European Journal of Sustainable Development (2023), **12**, 3, 131-138 ISSN: 2239-5938
Doi: 10.14207/ejsd.2023.v12n3p131

The Impact of Public Green Space Views on Indoor Thermal Perception and Environment Control Behavior of Residents - A Survey Study in Shanghai

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Abstract
To reduce energy consumption while meeting the indoor thermal comfort requirements of residential buildings, this survey study explores the visual-thermal cross-modal effect of public green space window view on residents' indoor thermal perception, and how this effect regulates residents' environment control behavior. Based on an online questionnaire, 424 valid data were collected from Shanghai residents during the lockdown period during which the window view is the only accessible connection to the outside. The result shows that public green space views, while not significantly changing the physical thermal sensation of residents, made a greater proportion of participants feel thermal neutral, and significantly improved the participants' environmental evaluation, thermal comfort, and thermal acceptance, resulting in a 7% decrease in using air conditioning and 7% increase in natural ventilation. Path analysis reveals that public green space window view can improve indoor thermal comfort by enhancing subjective environmental evaluation, and thus encourage passive environmental regulation behavior, reducing energy consumption. Complementing previous studies, this research provides direct evidence for the energy-saving potential of public green space in residential areas from a different angle.

Keywords: Visual-thermal interaction; cross-modal perception; Environment control behavior; Environmental psychology; Sustainable design

1. Introduction

In China, urban residential buildings cost 40% of the energy consumed in the civil building industry, primarily for heating and cooling (Lee & Song 2022). The huge energy consumption of building operation makes it necessary to study how to reduce energy use while maintaining indoor thermal comfort.

To reduce energy consumption while meeting the indoor thermal comfort requirements, a possible direction is affecting the thermal perception of participants (Kanaya et al. 2012). Research has shown that occupant behavior is an important factor influencing the energy performance of buildings (Nicol & Roaf, 2017). To achieve thermal comfort goals, occupants take proactive actions to improve the indoor environment (Luo et al., 2016; Barthelmes et al., 2016), and different behaviors can result in variations in energy consumption for the same building (Hong et al., 2016). Therefore, feasible strategies for energy-efficient design include influencing occupants' indoor environmental control behaviors while maintaining low energy consumption. Windowscapes, as important visual elements in residential indoor environments and integral components of residential design, are among the qualities that residents are most concerned about. They not only have

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positive impacts on the physical and mental health of occupants (Huang et al., 2019), but also influence occupants' thermal comfort evaluation and their willingness to control the environment, thus reducing indoor climate regulation energy consumption (Jiang et al., 2022). The presence of windows can make occupants feel more comfortable under the same physical environmental conditions, with lower blood oxygen saturation and lower stress levels (Ko et al., 2020), possibly because better environments lead to better moods and greater tolerance for deviations from the thermal comfort range (Mishra et al., 2016). Good window view design can also reduce additional energy consumption caused by uncomfortable outdoor environments (Singh et al., 2011). Research has shown that uncomfortable outdoor environments lead to increased demands and expectations for indoor comfort, leading to more active and intensive indoor climate regulation, thereby increasing building energy consumption (Li & Liu, 2020). Therefore, if indoor and outdoor thermal landscapes can be designed in synergy to reduce occupants' demand for indoor climate regulation, it can assist in achieving the goal of reducing overall energy consumption.

Public green space, defined as "every parcel of land classified as a natural surface" (Barbosa et al. 2007), is a common window view of urban residential areas and has been confirmed effective in regulating the microclimate at different scales (Pastore et al. 2017; Yang et al. 2022), even only visual exposure to it can also improve participants' outdoor thermal comfort (Rosso et al. 2016; Lam et al. 2020; Zhang et al. 2022). However, existing studies on public green space are mainly based on outdoor environments and participants, the impact of outdoor public green space, as a view, on residents' indoor thermal perception and environmental control behavior is still unknown. As an effective substitute for direct exposure to greenery (Soga et al. 2020), window views of the public green space may have a similar effect in improving indoor thermal comfort for residents as public green space can in outdoor environments.

Therefore, to fill the gap in previous studies, a hypothesis was established in this research that the window view of public green space can influence residents' indoor thermal perception. It assumes that public green space views can improve residents' indoor thermal comfort, regulating environment control behaviors and, as a result, reducing building energy consumption. The result of it can be a complement to previous software simulations and empirical measurements, providing direct evidence of the effectiveness of public green spaces in energy saving, and also providing references and suggestions for the design of residential areas.

2. Method

We conducted an online anonymous questionnaire survey on Shanghai residents from April 4 to 6, 2022. During the research time, the window views were designed to be the only connection to the outside world. The questionnaire was only available during the cloudy daytime when the temperature was at 17.5±0.5°C, the humidity was at 38±2% to ensure a uniform outdoor thermal and light environment. All participants voluntarily joined this research. The questionnaire design referred to relevant studies (Rosenbaum et al. 2016; Arsenault et al. 2012; Chinazzo *et al.* 2021; Vittori *et al.* 2021), and consists of four parts (Figure 1):

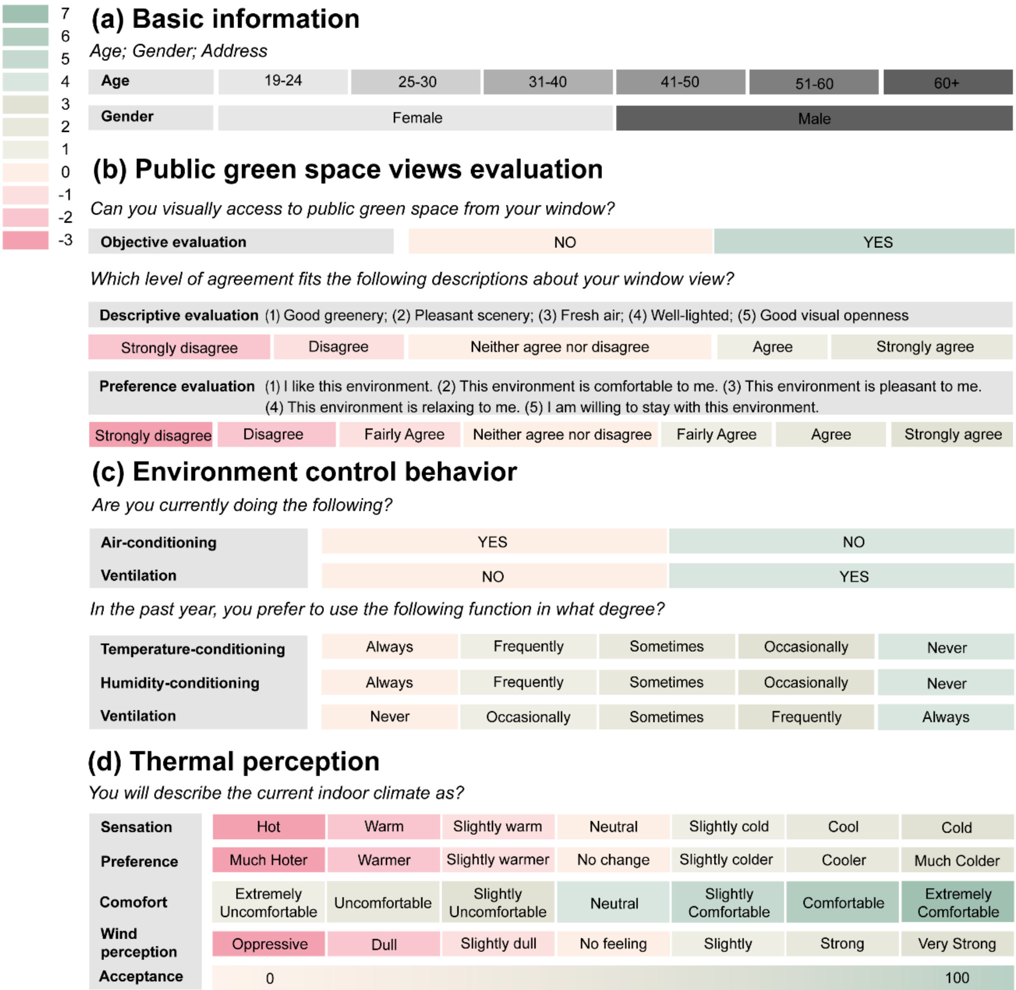

Figure 1: Questionnaire design

(a) **Basic information:** This part collects the basic statistical information of participants, including age, gender, and address.

(b) **Public green space views evaluation**: This part collects participants' subjective and objective evaluations of public green space views. The objective evaluation measures the visual accessibility of public green spaces. The subjective evaluation collects the comprehensive window view evaluation of participants and consists of two subscales: descriptive evaluation and preference evaluation, the value is the sum of the two. The descriptive evaluation measures the physical characteristics. It was based on 1-5 five-item Likert scales with five attributes: Greenery, Scenery pleasantness, Air quality, Brightness, and Visual openness. The preference evaluation measures psychological characteristics. It was based on 1-7 seven-item Likert scales with five attributes of visual window view:

Environmental preference, Comfort, Pleasantness, Relaxation, and Staying willingness. Both subscales passed the reliability test with Cronbach α and KMO values both greater than 0.8, representing good reliability and validity, and the average score of attributes was used as the final score.

(c) **Environment control behavior**: This part consists of 6 five-item subscales, measuring both the short and long-term behavior of residents in temperature-conditioning, humidity-conditioning, and ventilation. A higher score on each subscale indicates a higher level of energy saving. The final score of this part is the average score of the six subscales.

(4) **Thermal perception**: This part measures the comprehensive thermal perception of residents, consisting of 5 attributes: Thermal sensation, Comfort, Acceptance, Preference, and Wind perception. The ASHRAE 7-point scale measured thermal sensation and preference. Thermal comfort and wind strength are scored on a 7-point scale. Thermal acceptance is scored from 0 to 100. The thermal perception overall value was calculated from those 5 attributes in the following formula:

$$\text{Thermal perception (TP)} = TC - |TS + TP + WS| + 7 \times (TA \div 100)$$

3. Result

3.1 Descriptive analysis

424 valid data were collected, 158 males and 266 females distributed in all districts of Shanghai participate in this research. 269 participants (63.44%) reported the presence of public green space in their view. Participants with a window view of public green space and those without were divided into two groups named the Green group (GG) and the control group (CG). Details of these groups were presented in parallel (Figure 2), with the

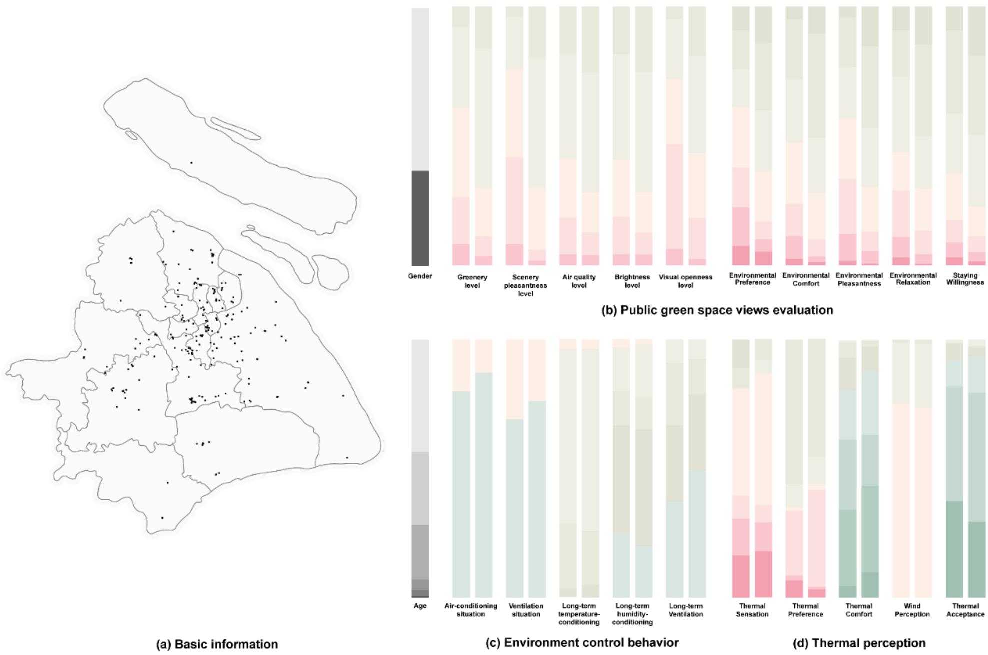

Fig.2 Descriptive result

CG on the left and GG on the right. It can be seen that GG (1) has a significant improvement in subjective evaluation. (2) active air conditioning methods were replaced by natural ventilation in both the short and long term. (3) a greater proportion of participants in GG felt thermal neutral. Overall, participants in GG reported higher environmental evaluations, a better sustainability level, and higher thermal evaluations. To precisely quantify the differences between the two groups, ANOVA was conducted.

3.2 Comparison analysis

ANOVA results showed that all four parts of the results show significant differences (Table 1) between groups. The most significant difference was shown in the subjective evaluation part, where all the attributes significantly differed at the $p<0.01$ level and GG scored significantly higher than CG. Public green space views also improved thermal perception evaluation. The two groups did not show statistically significant differences in thermal sensation, thermal preference, and wind perception, but do reveal significant differences in thermal comfort and acceptance votes. Public green space views affect environment control behaviors, causing a 7% decrease in air conditioner use and a 7% increase in opening windows for ventilation in the GG group.

Table 1. ANOVA of Public green space

ANOVA of Public green space				
	Mean±SD		F	p
	CG(n=155)	GG(n=269)		
Subjective evaluation	7.54±1.91	8.80±1.81	45.490	0.000**
Descriptive evaluation	3.13±0.77	3.68±0.74	52.18	0.000**
Greenery level	3.12±1.06	3.72±0.95	36.035	0.000**
Scenery pleasantness level	2.77±0.99	3.50±0.88	60.694	0.000**
Air quality level	3.44±0.88	3.82±0.86	18.862	0.000**
Brightness level	3.54±1.08	3.80±1.04	6.303	0.012*
Visual openness level	2.79±1.02	3.55±1.04	54.17	0.000**
Preference evaluation	4.41±1.35	5.12±1.24	29.795	0.000**
Environmental Preference	4.03±1.74	4.86±1.59	24.552	0.000**
Environmental Comfort	4.46±1.45	5.18±1.28	28.098	0.000**
Environmental Pleasantness	4.23±1.44	5.12±1.39	39.642	0.000**
Environmental Relaxation	4.49±1.54	5.16±1.37	21.312	0.000**
Staying Willingness	4.85±1.49	5.28±1.38	8.702	0.003**
Environment control behavior	3.47±0.78	3.66±0.73	5.988	0.015*
Air-conditioning situation	0.80±0.40	0.87±0.33	4.125	0.043*
Ventilation situation	0.69±0.46	0.76±0.43	2.609	0.107
Long-term temperature-conditioning	2.28±0.59	2.27±0.62	0.01	0.922
Long-term humidity-conditioning	3.68±1.12	3.62±1.07	0.328	0.567
Long-term ventilation	3.94±1.00	4.20±0.95	7.218	0.008**
Thermal perception	1.54±0.66	1.73±0.61	8.899	0.003**
Thermal Sensation	-0.43±1.36	-0.4±1.16	0.061	0.805
Thermal Preference	0.68±0.85	0.68±0.83	0.001	0.973

Thermal Comfort	4.72±1.35	5.00±1.29	4.53	0.034*
Wind Perception	1.26±0.47	1.28±0.48	0.088	0.767
Thermal Acceptance	73.46±18.89	78.64±16.16	8.894	0.003**
* p<0.05 ** p<0.01				

3.3 Path analysis

Fig.3 Path model

Based on the previous hypothesis and the results of the comparative analysis, the relationship model of public green space views and environmental control behavior was established (Figure 3). Path analysis was used to test the direct dependencies among variables and to verify the hypotheses (Klem 1995). The results (Table 2) showed that the normalized path coefficient value of all hypothesized influence paths is >0, and the paths all present a significance at the level of 0.01, indicating that all influence factors have a significant positive influence on the objects. All the model fit indices meet the test value requirements, reflecting that the fitting model is ideal. **Therefore, the hypothesis that public green spaces can improve indoor thermal comfort by enhancing subjective environmental evaluation, and thus increase passive environmental regulation behavior, is valid.**

Table 2. Path analysis

Model Fit Index and Test Values

Fit Index	χ2	df	p	χ2/df	GFI	RMSEA	RMR	CFI	NFI	NNFI
Test Values	-	-	>0.05	<3	>0.9	<0.10	<0.05	>0.9	>0.9	>0.9
Values	7.504	3	0.06	2.501	0.989	0.06	0.046	0.961	0.939	0.923

Default Model: χ2(6)=122.609, p=1.000

Model Regression Coefficient

Influence factors	→	Objects	Non-normalized path coefficient	SE	CR Value	p	Normalized path coefficient
Public green space	→	Subjective evaluation	1.254	0.185	6.761	0	0.312
Subjective evaluation	→	Thermal perception	0.122	0.015	8.232	0	0.371
Thermal perception	→	Environment control behavior	0.17	0.057	2.998	0.003	0.144

4. Conclusion

To explore the influence of public green space window view on residents' indoor thermal perception and environment control behavior, an online survey study was done on Shanghai residents during the lockdown period in 2022. 424 valid data were collected, and 269 (63.44%) reported public green space view presence. Descriptive statistical analysis indicated that the public green space view made a greater proportion of participants feel thermal neutral. Combined with the ANOVA analysis, the study found that the presence of public green space views, while not significantly changing the physical thermal sensation of residents, significantly increased the participants' environmental evaluation, thermal comfort level, and thermal acceptance level, resulting in a 7% decrease in the proportion of air conditioning using and encourages natural ventilation. The path analysis also reveals that public green space window view can improve indoor thermal comfort by enhancing subjective environmental evaluation, and thus increase passive environmental regulation behavior.

All above results show that even only the visual presence of public green space can still effectively influence residents' perception and reactions. Considering that thermal sensation votes did not differ significantly between groups, that is, window views did not lead to differences in physical thermal perception, this may be because pleasant window views provide residents with a higher degree of arousal. This hypothesis is supported by the results of several studies. For instance, the positive psychological impact of pleasant green window views has been documented (Gillis & Gatersleben, 2015; Soga et al., 2021), which are associated with higher arousal and pleasure levels and lower stress levels. Furthermore, exposure to the same indoor climate, but with the presence of outdoor natural landscapes visible through windows, has been found to enhance thermal comfort and increase the tolerance for a wider range of thermal deviations (Jiang et al., 2022). Additionally, the presence of 3D green plants in virtual environments has also been shown to influence participants' thermal comfort and visual pleasure (Sedghikhanshir et al., 2022). Complementing previous studies, this research provides direct evidence for the importance of public green space in residential areas from a different angle. By designing a pleasant outdoor landscape and improving residents' evaluation of window views, residents' thermal evaluation can be improved. This can also be used in the personalization of spaces. By accurately testing the environmental preferences of specific customers, the environmental evaluation and environmental emotion of the built environment can be controlled within the optimal range, thereby improving the thermal comfort of users and reducing the energy consumption required for air conditioning.

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