionnaire (5 min), complete a letter cancellation task (25 min), and again rate their mood (5 min). The process satisfied the requirement that, in daylight-behaviour studies, the exposure time should at least be 30 min. In each experimental session, noise and temperature were maintained at the same level in the two rooms. In the artificially-lit room, the light level was kept constant during each session; the artificial lights were adjusted to emit different lighting levels for different sessions. In the naturally-lit room, the light level was changing depending on the outdoor condition.

Positive and negative affect schedule

For measuring mood in this study, Watson's Positive and Negative Affect Schedule (PANAS)[24–26] was used. PANAS comprises two sets, one for measuring positive affect (PA) and the other for negative affect (NA), each set with 10-item mood scales. PA and NA have been used extensively as factors in the self-reported mood literature and lighting literature.[20,27–29]

In this study, the 10 descriptors for the PA scale were "attentive", "interested", "alert", "excited", "enthusiastic", "inspired", "proud", "determined", "strong", and "active" and those for the NA scale were "scared", "afraid", "upset", "distressed", "jittery", "nervous", "ashamed", "guilty", "irritable", and "hostile". The mood questionnaire was on a single page with 20 descriptors. The subjects were asked to rate on a 5-point scale the extent to which they had experienced each mood state at a given time. The points of the scale were labelled thus: "not at all", "a little", "moderately", "quite a bit", and "very much". PA and NA measure different aspects of emotional fluctuation. Mood was measured twice, once before the letter cancellation task and then again after the task. The task had a certain level of difficulty and might negatively affect the subject's mood. The mood change was measured by subtracting the second mood score from the first one. The measurement would then indicate to what extent the natural environment or artificial environment conditions in the room could moderate the mood change due to the task. PANAS could help detect a subtle mood variation – people might not be cognizant of this change.

Letter cancellation game

Letter cancellation game was used to evaluate participants' concentration and cognition. Though the game was designed as a task to assess an individual's capacity to sustain vigilance, it could also be conceptualized as a measure of one's ability to pursue a goal in the face of interference intrinsic to the task. In this study, the task involved six pages containing 126 rows of letters wherein the participants were instructed to locate and mark, by striking through, every "i" and count the number of "i's" included in each row. Participants could get 1 score if he or she counted the right number of "i" in one row. A score of 126 was considered perfect score. The task was difficult in several ways. For example, a target letter with few distinctive features could be selected that closely resembled one or more other characters. In this study, the target letter "i" closely resembled the letter "j". In fact, the physical form of "i" was wholly subsumed within the form of "j", thus making discrimination difficult. The letter cancellation task required an individual to search for a target in a visually noisy context. All participants were university students with basic capability of English, so there was no language barrier for them to play the game.

Measurement of lighting variation and temperature asymmetry

During each experiment session, for each participant, temperature, relative humidity, and light intensity were measured by HOBO data loggers at 10-s interval. HOBO data loggers could be rapidly deployed in monitoring environmental conditions. For each participant, two HOBO data loggers were placed, one at 0.1 m height and the other at 1 m to measure temperature asymmetry (difference between the temperatures at 1 and 0.1 m heights). The light intensity on the desk was also measured by the HOBO data logger placed at 1 m height. Totally, four HOBO data loggers were used in each experiment session for two participants. They were calibrated and their measurement range and deviation were the same. The operating range for temperature was from $-20^{\circ}C$ to $70^{\circ}C$; the range for humidity was from 0% to 95%; the range for light intensity was from 21.53 to 6458.35 lux with accuracy at ±21.53 lux. HOBO data loggers used footcandles as the unit of light intensity. To be consistent with International System of Units, this manuscript used lux at the conversion rate of 10.7639104 (one footcandle was equal to 10.7639104 lux).

Results

Physical environment

The physical measurement results are shown in Table 1. The group 1 subjects were tested in the naturally-lit environment. The light intensity and temperature varied significantly; the temperature at 1 m height, as also the temperature asymmetry, showed significant

Table 1. Physical measurements.

	Group	Minimum	Maximum	Mean	SD
Intensity (lux)	1	118.40	8901.75	2536.32	1939.56020
	2	107.64	635.07	257.61	120.70577
Temperature 1 (°C)	1	19.42	33.17	24.12192	3.227322
	2	19.04	25.17	22.85365	2.075972
Temperature 01 (°C)	1	18.66	24.01	21.50295	1.71358
	2	19.04	24.4	22.34161	1.608924
Asymmetry (°C)	1	0	10.31	2.267371	2.083164
	2	−0.77	1.55	0.512032	0.566235

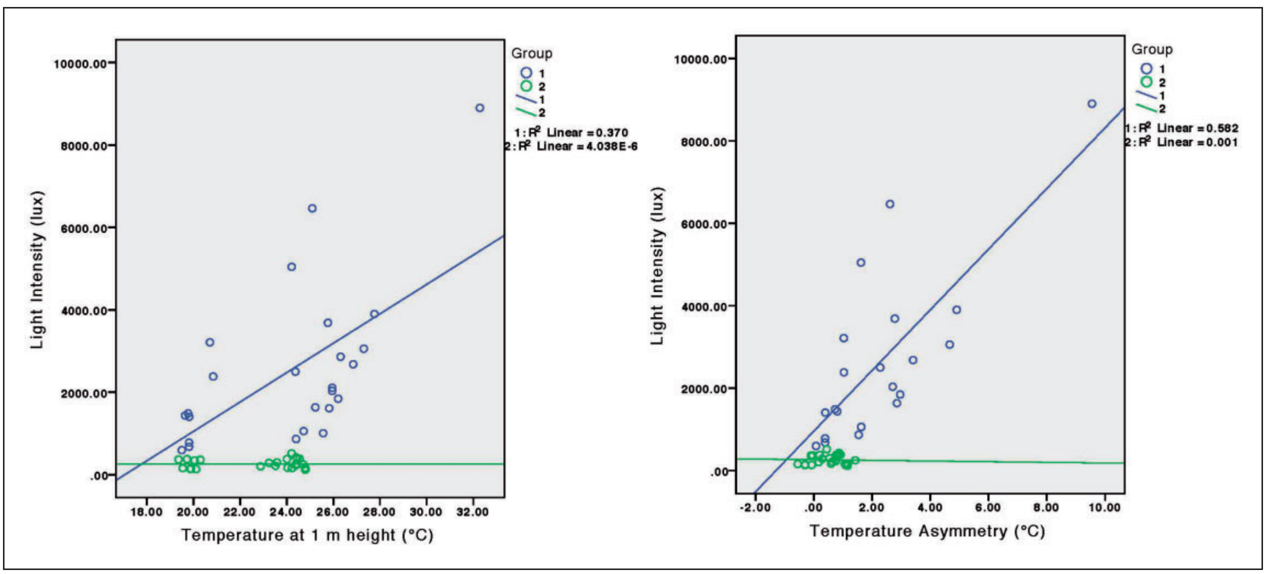

Figure 3. Relations between light intensity and temperature.

linear relation to the light intensity. However, this was not true for artificially-lit environment (Figure 3).

Task performance

The best performance score of both groups 1 (being tested in the naturally-lit environment) and 2 (being tested in the artificially-lit environment) was the perfect score (126). For group 1, the minimum score was 84.0 and mean score 115.0; the corresponding scores for group 2 were 97.0 and 117.5. The *t*-test showed that the difference ($p = 0.375$) between the two groups was not significant.

Mood

Table 2 showed sums of the PANAS items. Before the task, group 1 scored higher in PA while scored

Table 2. Sums of PANAS items.

	Group	Minimum	Maximum	Mean	SD
Positive affect	1	10	38	24.038	6.043
(before test)	2	13	35	23.731	5.937
Positive affect	1	10	30	18.423	6.488
(after test)	2	10	37	20.577	7.382
Positive affect	1	−25	8	−5.615	7.161
(after–before)	2	−17	11	−3.154	6.316
Negative affect	1	10	22	11.846	3.307
(before test)	2	10	28	11.962	3.715
Negative affect	1	10	25	13.500	4.375
(after test)	2	10	31	12.962	4.771
Negative affect	1	−8	10	1.654	3.521
(after–before)	2	−6	15	1.000	4.271

PANAS: Watson's Positive and Negative Affect Schedule.

Table 3. Paired-samples *t* test.

		Group 1			Group 2		
		Mean	Difference	Sig.	Mean	Difference	Sig.
Excited	Before	2.0	−0.6	**0.007**	2.1	−0.1	0.703
	After	1.4			2.0		
Interested	Before	2.8	−0.8	**0.001**	3.0	−0.9	**0.002**
	After	2.0			2.0		
Enthusiastic	Before	2.7	−1.1	**0.000**	2.3	−0.5	0.020
	After	1.6			1.8		
Proud	Before	1.9	−0.1	0.732	1.9	0.1	0.703
	After	1.8			2.0		
Determined	Before	2.5	−0.5	**0.049**	2.5	−0.1	0.739
	After	2.0			2.5		
Active	Before	2.5	−0.7	0.005	2.6	−0.4	0.125
	After	1.8			2.2		
Inspired	Before	2.5	−0.8	**0.003**	2.1	−0.1	0.677
	After	1.7			2.0		
Alert	Before	2.2	−0.5	**0.037**	2.2	−0.4	0.052
	After	1.8			1.7		
Strong	Before	2.2	−0.4	0.096	2.3	−0.5	**0.025**
	After	1.8			1.8		
Attentative	Before	2.7	−0.3	0.215	2.8	−0.3	0.244
	After	2.4			2.5		
Scared	Before	1.2	0.1	0.327	1.3	−0.1	0.523
	After	1.2			1.2		
Afraid	Before	1.1	0.2	0.057	1.2	−0.2	0.103
	After	1.3			1.0		
Upset	Before	1.3	0.1	0.327	1.1	0.3	0.110
	After	1.4			1.4		
Distressed	Before	1.1	0.2	0.057	1.0	0.2	0.134
	After	1.3			1.2		
Jittery	Before	1.3	0.1	0.478	1.5	0.1	0.416
	After	1.4			1.6		
Nervous	Before	1.3	0.3	**0.036**	1.4	0.2	0.306
	After	1.7			1.6		
Ashamed	Before	1.1	0.0	0.713	1.0	0.0	1.000
	After	1.1			1.0		
Guilty	Before	1.0	0.1	0.327	1.1	0.1	0.185
	After	1.1			1.2		
Irritable	Before	1.3	0.3	0.107	1.3	0.2	0.170
	After	1.7			1.5		
Hostile	Before	1.1	0.2	**0.043**	1.1	0.2	0.096
	After	1.2			1.3		

Note: Bold font represents values whose significance is <0.05.

lower in NA, probably implying that participants had a good first impression on the naturally-lit environment when they entered the room. After the task, the result was converse: group 2 scored higher in PA while scored lower in NA. Both the groups showed decreases in PA while increases in NA. Obviously, compared to group 2, group 1 decreased more in PA while increased more in NA.

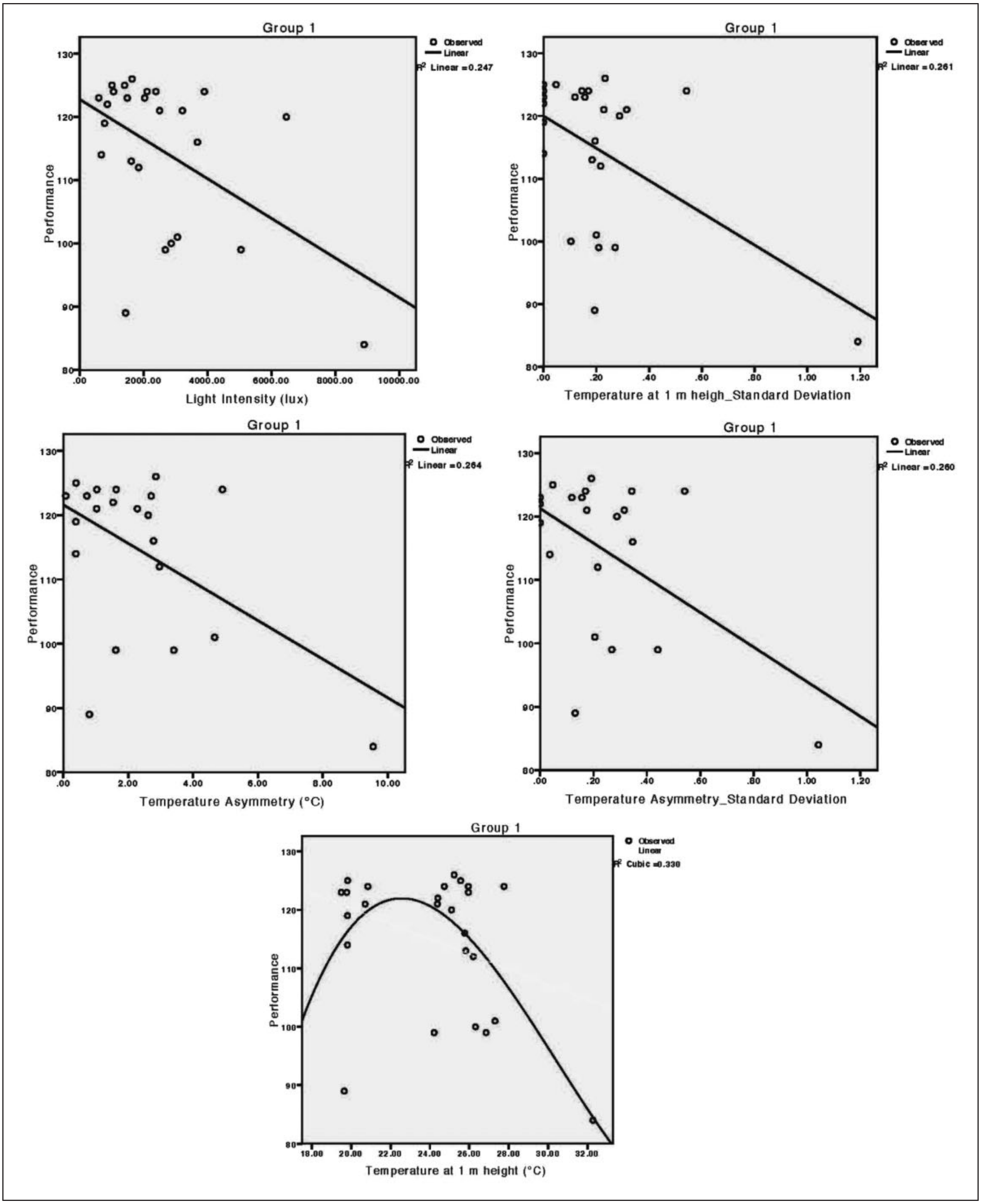

Figure 4. Most significant relationships between objective and subjective data.

Paired-samples *t* test was used to examine which PANAS items were perceived significantly different before and after the letter cancellation task (Table 3). Group 1 participants showed significantly less excited, interested, enthusiastic, determined, inspired, and alert while more nervous and hostile after they completed the task; group 2 participants only showed significantly more interested while less strong after they completed

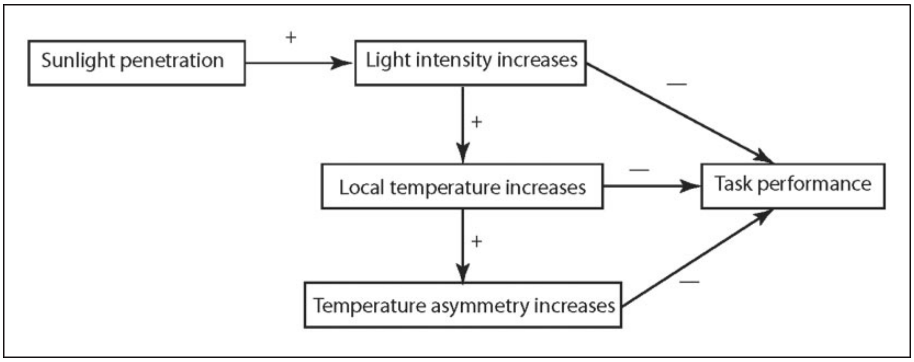

Figure 5. Relationships established in this study for naturally-lit environments.

the task. Obviously, the mood change, especially the decrease of positive mood, for group 1 was more significant than group 2.

Relationship

Regression analyses were conducted to ascertain if there was any relationship between the subjective and objective data and if this was present, what was the nature of the relationship? Subjective data referred mainly to the measured mood changes and task performance scores and objective data to the mean values and standard deviations of lighting intensity and temperature measured in each experimental session. Figure 4 presents the most significant relationships. For the participants of group 1 and group 2 tested respectively in naturally-lit and artificially-lit environments, there was no relationship between mood variables and measured environmental variables. For group 1, there was a linear relationship between task performance scores and some measured environmental variables: mean light intensity ($r^2 = 0.247$, $p = 0.011$), standard deviation for temperature at 1 m height ($r^2 = 0.261$, $p = 0.009$), mean temperature asymmetry ($r^2 = 0.264$, $p = 0.017$), standard deviation for temperature asymmetry ($r^2 = 0.260$, $p = 0.018$); also, there was a cubic relationship between task performance scores and mean temperature at 1 m height ($r^2 = 0.330$, $p = 0.013$). Task performance scores decreased significantly as the mean light intensity, temperature deviation and temperature asymmetry increased. There seemed to be an optimal mean temperature at 1 m height for the task performance, which was expected around 23°C. However, there was no relationship between lighting variation (standard deviations for the light intensity) and task performance scores. For group 2, no relationship was found between these variables.

Discussion and conclusion

The study compared the mood and task performance of two groups, one tested in naturally-lit environment and the other in artificially-lit environment, with a view to identify the negative effects of dynamic natural light on occupants' psychological well-being and task performance. The comparison was made in terms of the observations made before and after PA and NA schedule questionnaires and the letter cancellation task. The study led to three key findings.

First, physical measurements showed that the light intensity in the naturally-lit room changed significantly leading to local temperature changes. The mean light intensity on the desk was 2540.28 lux with the minimum 118.40 lux and the maximum 8901.75 lux. Most of the time, the light intensity fell out of the 300–500 lux range recommended by lighting design standards for normal desk work. The measured mean temperature asymmetry was 2.3°C, the minimum being 0°C, the maximum 10.3°C, and the standard deviation 2.1. Most of the time, the vertical temperature difference was more than 2°C, the limit recommended by ISO 7730: 2005 for vertical temperature difference between head and ankle.

Second, participants in the naturally-lit environment showed significant decreases on positive mood. Compared to group 2, group 1 participants had a good first impression on the naturally-lit environment when they entered the room. However, after the task, although both the groups showed decreases in PA while increases in NA, compared to group 2, group 1 decreased more in PA while increased more in NA. Wang and Boubekri[20] studied the impact of sunlight penetration using the PANAS questionnaire. They also found that participants in the sunlit position and being close to a window would experience a higher degree of mood decrease, possibly because of the extreme amount of natural light that could have induced a negative effect.

Third, participants in the naturally-lit environment scored a little less than those in the artificially-lit environment, though the difference was not significant. Regression analyses showed that the task performance in the artificially-lit environment was not affected by environmental conditions whereas that in the naturally-lit environment tended to decrease with increase in light intensity and temperature asymmetry. The results questioned the appreciation of natural light in working or learning environments and underline the need to differentiate between natural light appreciation and actual affects. When sunlight was present, the light intensity and local temperature at 1 m height would be much higher, whereas when sunlight was not present, the values would fall suddenly. People would prefer natural light, provided that no associated fluctuation disturbs their activities. Therefore, it was important to measure their performances while assessing their preferences.

To sum up, the findings had led to evolving a model (see Figure 5) that illustrated the relationships established in this study. The light intensity on the desk in the naturally-lit environment could be changed significantly. When sunlight was present, light intensity on the desk would increase dramatically, which consequently would cause an increase in local temperature (temperature at 1 m height) as well as temperature asymmetry (differences between temperatures at 1 and 0.1 m heights). All these changes could affect the task performance scores negatively. These relationships were found only in the naturally-lit environment and not in the artificially-lit environment. Although the statistical relationship between mood changes and physical environments was not found in this study, the significant decrease of positive mood in the naturally-lit environment should not be ignored as important evidence to challenge daylighting.

Implication

Although exposure to and the view of natural light are thought to be beneficial to occupants, the benefits for those who appear for a short exposure might not be significant. On the other hand, the dynamics of natural light, whose intensity would vary every second, could negatively affect occupants' performance, whereas in the artificially-lit environment, the environmental impact on occupants' concentration and performance could be insignificant. The present research suggests that those engaged in daylighting design of classrooms or offices should explore how to minimize negative impacts of natural light and stabilize the lighting and local thermal environment levels. The findings of this study could provide a guide to the future design of classrooms and offices to avoid direct exposure to sunlight and at high temperatures in tropical climates or during hot seasons, by using vertical shading, which can shade the desk as well as the student's whole body. For offices or classrooms in the mild or cold climate regions, where sunlight penetration is wanted, daylighting design should minimize the temperature asymmetry by lowering windowsills in such a way as to make the sunlight heat the student's whole body, rather than parts of the body.

Limitation

This study had three limitations in terms of the availability of the chamber as well as manpower. One of the limitations was the sample size. Only 26 pairs (52 participants) were involved in this study. More samples are needed to conduct structural equation model, such as factor analyses along each group to provide evidence for both lighting treatments functioning as a "construct". The second limitation was the exposure time. Forty-minute exposure time might not be adequate enough to enable artificial lighting or daylighting to cause significant impacts on the participants. Exposure time should be longer, say half-a-day or a whole day to check if daylight could contribute to significant differences between the two groups. However, during a normal classroom session, examination session, or in an office, the students or the office workers' concentration might not last more than 1 h, during which a dynamic environment might not necessarily be able to support psychological well-being and work performance, while a stable environment could be more undifferentiated to students or office workers in such circumstances. The third limitation was in the measurement of thermal environment by air temperature which would not be sufficient as a holistic thermal comfort index. Although this study focused on a relative value (difference between temperatures of two locations), more sophisticated instruments should be used for this kind of experiments.

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