Restorative Experience in Semi-outdoor Spaces
from Thermal Pleasure to Psychological Well-being

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ABSTRACT: Biophilic design holds great potentials for improving built environment occupants' psychological wellbeing through its restorative benefits. However, several limitations exist in current biophilic design research and practice, including the lack of considerations for the thermal experience and cultural aspects. This study aims to explore potential links between occupant thermal experience, their cultural backgrounds and psychological restorative benefits from exposure to biophilic inspired semi-outdoor spaces. A multisensory Virtual Reality experiment was conducted to examine the restorative responses to semi-outdoor environments. Findings highlight the relevance and importance of thermal delight for biophilic design in architecture to support occupant psychological well-being.
KEYWORDS: thermal pleasure, psychological well-being, adaptive opportunity, cultural factors, biophilic design

1. INTRODUCTION

With the rapid and continuous process of urbanisation, cities are expanding and densifying rapidly to accommodate the growing population, leading to the potential loss of urban green spaces and biodiversity. Opportunities for urban inhabitants to interact with nature are diminishing [1]. This has direct implications for human health and well-being because of the restorative benefits afforded by the experience of nature[2].

The concept of biophilic design has gained significant relevance over recent years for its potential to improve occupants' health and well-being through the embedded multisensory quality of nature[3]. Despite its recent progresses, there are still limitations.

Firstly, multisensory biophilic qualities are insufficiently discussed in biophilic design literature. The restorative benefits from exposure to biophilic environments, including its effects on attention restoration[4] and stress reduction[5], have been studied almost entirely in the visual domain, instead of other sensory domains, especially the ***thermal sense***. In practice, the introduction of nature has often been reduced to a superficial collection of discrete visual elements instead of a synthetic and immersive experience. For example, indoor living walls with high resource budgets for maintenance and irrigation may be introduced as simple add-ons to an otherwise irrelevant architectural design scheme, just to render a visually pleasant scene.

In thermal comfort research, the thermal pleasure principle, *thermal alliesthesia*[6], can contribute to the understanding of the dynamic thermal experiences in outdoor urban and natural settings. Thermal alliesthesia indicates that the hedonic tone (pleasant or unpleasant) of an environmental thermal stimulus depends on the stimulus itself and the individual's internal thermal state. The adaptive approach to thermal comfort provides an alternative perspective for understanding the rich thermal experiences of our interactions with outdoor environments through its recognition of the active role played by human occupants.

Secondly, ***sociocultural*** contexts have been largely overlooked in biophilic design. This is not surprising considering biophilia hypothesis is built on a biologically evolutionary perspective to human-nature relationships. One might observe an international style of biophilic architecture regardless of cultural origin. Yet, distinctive architectural expressions of nature have evolved in history, for example, the Japanese *Zen Garden* embedded in courtyard versus the formal and symmetrical *French garden*. Individual differences in restorative experiences[7] need to be explored, including not only visual preferences of nature, but also thermal preferences.

Built environment inhabitants with different sociocultural backgrounds may have distinct thermal preferences towards outdoor environments. Knowledge of these differences may contribute to a better understanding of individual experiences in biophilic outdoor environments. Cultural norms can influence an individual's habits, such as clothing and dietary habits, leading to different thermal experiences. Moreover, different cultural backgrounds may be associated with distinct environmental attitudes towards specific weather components, such as sunlight[8].

This paper aims to address the above-mentioned two limitations in biophilic design by exploring the interrelationships between thermal pleasure, cultural influence, and restorative benefits of semi-outdoor environmental experiences.

2. METHOD

This study adopted an empirical approach. An experiment with human subjects was conducted in an immersive Virtual Reality integrated climate chamber, where the visual, auditory, and thermal conditions of two semi-outdoor environmental scenarios were simulated. This includes a nonadaptive scenario where participants were exposed to strong sunlight with breeze but no adaptive opportunity, and an adaptive scenario where opportunities to choose between sunlight exposure and shade exist.

2.1 Research participants

Thirty-eight research participants, consisting of 19 Chinese and 19 Australian participants (male participants:15, female participants:23, average age = 24 ± 5), undertook the study in two experimental sessions. All experimental participants have lived in Sydney, Australia for at least three months to ensure physiological acclimatisation to the local climate.

2.2. Experimental conditions

The creation of the visual and auditory stimuli for the virtual semi-outdoor space was based on an actual roof garden – *SkyPark* in the Central Business District, Melbourne. The visual environment was constructed in VR using *Rhino3D* and *Unity* and delivered to participants via a head-mounted display *Oculus Rift S*. Different sunlight conditions were created for *sunlight only* and *sunlight + shade* scenarios (*Figure 1*). The auditory experience was simulated with *Unity*'s audio system, which enables a head-tracking binaural render of ambisonic audio recording for achieving an interactive urban soundscape experience.

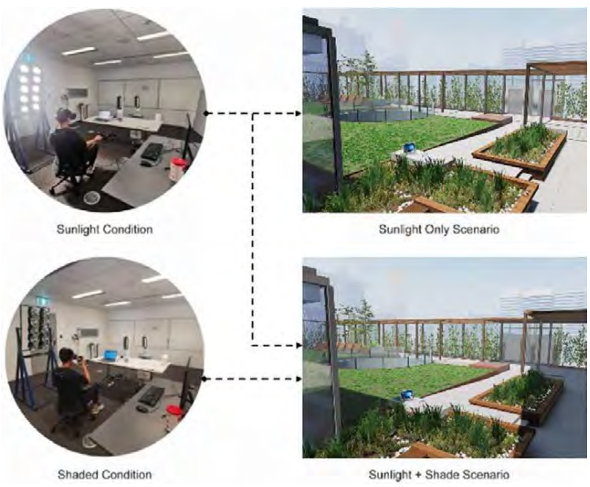

Figure 1: Experimental scenarios

Air temperature, airflow, and solar radiation of the semi-outdoor environment were simulated using the HVAC systems of the climate chambers, an array of halogen heat lamps, and digitally controlled bladeless fans. A summary of the simulated thermal conditions is shown in Table 1.

Table 1 : Thermal Experimental Conditions (T_{air}: air temperature, T_{mrt}: mean radiant temperature, RH: relative humidity, V_{air}: air velocity)

Thermal Condition	T_{air} (°C)	T_{mrt} (°C)	RH (%)	V_{air} (m/s)
Indoor	24.0 ± 0.1	24.0	55	0.05 ± 0.01
Semi-outdoor Sunlight	28.0 ± 0.1	39.7	60	1.00 ± 0.01
Semi-outdoor Shade	28.0 ± 0.1	28.0	60	1.00 ± 0.01

The solar radiation was simulated using a bank of ten quartz tungsten halogen lamps (250 W per lamp). The halogen heat lamps were controlled digitally with *Arduino* microcontroller and power relay, able to respond automatically to the user's actions in VR. The wind conditions were simulated using two digitally controlled bladeless fans to recreate the turbulence characteristics of an actual 30-min outdoor wind time series, as captured by high-speed (1 Hz) thermal anemometer in an urban setting.

2.3 Procedure

The experiment included three phases, pre-test, environmental exposure, and post-test.

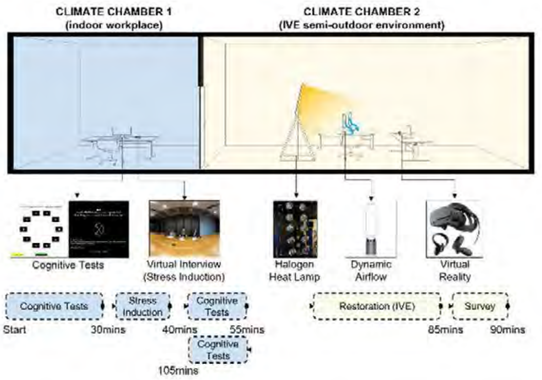

Figure 2: Experimental set-up and procedure

The *pre-test* was conducted in climate chamber 1 (*Figure 2*), simulating a workplace environment. Fatigue and stress inductions were administered to participants, including a series of cognitive tests (Backward Digit-span and Sustained Attention to Response Task), and a Trier Social Stress Test. Participants' cognitive performance and stress level were measured.

The *environmental exposure* took part in climate chamber 2 (*Figure 2*) immediately after the pre-test.

Participants experienced the simulated semi-outdoor environment for 25 min, during which they could freely explore the virtual environment. After the environmental exposure, participants completed a questionnaire regarding their subjective appraisal of the experience.

In the post-test stage, participants returned to chamber 1 and were asked to take the cognitive tests again.

2.4 Data collection

(1) Backward Digit-span Test (BD)

BD has been widely used as an indication of directed attentional capacity. During the test, participants were asked to recall a series of number sequences ranging from 3 to 12 in length in backward order.

(2) Sustained Attention to Response Task (SART)

SART reflects the subject's cognitive capacity to sustain attentional focus over an extended time. During the experiment, SART was administered to participants using Inquisit V6 (Millisecond Software). 225 digits from 1 to 9 were presented to subjects in a pseudo-randomised sequence. Participants were asked to withhold their response to the digit '3' but respond as quickly and accurately as possible by pressing the spacebar button on the keyboard.

(3) Questionnaire

A questionnaire was filled out by participants regarding their subjective experience of the virtual semi-outdoor environment, including perceived sensory pleasantness (visual, auditory, and thermal), perceived environmental influence on mood, and a short-form perceived restorativeness scale. Sensory pleasure was surveyed with seven-point continuous scale questions (*How pleasant did you feel about the visual/auditory/thermal environment? 3: very unpleasant, 0: neutral, +3: very pleasant*). The perceived mood influence was based on five bipolar scale of basic emotional dimensions (*How would you describe the effect of the environment on you in terms of the following emotions: depressed-elated, unsure-confident, grouchy-good-natured, anxious-relaxed, fatigued-energetic.* A five-item short-form perceived restorativeness scale[9] was used, with item for each restorative component from Attention Restoration Theory (*fascination*, *being-away, scope, coherent, compatibility*)[4]. *Fascination* refers to the ability of the environment to engage ongoing effortless attention. Being-away describes the psychological distance of an individual to attention demanding mental activities. *Scope* and *coherent* are important for an environment to have sufficient information for exploration and to have an ordered structure for comprehension. *Compatibility* refers to the mutual fit between an environment's affordance and the individual's purpose.

3. RESULTS

3.1 Thermal pleasure and restorative benefits

Thermal pleasure was significantly associated with restorative benefits in SART performance, as indicated by D-prime (β = 0.24, p < 0.05), subject's sensitivity to task stimuli, CV (β = −0.27, p < 0.05), differences in reaction time produced by lapsing attention (*Table 2*). Visual pleasure was associated with Delta Errors (β = −0.34, p < 0.01).

Table 2: Statistical Association between Sensory Pleasure and SART Performance (p<0.05, ** p<0.01, ns Non-significant)*

	β-Value		
	Delta D-prime	*Delta* CV	*Delta* Errors
Thermal Pleasantness	0.24*	Ns	-0.27*
Visual Pleasantness	ns	-0.34**	ns
Auditory Pleasantness	ns	ns	ns
F	5.12	10.84	6.48
R^2	0.06	0.11	0.07

Stepwise regression using individual sensory pleasantness as predictors for the overall environmental influence on perceived mood (sum of individual emotional dimensions) showed that among the sensory modalities, thermal pleasure was the most significant predictor of environmental influence on perceived mood (β = 0.52, R^2 = 0.43, p < 0.001). There was also a significant association between visual pleasantness votes and environmental influence on perceived mood (β = 0.27, R^2 = 0.06, p < 0.05), although accounting for much less variance. Auditory pleasantness was not a significant predictor.

Stepwise multiple regression analyses were conducted to examine the relationships of individual sensory pleasantness votes with the perceived restorative components. In Table 4, visual pleasantness was positively associated with fascination (β = 0.50, p < 0.001), being-away (β = 0.37, p < 0.01), coherence (β = 0.30, p < 0.01), scope (β = 0.38, p < 0.01) and compatibility (β = 0.48, p < 0.01). There were positive associations between the sense of being-away and thermal pleasantness (β = 0.25, p < 0.05).

3.2 Cultural influence on thermal experience and restorative benefits

As indicated in *Figure 3*, thermal pleasure assessments between Chinese (Median = − 0.45) and Australian groups (Median = 1.75) differed significantly during *sunlight-only* environmental exposure (p < 0.001). Chinese participants were more likely to experience thermal displeasure when exposed to direct sunlight (T_{mrt} = 39.7C°), while the opposite trend was observed in Australian subjects. In the *sunlight+shade* scenario, the difference between the two cultural groups was not significant (p > 0.05), due to improvement of thermal pleasure for Chinese participants (Median difference = 2.3, p < 0.0001).

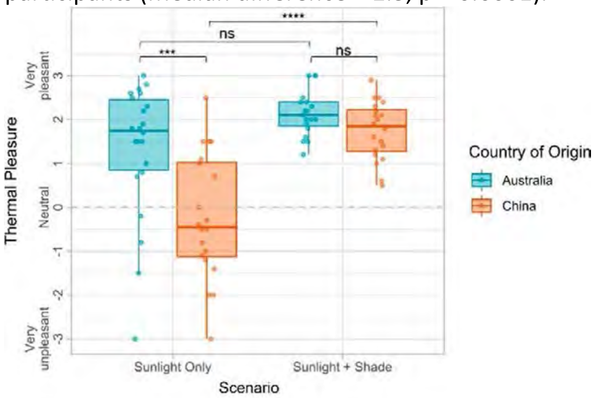

Figure 3: Thermal pleasure between groups and scenarios

Figure 4 shows that Australian participants received more improvement of their cognitive performance than Chinese participants in the *sunlight-only* scenario (Mean difference = 0.85, $p < 0.05$). No significant difference was found between the two cultural groups in the *sunlight + shade* scenario ($p > 0.05$) due to the improvement of cognitive performance for the Chinese group when given adaptive opportunity (Mean difference = 0.84, $p < 0.05$). A mixed-model Analysis of Variance (ANOVA) test on the backward digit-span test performance suggests no statistically significant effect of both Country of Origin, F (1, 72) = 2.67, p = 0.10, and Scenario, F (1, 72) = 0.24, p = 0.62.

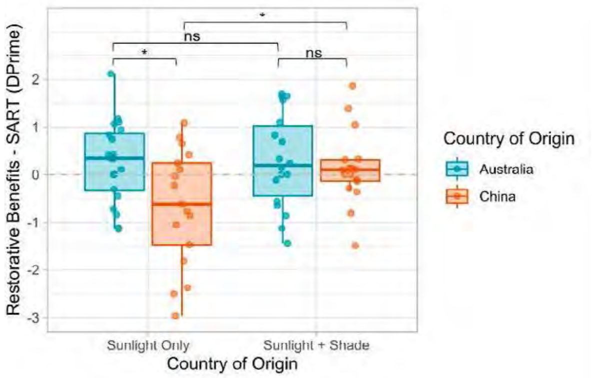

Figure 4: Comparison of SART performance between cultural groups and scenarios.

Figure 5 indicates the perceived environmental influence on mood was significantly positively associated with thermal pleasure rating ($\beta = 2.5$, $R^2 = 0.42$, $p < 0.001$). Given the significant difference in thermal pleasure between *Australian* and *Chinese* cultural groups, the restorative benefit on mood also differed significantly (Median difference = 3, $p < 0.01$). Australian participants had a more positive mood after the semi-outdoor environmental exposure compared to Chinese participants.

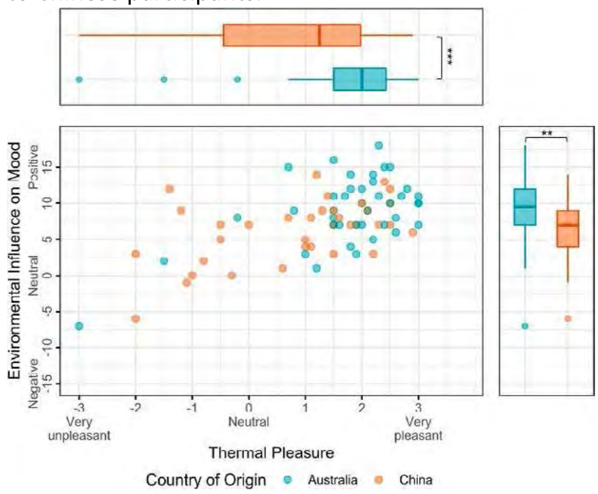

Figure 5: Statistical relationship between cultural group, thermal pleasure and environmental influence on mood.

4. DISCUSSION

This section discusses the results' relevance in the existing literature and synthesizes the findings into a conceptual model, depicting the process of occupant adaptation to the semi-outdoor thermal environment during the restorative experience. The implication of the findings on biophilic design in architecture is also discussed.

4.1 Conceptual model

Immediate environment (*Figure 6*) refers to the thermal milieu of an individual that directly impacts the person's heat balance and includes air temperature, humidity, airflow characteristics, and the radiative fluxes from sun, sky, ground, and nearby objects.

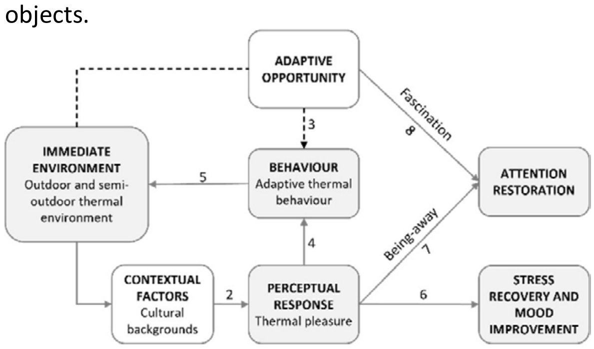

Figure 6: conceptual model - relationships between the thermal realm and psychological restoration

The subjective *perceptual response* to thermal stimuli is determined by the individual's internal thermal state and the capacity of the stimuli to restore heat balance of the body. This response is further shaped by *contextual factors*, such as *cultural backgrounds*. In the present study, significant differences in thermal pleasure responses were observed between *Chinese* and *Australian* participants when exposed to the same semi-outdoor thermal environment during the *sunlight-only* scenario. This disparity can be potentially explained by a *cultural difference* in the notions of skin beauty (*fair* vs *tanned* skin tone) which shape attitudes towards sunlight exposure. In addition, Australians' affinity to sunshine may also be associated with the Australian beach culture. The beach occupies a significant and multivalent place in Australia and Australian culture. The strong positive thermal pleasure derived from burning sunshine, cold waves, and cool breeze constituents a vital part of the sensory hedonistic alliesthesia experience for beachgoers, and contributes to Australians' affective bond to the place – *topophilia*[10]. In addition to cultural backgrounds, other contextual factors related to personal backgrounds and situations may also be relevant, such as socio-economic status[11], climatic backgrounds[12], purpose and frequency of visit, and perceived control[13].

Depending on the availability of adaptive opportunities in the environment and the individual's current thermal comfort state, adaptive behavioural responses may alleviate thermal displeasure or enhance thermal pleasure (Figure 6 links 3 and 4). The current study observed a significant improvement in thermal pleasure for the Chinese participants when offered choices during the *sunlight + shade* scenario (Figure 3).

Significant associations between thermal pleasure and restorative benefits of semi-outdoor environmental exposure were observed. Thermal pleasure was the strongest predictor of participants' subjective mood improvement resulting from semi-outdoor exposure compared to visual and auditory pleasure. The association between mood improvement and thermal pleasure can potentially be explained through *Stress Recovery Theory* and *alliesthesia* theory. Stress Recovery Theory views stress response and recovery as adaptive processes in which quick-onset emotional reactions to the external environment are necessary to initiate physiological adaptation and motivate avoidance behaviour in relation to environmental challenges or threats. Recovery occurs when the environment is beneficial to human well-being or survival, thereby recharging adaptive resources to sustain energy levels for future events or opportunities [5]. From an evolutionary perspective, it is vital to our species' survival that the alliesthesia mechanism (depending on the thermal stimuli's ability to restore homeostasis) can elicit strong affective responses, including sensory pleasure/displeasure, activation/recovery of stress response, and positive/negative mood.

The relationship between the thermal realm (thermal pleasure, thermal adaptive opportunity) and attention restoration was understood through the lenses of *fascination*, *being-away*, *extent*, and *compatibility* (Figure 6 links 7 and 8). In the current study, thermal pleasure was significantly positively associated with being-away ($\beta=0.25$, $p<0.05$), referred to as the psychological distance or disengagement from the current work task or attention-demanding mental activities. To cope with unpleasant thermal environmental stressors psychological resources are required, thus attenuating the sense of being-away. The results also indicate that access to adaptive opportunity is associated with higher ratings of *fascination* and *being-away*. Environments that are replete with adaptive opportunities promise more diverse experiences to the inhabitants, thereby enhancing the quality of *fascination*.

4.2 Design implication

The relative importance of sensory modalities in human experience has been the subject of much conjecture. Although holding great importance as input to cognitive processing about the external world[14], the visual sense alone may not have the most significant influence on our experience of the world, certainly not emotional experiences. Findings of the current study provide evidence to the theoretical discussions of the active role of the thermal sense in affecting the emotional experiences of built environment inhabitants.

The potential of the built space to engage a rich texture of thermal experiences for its inhabitants has been articulated in the book *Thermal Delight in Architecture*[15] as well as scientifically explored in *Thermal Alliesthesia*[16]. This current study further supports the discussions around thermal delight in architecture with its association with tangible restorative benefits to building occupants. The results suggest that thermal pleasure contributes substantially to the restorative experience, leading to enhanced cognitive performance and improved mood states. The atmosphere created by the active engagement of thermal pleasure in outdoor nature fosters an enhanced sense of well-being in architecture.

Understanding thermodynamics in nature and how we interact with it physiologically, emotionally, and behaviourally has potential application in architectural design conception. Metaphors are regarded as essential tools of thought for design conception that express and articulate human existential experience in the world[17]. A departure of the guiding metaphors for architectural conception from mechanistic images requires a deep understanding and integration of the subtlety and dynamic complexity of biological phenomena in the natural world. Edward Wilson stated in his landmark book Biophilia[18] that "the superorganism of a leaf-cutter ants' nest alone is a more complex system in its performance than any human invention and unimaginably old" (p.37).

Understanding the biological world with the lens of our own biological heritage will bring new models for the contemporary architecture. This understanding cannot be achieved via only visual terms but also the multisensory comprehension of the interactions between humans and the natural world. Aspirations towards an architecture that engages the dynamic thermal interaction in nature can be seen in the works such as Glenn Murcutt's *Simpson-Lee House*, Peter Zumthor's *Thermal Vals* and Philippe Rahm's *Meteorological Architecture*[19].

The current study also emphasises inhabitants' cultural backgrounds as a significant factor in biophilic design. The culturally distinct groups of Chinese and Australian participants showed pronounced differences in their thermal pleasure assessments, adaptive behaviours, and restorative outcomes from exposure to semi-outdoor environments. These findings highlight the need for a shift in biophilic design from a generic one-size-fits-all design guideline to a more contextualised and nuanced framework taking into account local culture, climate, and user's backgrounds. Most of the current biophilic design frameworks propose a collection of discrete design patterns that attempts to introduce natural elements or emulate natural characteristics in the design of the physical environment. The successful integration of these universally-defined design themes, such as thermal & airflow variability, presence of water, and prospect & refuge[20], needs to be grounded in the specific context of place and people to achieve biophilic design's goal of fostering human well-being.

5. CONCLUSION

This study explored the potential relationship between thermal experience and psychological restorative benefits. The findings of current study bring empirical evidence to support the key roles of thermal pleasure and cultural considerations within the biophilia theme in contemporary architecture.

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