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Effects of sensory IEQ comfort on employees' indoor satisfaction and well-being in overall office spaces: A multi-group SEM approach

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Abstract
Indoor Environmental Quality (IEQ) in office settings plays a critical role in occupant satisfaction and well-being, directly influencing health, productivity, and overall quality of life. Current research, however, lacks an integrated understanding of the mechanisms linking sensory IEQ comfort to satisfaction and well-being. Furthermore, many studies overlook the interactive effects of IEQ across different functional spaces, which may lead to biased estimations of IEQ's impact on well-being. To address these gaps, this study collected 264 valid questionnaires from employees across nine floors in four office buildings. The survey encompassed sensory IEQ Comfort, Total Environmental Comfort Vote (TECV), Work Environmental Satisfaction (WESA), Work Satisfaction (WSA), and Life Satisfaction (LSA). A multi-group Structural Equation Model (SEM) was employed for multi-spatial integrated analysis. The results indicate that Sensory IEQ comfort in Leisure Space (LS) exhibits more significant pathways to LSA compared to Work Space (WS). In both WS and LS, IEQ comfort promotes WESA and WSA primarily through the mediation of TECV; notably, the impact of WESA is more pronounced in LS. WSA serves as a stronger driver of LSA than WESA in the office. The multi-spatial model significantly reduced the effect sizes of independent pathways compared to single-space models, suggesting that neglecting spatial diversity may lead to result errors. Furthermore, computer usage time was identified as a core factor influencing WESA and WSA, and indirectly affecting LSA. This study provides explicit design guidance for optimizing sensory IEQ to enhance occupant well-being and emphasizes the necessity of multi-spatial considerations in office design.
Keywords: Indoor Environmental Quality; Comfort; Work Satisfaction; Computer Usage Time; Well-being; Multi-group SEM

1. Introduction

1.1. Background

Under the backdrop of urbanization, the human-centered design strategy has gradually emerged, aiming to achieve low-carbon, energy-efficient, healthy and green architectural benefits. Various types of research results have been produced, such as the proposal of Asian Urban Environmental initiatives, which advocates that all countries actively address climate issues, promptly take win-win measures, and contribute effective methods to address the problems [1], such as incorporating sponge city programs into urban design to promote the development of eco-cities [2]; using a combination of architectural form, passive and active technologies to control building energy consumption and carbon emission indicators [3], which can improve the urban heat island problem and reduce the duration and harm of heatwave events. In this context, outdoor environmental quality indicators have received significant attention, with the core indicators mainly focusing on thermal environment, acoustic environment, air quality and visual perception [4]. In modern urban life, individuals spend approximately 80 %–90 % of their time indoors, with the office environment representing the non-residential space where adults spend the longest duration [5]. As architectural design paradigms shift from production-oriented goals toward employee health and well-being, office spaces are being redefined as critical vehicles for regulating individual psychological homeostasis and emotional health [6]. Existing research indicates that Indoor Environmental Quality (IEQ) is a core dimension of workplace health and well-being; consequently, the design requirements for indoor environmental factors such as noise, temperature, and lighting are receiving increasing attention [7, 8, 9]. Although IEQ affects individual work and health performance, the same IEQ conditions may still yield significant differences in evaluation across different functional spaces within the same premises [10]. Generally, when IEQ comfort is ensured, individual well-being is enhanced [7].The IEQ of different spaces may impact an individual's well-being through long-term emotional and cognitive accumulation [11]. However, while IEQ has been proven to significantly improve Work Environmental Satisfaction (WESA) and Work Satisfaction (WSA), its influential factors are often simplified into relationships between environmental satisfaction variables. This limitation stems from an insufficient understanding of the mechanisms by which IEQ stimuli are transformed into complex individual psychological evaluations. The specific role of IEQ comfort remains overlooked, and there is a lack of empirical evidence clarifying the benefit relationships of IEQ across different usage spaces within the same site. This significantly limits the potential for enhancing well-being through office environment design.

1.2. Indoor environmental quality and well-being

As a primary indoor environmental factor, IEQ—driven by physical stimuli within the office environment—is considered to be deeply coupled with employees' mental health and cognitive performance [12]. While IEQ traditionally encompasses indoor air quality, acoustic, thermal, lighting, and visual aspects, it has recently expanded to include decoration, control, and even personal perception [13]. Colenberg et al. noted that high background noise and poor speech intelligibility in the workplace are associated with negative physical and psychological impacts [14]. Simultaneously, improvements in natural light are linked to enhanced health and sleep quality for building occupants [15]. At the same time, thermal comfort among office workers has been reported to correlate significantly with perceptions of well-being and productivity [16]. Research in these areas confirms that IEQ can generate integrated benefits for employee health, cognitive function, productivity, and overall well-being through multi-sensory interactions.

However, despite the extensive literature on the impact of office IEQ on satisfaction and health, most environmental evaluation models explore well-being only through direct correlation analyses, lacking a comprehensive mechanical analysis of the office environment. Existing studies have confirmed that WESA and WSA exert a mutually positive influence on one another [17, 18], as well as a positive promotion of Life Satisfaction (LSA). Nevertheless, model construction often obscures the sequential relationship between WESA and WSA. In fact, research indicates that WESA belongs to the perceptual evaluation level, representing a proximal feedback to the immediate physical stimuli of IEQ [19]. In contrast, WSA belongs to the judgement level, representing a distal evaluation result formed based on an employee's emotional orientation toward their work [20]. These two are not psychological constructs on the same level; a significant cognitive distance exists between them, and WESA contributes to the improvement of an employee’s WSA [21]. For example, an employee may experience irritability due to glare on an office desk or persistent noise. This intuitive perception first manifests as a low level of WESA, which is subsequently attributed to a lack of organizational care or disregard for employee health, leading to a lower WSA. Through the long-term interaction between work and life, this sentiment generalizes into a negative evaluation of the overall quality of life, ultimately resulting in reduced LSA. However, current research lacks a systematic pathway to verify this mechanism of attribution and generalization from environmental perception to life evaluation, and the validity of such pathways is inherently linked to the specific spatial context in which the individual is situated [18].

1.3. Heterogeneity of spatial functional zoning

Existing research on office environments and employee satisfaction predominantly treats the office as a homogeneous entity, overlooking the fundamental differences in usage objectives, cognitive loads, and psychological needs across different functional zones. Research in environmental psychology indicates that identical physical environmental elements can trigger vastly different psychological mechanisms and satisfaction pathways depending on the spatial context [22]. Furthermore, an inter-spatial correlation mechanism may exist, whereby different zones collectively promote the enhancement of WESA, WSA, and LSA. Functional zones, such as the Work Space (WS) and Leisure Space (LS), carry distinct functional and psychological benefits. The WS supports high cognitive-load tasks, where employee demands for IEQ focus on task support and focus maintenance. Conversely, the LS serves the functions of stress buffering and informal interaction, where employees are more inclined towards psychological recovery and emotional regulation [23].

Consequently, from the perspective of task demands and psychological recovery needs, the chain-path mechanisms through which IEQ factors trigger WESA and WSA may differ significantly across spaces. For instance, illuminance and the acoustic environment in the WS often act indirectly on WSA by influencing attention, task performance, and cognitive efficiency. In contrast, natural lighting, visual landscapes, and comfort in the LS or informal spaces are more likely to directly influence LSA through psychological recovery and emotional regulation [18, 24]. Arata et al. [18] proposed through structural equation modelling that perceptions of the office environment have a multidimensional driving effect on employee well-being. This study emphasizes that the environmental characteristics of different functional zones affect WSA through differentiated psychological mediation paths and ultimately lead to a comprehensive improvement of LSA over the long term. Zhang et al. [24] highlighted the heterogeneity of spatial functions, noting through quantitative analysis that different types of office spaces contribute significantly differently to restorative perceptions. The study found that while the WS ensures task execution through physical optimization, the LS (such as pantries and green rest areas) provides a higher contribution to alleviating mental fatigue and providing emotional replenishment. Furthermore, the influence paths of physical design features on WESA exhibit an apparent asymmetry between different spaces.

Existing studies suggest that the contributions of IEQ to WESA, WSA, and LSA may exhibit space-oriented differentiation. In contrast, while some traditional studies have confirmed the positive impact of the physical environment on WESA and WSA, their conclusions remain limited when explaining complex office contexts due to the lack of functional zoning [25, 26, 27]. This omission prevents the precise identification of key spatial nodes that can enhance overall employee well-being. Therefore, exploring the heterogeneity of IEQ influence paths across different functional zones not only deepens the understanding of office environment attribution mechanisms but also provides an empirical basis for precise and differentiated office space design.

1.4. IEQ and personal traits impact on comfort, satisfaction and well-being

Research has confirmed that providing IEQ comfort contributes to promoting employee satisfaction and well-being [7]. From a multi-sensory perspective, IEQ comfort factors, such as acoustic, lighting, and thermal conditions, function by regulating cognitive load and psychological stress [17, 28]. Haynes argued that since office comfort is a relative concept, a "human-centered" perspective—combining observational data with measurement indicators to evaluate user perception—must be adopted to comprehensively examine the profound impact of the environment on health and well-being [29].

Sensory IEQ comfort, as individual sensory evaluation indicators, mainly involves thermal, light, acoustic, air flow and visual comfort. Additionally, non-sensory IEQ factors that cannot be subjectively perceived through the senses, such as personal control, private space and furnishing, jointly contribute to the Total Environmental Comfort Vote (TECV) [30]. In the sensory dimension, noise is a primary factor influencing performance in the office environment

[31]. Noise in the workplace can produce various effects, including physiological effects (such as headaches and fatigue), as well as psychological, cognitive, and social effects [32]. However, the impact of office noise is subjective, depending on various factors such as the occupants' ability to control noise, the type of work, gender, and age [33]. In contrast, the lighting and thermal environments influence well-being through cognitive resource allocation and physiological comfort [34]. Jung et al. confirmed through experiments that enhancing illuminance in the WS significantly optimized employees' cognitive resource allocation and achieved synchronous improvements in task performance [35]. However, determining the visual comfort of office occupants remains a challenging field of study. This issue is complicated by the fact that human heat output is influenced by multiple factors, including the amount of clothing worn, the type of work performed, and numerous other external variables [36]. Braga et al. noted that the evaluation of thermal comfort is more complex; its contribution to productivity follows an "inverted U-shaped" curve [37]. Since individual heat output is influenced by clothing, metabolic rate, and environmental parameters, the assessment of personal thermal comfort requires simultaneous consideration of these factors to more accurately ensure that individuals remain within the thermal balance and comfort zones. Failure to do so may lead to thermal discomfort, thereby reducing overall well-being.

Notably, visual elements possess a unique dual-path attribute in enhancing well-being. On one hand, physical parameters such as illuminance and glare primarily affect WESA and WSA through cognitive and performance pathways. On the other hand, window views, colour coordination, and spatial aesthetics are more likely to enhance LSA through direct emotional and aesthetic experiences. Chang and Schiavon [38] demonstrated that under identical physical lighting conditions, high-quality window views (particularly natural landscapes) can significantly improve occupant well-being. Manu and Rysanek [39] explored how WESA translates into organizational commitment and quality of life over time, emphasizing the role of the environment in long-term well-being. Simultaneously, heterogeneity exists in the expectations of employees of different ages regarding office privacy and spatial quality; these differences in expectation directly determine the threshold at which IEQ translates into WESA.

Meanwhile, several studies have found that personal preference significantly affects comfort, satisfaction, and well-being [40], which may involve environmental variations, workplace conditions, and personal experiences [41]. The indoor environment is relatively stable but undergoes IEQ fluctuations throughout the day due to time, facility operation, and occupant behavior. These continuous impacts on employees lead to the formation of individual memories and subsequent preferences after long-term exposure and habituation. Among sensory IEQ preferences, thermal, light, and acoustic factors are potentially more prominent, as they often form fixed memories associated with specific individual behaviors and habits. Conversely, sensory Indoor Air Quality (IAQ) may be overlooked due to prolonged indoor occupancy, as the human body can adapt within a very short period, thereby reducing sensitivity [42, 43]; typically, only strong stimuli trigger feelings of pleasure or aversion. Consequently, the investigation of IAQ often requires more comprehensive indicators. Furthermore, preference involves subjective evaluations of different spaces and environmental factors [40], and individual characteristics also play an influential role [41]. Research has clarified that age, gender, and educational level all affect preferences, which may be driven by individual needs and personality traits [44].

Furthermore, as a key indicator of office behavioral load, Computer Usage Time (CUT) is significantly negatively correlated with IEQ satisfaction. Long-term exposure to screen back-lighting not only degrades an individual's evaluation of artificial light comfort and reduces WESA but also hinders the positive overflow from work achievement to life satisfaction by exacerbating visual fatigue and cognitive depletion [45]. Additionally, leisure satisfaction has been found to have a positive association with LSA. At the same time, work interference with life is negatively correlated with LSA, indicating that the presence of leisure attributes is vital for LSA [46].

1.5. Research gaps

Existing research remains insufficient in three aspects: (1) there are spatial perception differences within the office environment, and while workplace residency accounts for a high proportion of time, existing studies have largely ignored the integrated impact of multi-spatial IEQ on employee well-being, with no exploration of the joint mechanism of both types of spaces; (2) there is currently a lack of research regarding the satisfaction benefits of multi-sensory comfort within the office, as well as a lack of evidence concerning the impact of comfort on WESA and WSA; (3) the pathway through which IEQ comfort generates well-being remains unclear. To address these issues, this paper proposes a dual-path promotion model of IEQ comfort on LSA based on the WS and LS within the office, clarifies the extent to which IEQ comfort influences satisfaction and elucidates the functional benefits of sensory IEQ comfort. Furthermore, it explicates the necessity and efficacy of satisfaction as a mediator in the relationship between comfort and well-being. Examining the key mechanisms of IEQ that impact employees' work and life satisfaction to provide a theoretical basis for designing a healthy office environment and enhancing employee well-being.

2. Methodology

2.1. Sampling scope

This study was conducted between September and November 2024, involving an investigation of nine floors across four high-rise office buildings in Hefei. To ensure consistency across the survey, the research focused exclusively on employees equipped with individual workstations within the WS. The survey samples were selected using the spatial sampling method, whereby employees were sampled at intervals based on their spatial positions; this approach was adopted to accurately reflect the sample conditions of similar WS environments in the region. Specifically, the layout consisted of 4–5 persons per row in each space, with 6–10 rows in each oriented work area. Participants were selected by interval sampling between rows and columns, resulting in a widespread distribution of employees across each floor. This survey methodology has been applied in several studies and is well-recognized [24, 47]. This study involved nine survey floors distributed across four high-rise office buildings, with each floor belonging to the same company. Across the nine office plans, various orientations of both workspace and leisure space layouts were included. Indoor lighting was required to remain on during the day to satisfy the demands for sufficient indoor task lighting. During the selection of sample office spaces, a comprehensive evaluation of spatial facilities, layout, and scale was conducted by a review panel comprising one professor and three experts. Based on this assessment, four buildings with relatively similar office environments and settings were selected for the investigation. Furthermore, the survey sample included only those employees who had been working at the site for more than six months, ensuring that participants maintained a high level of familiarity with their environment.

The selection of space types for this study followed a structured process. Sixteen employees with long-term experience in high-rise open-plan office buildings were selected for semi-structured interviews, with an average duration of 17 minutes per participant. The interviews primarily addressed the following questions: 1) Which spatial environments do you frequently use during your daily work? 2) Which spatial environments make you feel comfortable during your daily work? 3) Which spatial environments do you wish to see added or improved in your daily work? The interview results synthesized the environments and spaces where employees perceived comfort; areas such as work areas, meeting rooms, discussion areas, pantry/water bars, lounge chairs, and auxiliary rooms were frequently mentioned. To maintain a balanced and integrated open-plan environment, we categorized only the work areas into WS, while the discussion areas, pantry, water bars, lounge chairs, and open auxiliary spaces were categorized into LS.

2.2. Questionnaires

A structured questionnaire was developed to investigate IEQ comfort from a sensory perspective within the WS and LS, respectively, aiming to explore the underlying mechanisms affecting LSA. The investigative factors comprised four primary components: 1) IEQ comfort factors related to sensory dimensions, including thermal, acoustic, visual, and light, alongside an investigation of the respective TECV for both spaces; 2) WSA, WESA, and LSA; 3) Work stress; and 4) Participant information.

The institutional of Suzhou university ethics review committee approved the questionnaire protocol to protect human subjects. Prior to completing the survey, each participant signed an informed consent form. During the investigation period, the questionnaire was distributed via electronic links to floor managers, who subsequently forwarded it to the subjects. All research was performed in accordance with relevant guidelines/regulations. A total of 300 questionnaires were distributed, resulting in 264 valid responses being retrieved and included in the statistical analysis. All data and figures in the research were used with the consent of the subjects.

2.2.1. Comfort of indoor environment factors and total environments

Regarding the sensory factors of IEQ comfort, the study established the Thermal Comfort Vote (TCV), Acoustic Comfort Vote (ACV), Visual Comfort Vote (VCV), Natural Light Comfort Vote (NLCV), and Artificial Light Comfort Vote (ALCV). Furthermore, the TECV for both the WS and LS was investigated separately. For each item, participants were asked: "How do you perceive the ... comfort of your current WS/LS?" A seven-point Likert scale was employed, ranging from "-3" to "0" to "3", representing a scale from "very discomfort" to "neutral" to "very comfort". While indoor air quality is an inherent attribute of IEQ, sensory-based investigations typically focus on air flow or odor comfort. However, previous research has indicated that the effects of these factors are not statistically significant [18]. Furthermore, the potential for sensory adaptation to indoor air conditions within a short time may introduce perceptual bias, thereby affecting the accuracy and reliability of the subjective assessments [43], and as this study focuses on high-rise office buildings predominantly utilized with mechanical ventilation, air flow may only exhibit minor variations, therefore the air flow of IAQ comfort were excluded from the scope of the investigation.

2.2.2. Work, office environment and life satisfaction

The WSA was measured using an established scale from previous research [17]; participants were asked: "Taking everything into account, I am satisfied with my job as a whole at present." A similar approach was adopted for the WESA, where participants were asked: "Taking everything into account, I am satisfied with my overall work environment at present." To mitigate participant fatigue, the third question of the Satisfaction with Life Scale (SWLS) was utilized to evaluate life satisfaction [48]. This tool is widely used within the social sciences as a measure of the LSA component of subjective well-being. Participants were asked to respond to the statement: "I am satisfied with my life." All responses were recorded using a 10-point scale, ranging from "1" to "10", representing "strongly disagree" to "strongly agree".

2.2.3. Work stress

The investigation of participants' Work stress was conducted using a single-item scale question. Participants were asked: "Taking all factors into account, how do you feel about your job stress?" Responses were recorded using a 10-point scale, ranging from "1" to "10", representing "no stress" to "very high stress".

2.2.4. Sensory IEQ preference

To clarify the functional benefits of individual IEQ preferences, the survey investigated participants' sensory IEQ preferences, specifically: Thermal Preference Vote (TPV), Light Preference Vote (LPV), and Acoustic Preference Vote (APV). Participants were asked: "What kind of thermal/light/sound environments do you prefer?" Responses were collected using a 7-

point Likert scale, with options ranging from -3 to 3, representing "much cooler/darker/quieter" to "much warmer/brighter/noisier" respectively.

2.2.5. Participant information

Regarding the collection of participant information, data were gathered concerning CUT, Occupation, Age, Gender, and Education. Within this dataset, CUT pertains to the duration within an 8-hour working day; consequently, responses were categorised into five options: "less than 1 hour", "1–3 hours", "3–5 hours", "5–7 hours", and "more than 7 hours".

2.3. Structural Equation Model

2.3.1. Categories and Functions of SEM

As the Structural Equation Model (SEM) can more accurately identify the multidimensional relationships within cross-sectional data and effectively parse the underlying mechanisms between multiple factors, it has been widely utilized in the analysis of mechanisms concerning comfort, job satisfaction, and well-being [49, 50]. The two most frequently employed models are Covariance-based SEM (CB-SEM) and Variance-based Partial Least Squares SEM (PLS-SEM); the selection between them is typically determined by four factors: data distribution, sample size, measured constructs, and model complexity [17]. Specifically, there are two types of model measured constructs: Reflectively Measured Constructs (RMC), where the arrows point from the construct to the indicators, and Formatively Measured Constructs (FMC), where the arrows point from the indicators to the construct. CB-SEM is more suitable for RMC, whereas PLS-SEM is more appropriate for FMC [51]. As this study requires the establishment of a model incorporating both latent variables and manifest variables, CB-SEM was deemed more appropriate for this research based on the normal distribution of data, sample size, RMC, and the overall model form. It should be clarified that although the interpretation of SEM for cross-sectional data involves a sequentiality of influence, it can still only be regarded as an association; therefore, the results of this study should not be viewed as empirical evidence of causality.

When establishing a model framework for an integrated spatial setting, the spatial levels of the target mechanism must be clearly defined. If multidimensional progressive relationships or parallel construct relationships exist, multiple sub-models representing these progressive relationships should be constructed within a single model to form an integrated framework. This integrated model is then compared with independent sub-models, a method known as multi-group SEM, which can reflect the differences between the joint effects and the independent effects of two spatial types [52]. To clarify the joint effect of comfort in two types of office environments on LSA, this study adopts a multi-group SEM approach, incorporating both WS and LS into the model.

2.3.2. Validation of SEM

In this study, IBM SPSS Amos 27.0 software was utilized to construct the multi-group SEM for the two types of office spaces. The model was validated using Confirmatory Factor Analysis (CFA). During the SEM validation process, the Average Variance Extracted (AVE) and the Composite Reliability (CR) were employed to assess the goodness-of-fit of the indicators. Simultaneously, the effectiveness and validity of the model were verified using several indices, including Degrees of Freedom (DF), the Chi-square (X^2), the CMIN/DF, the Incremental Fit Index (IFI), the Comparative Fit Index (CFI), and the Root Mean Square Error of Approximation (RMSEA). Through the multi-group SEM analysis, the rational model paths were identified, allowing for a comparison of how variations in space and PR influence each path. Furthermore, the bootstrapping method was applied to analyse the direct effect and indirect effect of comfort on LSA.

2.4. Hypothesis of SEM

Drawing on a literature review that integrates the potential relationships between TECV, WESA, WSA, and LSA, this study explores the mechanisms by which IEQ comfort influences LSA within the two primary types of office spaces. Consequently, with the environment as the independent variable, the influence patterns of variable relationships follow a progressive logic from environmental factors (TECV and WESA) towards WSA or well-being (LSA). An "environmental comfort"—"work"—"well-being" mechanism model was established within the office (Figure 1). Furthermore, factors such as CUT, work stress, age, and gender were incorporated into the exploratory model to investigate potential variances arising from individual characteristics. While IEQ preference serves as a moderating factor for comfort, this study only involves an analysis of its associated effects and does not incorporate it into the structural model.

Supported by the literature review, several hypotheses were formulated for the model:

Based on the literature review and the underlying logic of this study, and premised on the directional impact of the environment on well-being: H1: WESA positively influences WSA; H2: WESA positively influences LSA; H3: WSA positively influences LSA;

Premised on the defined causal pathways of IEQ comfort on satisfaction and well-being: H4: TECV positively influences WESA; H5: TECV positively influences WSA; H6: TECV positively influences LSA;

Premised on the literature review indicating that CUT and work stress may negatively impact well-being, and that personal traits exert potential influences: H7: CUT and work stress negatively influence LSA, while age and gender exert significant effects on LSA;

Premised on the pathway through which IEQ comfort acts upon satisfaction and well-being: H8: (a) comfort (WS) and (b) comfort (LS) positively influence TECV; H9: (a) comfort (WS) and (b) comfort (LS) positively influence WESA; H10: (a) comfort (WS) and (b) comfort (LS) positively influence WSA; H11: (a) comfort (WS) and (b) comfort (LS) positively influence LSA;

Premised on the assumption of differential effects across multiple spaces: H12: The pathway mechanisms for the indirect effects of WS and LS on LSA differ.

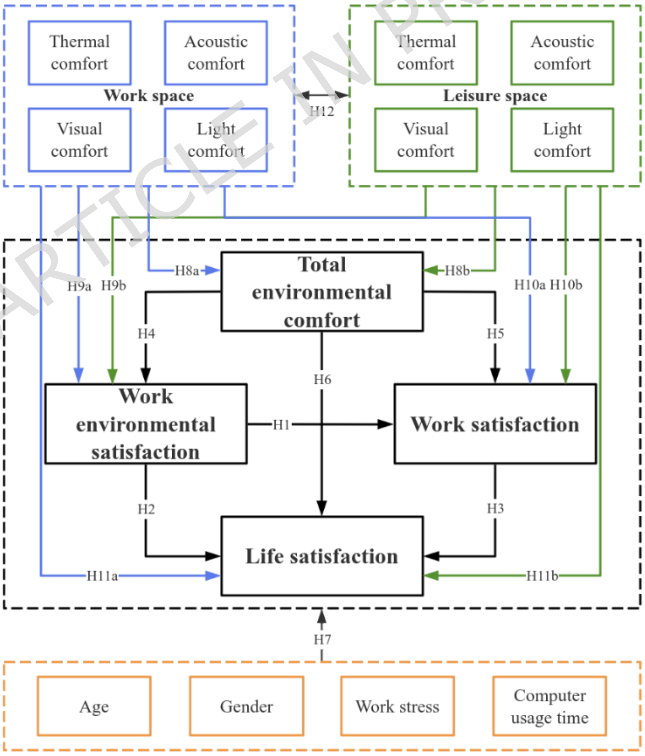

Figure 1. A framework of IEQ comfort impact path on well-being in the overall office space.

3. Results

3.1. Participant demographics and investigate outcomes

The demographic characteristics of the participants are presented in Table 1. Overall, the sample data are well-balanced; all respondents are employees working in open-plan office environments, with the majority being under 30 years old. Regarding CUT, the highest proportion of employees reported a duration of more than seven hours (40.2 %), while only 4.9 % reported using a computer for less than one hour.

Table 1. Participant demographics.

Trait	Item	No.	Per.
Computer usage time	< 1h	13	4.9
	1h-3h	30	11.4
	3h-5h	49	18.5
	5h-7h	66	25
	> 7h	106	40.2
Occupation	Architect	106	40.2
	Programmer	43	16.3
	Officer	79	29.9
	Designer	36	13.6
Age	21 - 25	117	44.3
	26 - 30	76	28.8
	31 - 40	26	9.8
	41 - 50	14	5.3
	Above 50	31	11.8
Gender	Male	139	52.7
	Female	125	47.3
Education	Specialty and below	23	8.7
	Bachelor	116	43.9
	Master	107	40.5
	Doctor	18	6.8

Table 2 presents the mean values and standard deviations for the investigated factors. The comfort vote for all factors was found to be moderately high; however, the comfort vote in the WS was consistently lower than that in the LS. Work stress was reported at a relatively high level. Among the satisfaction-related factors, WSA recorded the lowest score, while LSA was the highest, with overall results indicating a generally satisfied level. Regarding specific factors, ACV was the lowest in both spaces, which aligns with findings from previous studies [53, 54]. Conversely, TCV reached the highest level; this may be attributed to the investigation occurring during autumn, when temperatures are relatively mild, thus preventing significant indoor-outdoor temperature differentials from affecting the results. Furthermore, among the IEQ preferences, LPV was the highest, while APV was the lowest.

Table 2. Average and standard deviation of investigate variables.

Variable	Mean	SD
TCV (WS)	0.82	1.632
NLCV (WS)	0.79	1.618
ALCV (WS)	0.75	1.566
ACV (WS)	0.68	1.656
VCV (WS)	0.78	1.552
TECV (WS)	0.81	1.619
TCV (LS)	1.07	1.546
NLCV (LS)	0.91	1.515
ALCV (LS)	0.87	1.568
ACV (LS)	0.82	1.578
VCV (LS)	1.01	1.539
TECV (LS)	0.98	1.519
TPV	0.60	1.576

LPV	0.93	1.506
APV	0.49	1.775
Work stress	6.93	2.212
WSA	6.29	2.316
WESA	6.47	2.24
LSA	6.74	2.198

3.2. ANOVA, correlation and interaction effects analysis

3.2.1 Welch's ANOVA of personal traits and IEQ preference

By using IBM SPSS 26.0, the study employed Welch's ANOVA to examine the differences in factors related to comfort and satisfaction across CUT, age, gender, education, occupation and IEQ preference (Table 3). The results indicate that CUT significantly influences WSA, WESA, and LSA, with all demonstrating large effect sizes; however, regarding comfort factors, only NLCV (WS) showed near-significant differences. Age exhibited significant differences across VCV in both types of spaces, as well as in work stress, WSA, WESA, and LSA. In contrast, gender differences were only significant in VCV (WS), TCV (LS), and ALCV (LS). Education shows high difference on WESA and LSA, and low difference on WSA, and variations in ACV across different spaces are observed based on education levels. Occupation exhibits weak differences in WESA, and variations in ALCV across all spaces. Notably, IEQ preference shows substantial and significant differences across comfort, WSA, WESA, and LSA in various spaces, suggesting that IEQ preference may possess significant functional benefits.

Table 3. Welch's ANOVA of personal traits and IEQ preference.

Variables	Traits					
Factors	*Computer usage time*		*Age*		*Gender*	
	F	np2	F	np2	F	np2
TCV (WS)	0.201	0.013	0.816	0.054	0.154	0.001
NLCV (WS)	2.138^	0.122[b]	0.893	0.059	1.997	0.008
ALCV (WS)	1.484	0.088	2.32^	0.135[b]	1.165	0.005
ACV (WS)	1.049	0.063	2.404^	0.141[c]	1.267	0.005
VCV (WS)	0.479	0.031	4.97**	0.25[c]	4.127*	0.016[a]
TECV (WS)	0.913	0.057	2.115^	0.128[b]	0.481	0.002
TCV (LS)	0.823	0.051	3.045*	0.166[c]	6.024*	0.023[a]
NLCV (LS)	0.182	0.012	2.467^	0.146[c]	2.488	0.01
ALCV (LS)	1.325	0.08	3.605*	0.201[c]	4.416*	0.017[a]
ACV (LS)	0.539	0.034	1.319	0.086	1.92	0.007
VCV (LS)	0.515	0.033	2.911*	0.167[c]	0.85	0.003
TECV (LS)	1.849	0.109	1.132	0.071	1.358	0.005
Work stress	1.811	0.108	4.3**	0.231[c]	0.566	0.002
WSA	5.716**	0.267[c]	3.128*	0.181[c]	0.477	0.002
WESA	5.105**	0.248[c]	2.637*	0.154[c]	0.854	0.003
LSA	4.849**	0.238[c]	3.255*	0.181[c]	0.877	0.003
	Education		*Occupation*		*IEQ Preference*	
TCV (WS)	0.143	0.008	1.331	0.039	53.856**	0.891[c]
NLCV (WS)	2.278^	0.119[b]	1.977	0.057	46.011**	0.87[c]
ALCV (WS)	2.166	0.111	2.634^	0.074[b]	28.884**	0.816[c]
ACV (WS)	5.264**	0.24[c]	2.9*	0.08[b]	29.412**	0.818[c]
VCV (WS)	0.735	0.042	0.784	0.023	22.416**	0.774[c]
TECV (WS)	2.173	0.114	1.454	0.042	17.402**	0.732[c]
TCV (LS)	1.264	0.07	1.229	0.037	17.865**	0.737[c]

NLCV (LS)	1.128	0.062	1.191	0.034	20.309**	0.76[c]
ALCV (LS)	1.397	0.075	2.968*	0.085[b]	25.303**	0.798[c]
ACV (LS)	3.286*	0.16[c]	0.958	0.029	30.74**	0.828[c]
VCV (LS)	0.996	0.056	1.253	0.037	29.783**	0.82[c]
TECV (LS)	1.411	0.074	1.565	0.046	54.122**	0.89[c]
Work stress	0.808	0.047	0.854	0.026	2.109	0.244
WSA	2.868*	0.142[c]	1.6	0.045	5.489**	0.467[c]
WESA	11.56**	0.398[c]	3.332*	0.091[b]	6.404**	0.504[c]
LSA	4.158**	0.19[c]	0.789	0.023	5.456**	0.465[c]

**, Significance at the 0.01 level; *, Significance at the 0.05 level; ^, Significance at the 0.1 level.

np^2, a□0.0099 small; b□0.0588 medium; c□0.1379 large.

Meanwhile, the study analyzed potential differences in individual characteristics across various preferences (Table 4). Among them, APV exhibited the most substantial differences, with gender being the only factor showing no significant effect, while CUT exerted the greatest influence. Secondly, TPV showed significant differences only in terms of education and CUT. In contrast, no significant differences were observed for LPV across any individual characteristics.

Table 4 Welch's ANOVA of personal traits on IEQ preference.

Variables	*TPV*		*LPV*		*APV*	
Traits	F	np^2	F	np^2	F	np^2
Occupation	1.842	0.053	1.798	0.052	3.525*	0.095[a]
Education	4.245**	0.198[c]	2.626	0.135	4.515**	0.205[c]
Gender	0.407	0.002	0.282	0.001	2.822	0.011
Age	2.439	0.145	1.455	0.091	2.662*	0.154[c]
CUT	2.754*	0.153[c]	1.843	0.11	5.175**	0.25[c]

**, Significance at the 0.01 level; *, Significance at the 0.05 level.

np^2, a□0.0099 small; b□0.0588 medium; c□0.1379 large.

To evaluate the impact on LSA within the proposed framework, this study established two General Linear Models based on the model in Figure 1 to verify the integrated effects of IEQ preference, comfort, and satisfaction in both WS and LS. Model (1) examines the interaction between IEQ preference and comfort, representing the pathway from IEQ preference to LSA via TECV. Model (2) represents the central framework of Figure 1, focusing on the interaction between comfort and satisfaction. The results of Model (1) indicate that within IEQ preference, only LPV exhibited a significant main effect. In contrast, for the comfort and satisfaction indicators, the main effects of TECV (WS), TECV (LS), WESA, and WSA were all significant, whereas CUT showed no significant effect. This suggest that the effect of IEQ preference is weaker than that of the comfort and satisfaction indicators. Regarding interaction effects, a significant interaction was observed between TECV and TPV in WS, and between TECV and APV in LS. Other interaction effects were non-significant, indicating that the model incorporating IEQ preference has a relatively low impact on LSA.

Subsequently, Model (2), which includes comfort and satisfaction, was tested for integrated effects. The results show that TECV, WESA, WSA, and CUT all possess significant main effects on LSA, with WESA, WSA, and CUT ranking as the top three in terms of effect size. Notably, the effect of TECV (LS) was higher than that of TECV (WS), highlighting the role of TECV in LS for enhancing LSA. Regarding interaction effects, CUT only produced significant interactions with WESA or WSA, while no significant interaction was observed between TECV and CUT. The primary interaction factors with high effect sizes included TECV (WS) * WESA, TECV (WS) * WSA, TECV (LS) * WESA, TECV (LS) * WSA, and WESA * WSA. In the three-way interaction analysis, only TECV (LS) * WESA * WSA was significant. This confirms that TECV in LS outperforms that in WS, though only with a small effect size; therefore, the mechanism is primarily driven by two-way interactions.

Table 5 The main effects and interaction effects of IEQ comfort and satisfaction on LSA.

(1) Preference and comfort			(2) Comfort and satisfaction		
Variables	F	np^2	Variables	F	np^2
Intercept	163.9	-	Intercept	6278.9	-
TPV	1.339	0.146	CUT	8.291**	0.112[b]
LPV	2.966*	0.24[c]	WESA	12.697**	0.302[c]
APV	1.831	0.189	WSA	9.803**	0.25[c]
CUT	0.87	0.069	TECV (WS)	2.681*	0.057[a]
WESA	4.018**	0.435[c]	TECV (LS)	7.546**	0.125[b]
WSA	3.923**	0.429[c]	CUT * WESA	5.694**	0.097[b]
TECV (WS)	2.449*	0.238[c]	CUT * WSA	3.09**	0.076[b]
TECV (LS)	2.418*	0.236[c]	WESA * WSA	3.958**	0.152[c]
CUT * TPV	1.618	0.292	TECV (WS) * CUT	1.34	0.01
CUT * LPV	1.258	0.194	TECV (WS) * WESA	5.995**	0.137[b]
CUT * APV	1.457	0.254	TECV (WS) * WSA	4.397**	0.104[b]
TECV (WS) * TPV	2.642*	0.336[c]	TECV (LS) * CUT	1.133	0.009
TECV (LS) * TPV	1.339	0.204	TECV (LS) * WESA	5.233**	0.106[b]
TECV (WS) * LPV	0.841	0.111	TECV (LS) * WSA	7.727**	0.17[c]
TECV (LS) * LPV	1.438	0.133	TECV (WS) * WESA * WSA	0.518	0.004
TECV (WS) * APV	1.547	0.248	TECV (LS) * WESA * WSA	4.911*	0.018[a]
TECV (LS) * APV	2.317*	0.283[c]	TECV (WS) * TECV (LS) * WESA * WSA	1.722	0.013

**, Significance at the 0.01 level; *, Significance at the 0.05 level.
np^2, a□0.0099 small; b□0.0588 medium; c□0.1379 large.

Then, a correlation analysis was conducted across all factors (Figure 2). The results indicate that CUT is negatively correlated with age, WSA, WESA, and LSA, while being positively correlated with work stress. Regarding comfort, CUT generally exhibited a negative trend; however, a significant negative correlation was only observed with ALCV (WS). This may be attributed to the influence of monitor glare on individual ALCV perceptions. Similarly, work stress was negatively correlated with ALCV (WS), in addition to being negatively correlated with WESA and age. WSA, WESA, and LSA were all positively correlated with comfort. Among these, WESA demonstrated the highest correlation, followed by LSA, while the correlation for WSA was higher in the WS than in the LS. Specifically, WESA is highly associated with IEQ comfort indicators such as VCV (WS), ACV (WS), ALCV (LS), and VCV (LS). Meanwhile, WSA shows a strong correlation with NLCV (WS), ACV (WS), NLCV (LS), and ALCV (LS). VCV is positively correlated with the enhancement of WESA across all spaces. Previous studies have indicated that factors such as window scenery, green walls, and wall color often stimulate employees visually; high-satisfaction factors coordinated through visual characteristics can enhance VCV, thereby improving WESA. In WS, a low evaluation of the acoustic environment is generally considered to have a negative impact on WESA [55], which is consistent with the findings of this study. Furthermore, NLCV is associated with the improvement of WSA in all spaces, suggesting that employees' demand for natural light in indoor environments may be directly linked to their work. Key factors involved include the window-to-wall ratio (WWR), window scenery, window fittings, and office orientation. Additionally, IEQ comfort indicators with high correlations to TECV include VCV (WS), NLCV (WS), ACV (WS), NLCV (LS), ACV (LS), and VCV (LS). This indicates that acoustic and visual comfort have a more significant impact on TECV and should be prioritized as design objectives, with no observed differences in comfort types between the two spaces. Furthermore, WSA, WESA, and LSA were found to be highly intercorrelated, which is consistent with previous research findings. This also confirms hypotheses H1–H3 and validates the theoretical approach of moderating WSA through WESA to enhance LSA. Notably, age showed no significant association with LSA, yet it was positively correlated with both WSA and WESA.

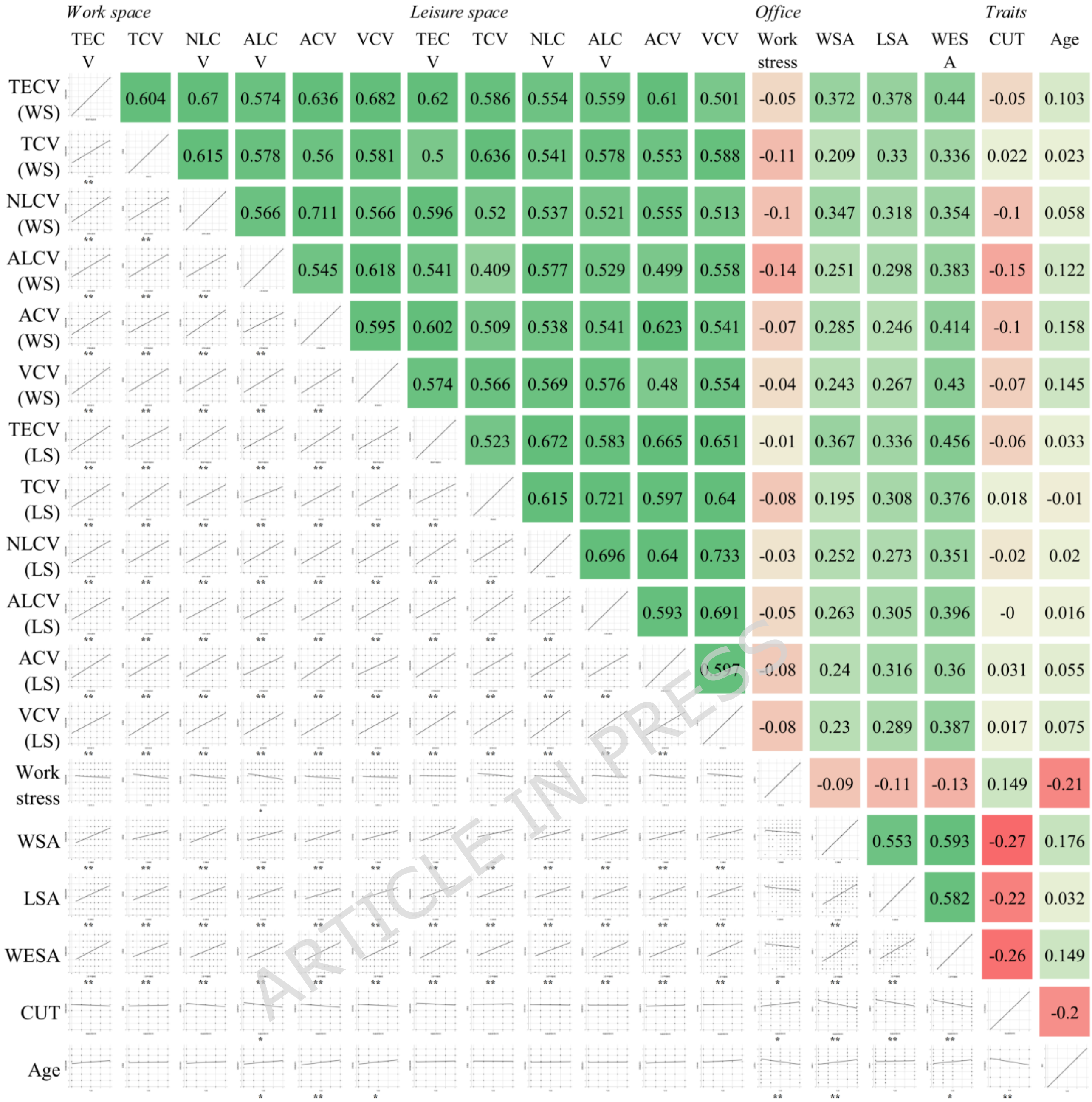

Figure 2. Correlation between comfort, satisfaction, well-being and personal traits.

3.3. Multi-group SEM establishment and validation

3.3.1. CFA and validation

The study established a multi-group SEM from a spatial perspective to verify the underlying mechanisms of comfort on LSA across different environments. Consequently, three separate SEMs were developed: WS, LS, and Office. Prior to model construction, CFA was employed to examine the validity of the factors. As presented in Table 6, the CR values were all above 0.8, and the AVE values exceeded 0.5. Subsequently, the fit of each model was evaluated; Table 7 illustrates the model fit indices, indicating that all models achieved a stable and satisfactory state.

Table 6. CFA results of latent variables.

Latent variable Comfort (WS)	Estimate	CR	AVE	Latent variable Comfort (LS)	Estimate	CR	AVE
TCV (WS)	0.75	0.879	0.593	TCV (LS)	0.782	0.904	0.655

NLCV (WS)	0.792	NLCV (LS)	0.838
ALCV (WS)	0.734	ALCV (LS)	0.827
ACV (WS)	0.789	ACV (LS)	0.767
VCV (WS)	0.785	VCV (LS)	0.831

Table 7. SEM validation parameters.

Model	CMIN/DF <3	GFI >0.9	NFI >0.9	IFI >0.9	CFI >0.9	RMSEA <0.08
Model WS	2.061	0.958	0.944	0.971	0.97	0.064
Model LS	1.65	0.968	0.962	0.985	0.984	0.05
Model Office	2.232	0.917	0.918	0.953	0.952	0.068

3.3.2. Multi-group SEM results

Regarding the spatial multi-group SEM, an overall space model and sub-space models were established, as illustrated in Figure 3. In all models, IEQ comfort exerted a significant influence on TECV; WESA positively influenced both WSA and LSA, while WSA positively influenced LSA. These findings fostered a multi-path mechanism model and confirmed hypotheses H1, H2, and H3. Figure 3 (right) displays model WS and model LS as peer-level models. Similarities between the two spaces include: comfort exerts a positive influence on WESA, and TECV positively influences WSA, while neither has a direct effect on LSA. Regarding individual factors, CUT has a negative influence on both WESA and WSA, and its effect on work stress is marginally significant in both cases. Differences in influence between the two spaces were observed: comfort (WS) only positively influences WESA, whereas comfort (LS) influences both WESA and LSA.

Furthermore, TECV (WS) only affects WSA, while TECV (LS) influences both WESA and WSA. Additionally, CUT only exerts a negative influence on TECV in the LS. These results suggest that when WS and LS are considered independently, the LS provides a higher promotional benefit to WESA and LSA compared to the WS. As shown in Figure 3 (left), the establishment of the overall space model (Office) reveals that the direct effect of comfort is diminished. In contrast, the effects of TECV and individual factors remain constant. This suggests that, under the interaction of multiple spatial models, the actual benefit of IEQ comfort may be lower than previously reported in the literature. Instead, TECV more effectively influences WESA and WSA, thereby indirectly affecting LSA. This suggests that the interactive benefits of different spaces within the same premises should not be overlooked; the integrated benefits of multiple spaces must be clearly defined to determine critical design indicators.

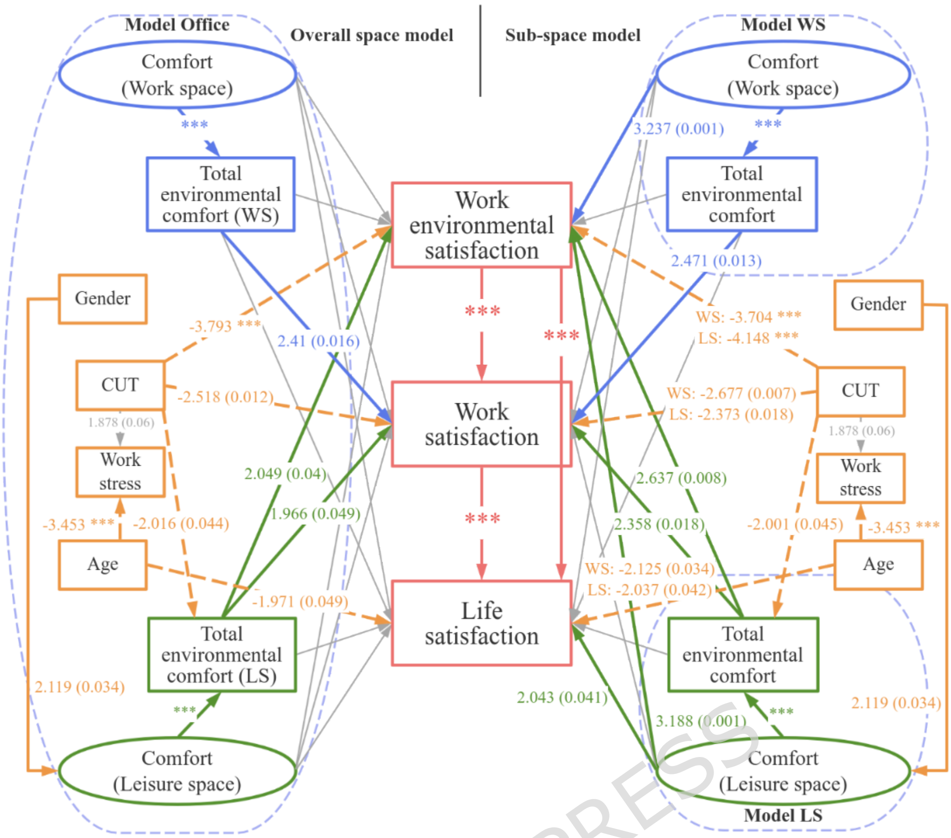

Figure 3. Multi-group SEM for indoor environmental comfort influence model in two type of office spaces. (Left: overall space model; Right: sub-space model).

3.4. Effects and path on life satisfaction

The study utilized the Amos 27.0 platform to conduct significance testing of the influence effects via a bootstrapping procedure. This process involved 4,000 random sub-samples, with significance set at the 0.05 level. The resulting direct, indirect, and total effects on WESA, WSA, and LSA are presented in Table 6, reflecting the various benefits generated by these factors. The results indicate that IEQ comfort does not exert a direct effect on LSA. Specifically, comfort (WS) can indirectly promote WSA (0.304), while comfort (LS) provides an indirect promotional effect on both WESA (0.141) and WSA (0.257). Conversely, TECV effectively promotes WESA, WSA, and LSA. Within the work environment, TECV (WS) has no direct effect on WESA but directly promotes WSA (0.233), subsequently exerting an indirect effect on LSA (0.128), with WSA acting as the mediating variable. This suggests that enhancing TECV in the WS will improve LSA by first increasing WSA. In contrast, TECV (LS) directly promotes WESA (0.18) and simultaneously exerts both direct and indirect promotional effects on WSA, thereby enhancing LSA (0.138). Enhancing TECV in the LS therefore improves LSA through the combined promotion of WESA and WSA. It is noteworthy that specific non-significant effects may involve negative associations, which can lead to non-significant total effects; therefore, specific influence pathways must be confirmed via path analysis. Furthermore, CUT demonstrates a strong influence on WESA, WSA, and LSA. CUT directly inhibits WESA (-0.209) and WSA (-0.133) and does not exert an indirect influence on WESA through comfort. However, it does produce indirect harmful effects on WSA (-0.115) and LSA (-0.138). These findings confirm the negative impact of CUT on satisfaction and well-being. Among the remaining factors, only age was found to have a small indirect effect on LSA (0.093).

Table 6. The direct and indirect effects of model Office.

Variables		Comfort (WS)	Comfort (LS)	TECV (WS)	TECV (LS)	WESA	WSA	Gender	Age	CUT	Work stress
WESA	Direct effect	0.133	0.126	0.113	**0.18**	0	0	0.008	0.059	**-0.209**	-0.049
		0.52	0.533	0.323	**0.047**	-	-	0.872	0.32	**0.001**	0.349
	Indirect effect	0.094	**0.141**	0	0	0	0	0.048	0.052	-0.015	-0.025
		0.326	**0.045**	-	-	-	-	0.156	0.155	0.681	0.489
	Total effect	0.227	0.266	0.113	**0.18**	0	0	0.056	*0.11*	**-0.224**	-0.074
		0.164	0.132	0.323	**0.047**	-	-	0.351	*0.064*	**0.001**	0.23
WSA	Direct effect	-0.199	-0.037	**0.233**	*0.162*	**0.491**	0	-0.068	0.07	**-0.133**	-0.002
		0.376	0.836	**0.026**	*0.052*	**0.001**	-	0.181	0.2	**0.019**	0.983
	Indirect effect	**0.304**	**0.257**	0.056	**0.088**	0	0	0.024	0.055	**-0.115**	-0.022
		0.011	**0.017**	0.316	**0.042**	-	-	0.5	0.163	**0.011**	0.567
	Total effect	0.105	0.22	**0.289**	**0.25**	**0.491**	0	-0.044	**0.125**	**-0.248**	-0.024
		0.561	0.185	**0.012**	**0.008**	**0.001**	-	0.452	**0.039**	**0.001**	0.72
LSA	Direct effect	-0.096	0.189	0.117	-0.085	**0.332**	**0.314**	0.029	*-0.099*	-0.077	-0.044
		0.686	0.296	0.27	0.3	**0**	**0.001**	0.591	*0.056*	0.18	0.366
	Indirect effect	0.205	0.091	**0.128**	**0.138**	**0.154**	0	0.018	**0.093**	**-0.138**	-0.042
		0.133	0.416	**0.035**	**0.007**	**0**	-	0.65	**0.03**	**0.003**	0.307
	Total effect	0.109	0.279	**0.245**	0.053	**0.486**	**0.314**	0.048	-0.006	**-0.214**	-0.086
		0.525	0.12	**0.044**	0.599	**0**	**0.001**	0.437	0.929	**0.001**	0.167

In each effect line, the first line shows the effect size, and the second line shows the p-value.
Bold: Significant at 0.05 level; *Italic*: Significant at 0.1 level.

3.5. Path and weights of IEQ comfort impact on life satisfaction

A bootstrapping procedure was applied to the entire multi-group SEM to test the efficacy and significance of the pathways through which comfort influences LSA across the three model components. According to the results in Table 7, when separate SEMs were established for WS and LS environments, comfort in both cases required WESA to facilitate the promotion of LSA. Specifically, within the WS, when comfort acted through TECV, it could only promote LSA via WSA, with WESA yielding no promotional benefit for LSA. In contrast, within the LS, the influence of comfort via TECV required the mediation of both WESA and WSA, with WESA demonstrating a higher level of efficacy. However, when the WS and LS were integrated into a combined model, Model Office exhibited significant shifts. In this integrated framework, comfort only promoted LSA through TECV. Within the WS component of this model, benefits were generated exclusively through WSA, while WESA proved ineffective. Conversely, in the LS, comfort enhanced both WESA and WSA via TECV, thereby promoting LSA.

Furthermore, under the joint interaction of both spaces, although the significant efficacy of the WS pathways was lower, the overall promotional benefit of comfort on LSA via TECV was amplified. In contrast, the efficacy of the LS was reduced; although the influence of comfort on LSA via TECV was not statistically significant in this context, it counterbalanced the overall effect. Consequently, in holistic spatial design, it is essential to identify the potential direct influence of TECV on LSA to enhance overall environmental efficacy.

Table 7. Multi-group SEM path analysis of comfort to LSA.

Path of Comfort to LSA	Model WS		Model LS		Model Office	
	Estimate	p	Estimate	p	Estimate	p
Comfort (WS) → WSA → LSA	-0.077	0.245	-	-	-0.111	0.355
Comfort (WS) → WESA → LSA	0.243**	0.001	-	-	0.078	0.485
Comfort (WS) → WESA → WSA → LSA	0.113**	0.001	-	-	0.036	0.47
Comfort (WS) → TECV (WS) → LSA	0.159	0.324	-	-	0.171	0.271
Comfort (WS) → TECV (WS) → WSA → LSA	0.118*	0.017	-	-	**0.107***	**0.019**
Comfort (WS) → TECV (WS) → WESA → LSA	0.048	0.327	-	-	0.055	0.28
Comfort (WS) → TECV (WS) → WESA → WSA → LSA	0.023	0.317	-	-	0.025	0.284
Comfort (LS) → WSA → LSA	-	-	-0.043	0.404	-0.021	0.808
Comfort (LS) → WESA → LSA	-	-	0.172**	0.001	0.075	0.482
Comfort (LS) → WESA → WSA → LSA	-	-	0.085**	0.001	0.035	0.478
Comfort (LS) → TECV (LS) → LSA	-	-	-0.094	0.439	-0.12	0.291
Comfort (LS) → TECV (LS) → WSA → LSA	-	-	0.085*	0.017	**0.071***	**0.034**

Comfort (LS) → TECV (LS) → WESA → LSA	-	-	0.104*	0.012	**0.084***	**0.033**
Comfort (LS) → TECV (LS) → WESA → WSA → LSA	-	-	0.051*	0.01	**0.039***	**0.03**
Comfort (WS) (no TECV (WS))	0.28*	0.027	-	-	0.004	0.991
Comfort (WS) (with TECV (WS))	0.348^	0.065	-	-	**0.358***	**0.045**
Comfort (LS) (no TECV (LS))	-	-	0.215*	0.029	0.089	0.627
Comfort (LS) (with TECV (LS))	-	-	0.146	0.255	0.074	0.584
Comfort (WS)	0.628**	0.002	-	-	0.362	0.135
Comfort (LS)	-	-	0.361**	0.004	0.163	0.411

**: Significant at 0.01 level; *: Significant at 0.05 level; ^: Significant a 0.1 level.

4. Discussion

This study conducted a systematic investigation across nine floors of four high-rise office buildings. Distinct from previous research, both the WS and LS were incorporated into the scope of the investigation to explore the potential integrated benefits existing within these environments. By analyzing the influence pathways of IEQ comfort, this research identified the core impact by which comfort influences TECV and WESA, which subsequently impacts WSA and LSA. Based on these findings, a mechanism model for the impact of the environment on well-being was established. Furthermore, through the construction of a multi-spatial multi-group SEM, the study clarified the direct and indirect effects of IEQ comfort and TECV on employees' WESA, WSA, and LSA.

4.1. Mechanisms of comfort and TECV on WESA, WSA, and LSA

Previous studies have noted that collaborative research into comfort and satisfaction often involves ambiguous boundaries and a lack of exploration into their mutual factors, which can lead to the confounding of their respective effects [54]. In recent years, researchers have established integrated frameworks that incorporate well-being into the domains of satisfaction and comfort [56], suggesting that their associated benefits are subject to a comprehensive influence. This study investigated IEQ comfort within two types of office spaces, and the results demonstrated a strong promotional effect on the TECV of each respective space. Furthermore, TECV was identified as the critical factor through which IEQ comfort influences WESA, WSA, and LSA. However, IEQ comfort only generated promotional benefits via TECV and was unable to exert an independent influence; this confirms hypothesis H8 while refuting H9, H10, and H11. Simultaneously, the efficacy of TECV on WSA was found to be greater than its effect on WESA. This reflects that the influence pathway of comfort may be more dominant at the psychological level than the direct reaction to the environment, thus validating hypotheses H4 and H5.

Regarding well-being outcomes, the pathway by which WESA influences WSA to enhance LSA aligns with existing research findings [17]. A point of departure in this study, however, is that multi-sensory IEQ comfort and TECV were unable to provide a direct promotional effect on LSA. This suggests that the collective interaction of multidimensional IEQ factors may be required to enhance LSA indirectly; consequently, hypotheses H6, H11 (a), and H11 (b) were rejected. Furthermore, the enhancement of TECV could be further explored by extending research into non-sensory IEQ domains, such as coffee spaces [24] and recreational areas [17].

4.2. Differences in the impact of comfort across different spaces

In this study, a multi-group SEM was established for the WS and LS, followed by a comparative analysis of the influence pathways between the overall office model and the sub-space models. The results indicate that the influence of the LS on well-being is greater than that of the WS, which aligns with previous research findings [39]. However, existing studies have largely overlooked the nuances of the pathways through which the LS affects satisfaction and well-being. Our findings reveal that within the WS, IEQ comfort only enhances LSA by promoting WSA via TECV. In contrast, within the LS, IEQ comfort effectively improves WESA and WSA through TECV (LS), thereby facilitating an increase in LSA. This suggests that the pathway through which WESA influences LSA is primarily realized within the LS. Nevertheless, as the total effect of IEQ comfort on LSA was not statistically significant, it implies that the factors influencing LSA in the LS extend beyond sensory IEQ comfort, necessitating a broader exploration of other IEQ factors. Furthermore, while previous research has focused predominantly on the WS, our sub-space model analysis demonstrates that both the WS and LS generate independent benefits. Critically, the overall office model shows that combined effects tend to weaken these individual relationships. This underscores the necessity of investigating comfort across multiple spatial types; failure to do so may introduce significant, incalculable errors into the results. Consequently, these findings confirm hypothesis H12. Research design should prioritize employees' multidimensional perceptions of IEQ comfort, satisfaction, and sensory factors across various spaces, rather than adopting a uniform view of IEQ influence. This study also confirms that IEQ comfort research should not focus exclusively on sensory factors, but should expand to include elements such as seat comfort and other mental sensory factors, including nature elements, window-to-wall ratio, and spatial size.

4.3. Impact of CUT and personal traits on satisfaction and well-being

Regarding the impact of individual characteristics, this study analyzed gender, age, and work stress. It was found that gender exerts a significant influence on comfort (LS). When integrated with the variance analysis in Table 3, TCV and ALCV are the critical factors underlying this difference. Consequently, gender-based variations may become a primary focus in the design of LS. Furthermore, the study revealed that LSA decreases with age. Existing literature indicates that LSA typically follows a U-shaped curve with age, reaching its lowest point during middle age, potentially due to increased life pressures. As no participants over the age of 60 were involved in this study, the results are consistent with these established conclusions. Additionally, work stress was found to decrease with increasing age. A significant factor incorporated into this research is CUT, the results of which reflect a significant negative correlation with WESA and WSA. Notably, WESA is more heavily impacted, leading to a subsequent indirect negative influence on LSA. From a comfort perspective, CUT is negatively correlated with TECV (LS) but shows no significant effect on TECV (WS). This may be because employees prioritize comfort more highly within the LS; consequently, excessive CUT leads to a perceived reduction in comfort, which adversely affects their perception of the LS and reduces WESA. Future research should clarify the underlying mechanisms of this correlation. Furthermore, CUT exhibited a marginally significant negative correlation with work stress, which may be attributed to variations in occupational stress levels. Given the impacts generated by CUT, future office research should pay closer attention to differences in CUT across various professions and identify specific factors related to it—such as differences in screen brightness and individual light sensitivity—to clarify the potential technical impacts on satisfaction, health, productivity, and well-being. Since the personal traits examined in H7 could not directly influence LSA, the hypothesis was refuted.

4.4. Design strategies on satisfaction and well-being in different office spaces

This study developed an SEM framework integrating sensory IEQ comfort, TECV, WESA, and WSA to investigate their effects on well-being. Detailed analyses were conducted by incorporating individual characteristics (e.g., age, gender, education, and occupation) and environmental indicators (e.g., CUT and IEQ preference), culminating in design strategies to enhance indoor employees' well-being. Regarding sensory IEQ comfort, employees reported that VCV facilitates the enhancement of WESA in both types of spaces. Associated indicators include window scenery, green walls, wall color, and workstation layout and facilities. Existing research has demonstrated that window scenery and green walls effectively regulate physiological stress and alleviate anxiety [57, 58]. The benefits of green walls have been established in terms of visual proportion and layout types [59]. Furthermore, different wall colors can lead to significant variations in visual perception; certain colors may act as stressors, triggering tension and subsequent health issues [55]. Studies suggest that the use of wooden materials may result in lower reported stress [60]. For the workstations where employees spend extended periods, VCV design is equally critical. In open-plan WS, high-density layouts are often implemented to boost productivity, leading to crowded facilities. In such contexts, workstation layout and facilities should prioritize the visual space of the desktop, which differs from the broader indoor visual fields addressed in previous research. There is still a lack of design strategies specifically targeting desktop layouts or facility types, highlighting potential perceptual differences across various spaces. Due to the nature of open-plan WS, ACV also showed high correlation; low evaluations of the acoustic environment are generally considered to negatively impact WESA [55]. Both VCV and ACV are highly correlated with TECV, WESA, and WSA, underscoring the demand for optimized acoustic environment design. From the perspective of WSA, NLCV maintains high correlation in both spaces. Research confirms that consistent daily light exposure effectively maintains circadian rhythm stability and regulates melatonin secretion, benefiting overall physical and mental health [61]. Key factors include WWR, window fittings, and office orientation. WWR directly influences the amount of natural light received, although larger WWR often leads to excessive heat gain [62], which may cause thermal discomfort even when lighting conditions are met. Thus, window fittings (e.g., curtains or blinds) allow for effective control of lighting conditions [63], enabling improvements based on individual needs and potentially promoting WSA. Regarding the effects of sensory IEQ comfort on TECV, the highly correlated indicators—specifically VCV, ACV, and NLCV—showed no significant differences across spaces; these factors can substantially enhance TECV. Furthermore, TECV is associated with private space [64], office typology [64], personal control [65], cleanliness [66], and work area aesthetics [67]. Therefore, multidimensional enhancements targeting different types of IEQ comfort should be implemented to comprehensively improve TECV benefits.

Furthermore, SEM mechanistic analysis reveals distinct design requirements for different functional spaces. The standardized design patterns in previous research possess significant limitations. In the overall space model, sensory IEQ comfort across all spaces influences comfort only through TECV, which differs significantly from the sub-space model that considers only a single space. The overall space model shows that in WS, TECV is associated only with WSA and has no effect on WESA, whereas in LS, it influences both WESA and WSA. This indicates that TECV (LS) has a superior effect on WESA compared to TECV (WS). Enhancing TECV in LS should focus on design methods that simultaneously address WESA and WSA, such as improving NLCV, ACV, and VCV, or increasing private space to enhance privacy. Improving facility quality and variety in LS provides ample environmental resources; specifically, public discussion areas can be reinforced through NLCV, ACV, and VCV design to enhance TECV. In WS, the goal of increasing TECV should focus on WSA, including workstation layout, ACV, and other factors related to personal belonging and engagement.

Additionally, investigations into individual characteristics revealed that CUT has a significant negative correlation with TECV (LS), WESA, and WSA. While computers are ubiquitous in modern work, specific strategies for WESA and WSA remain insufficient. CUT is negatively correlated with ALCV in WS and positively correlated with work stress. This suggests that ALCV for long-term computer users requires prioritized attention, alongside efforts to reduce work stress. The SEM results indicate that CUT influences LSA through WESA and WSA. Factors such as monitor brightness, the health and comfort impacts of long-term screen exposure, and the effects of sedentary behavior should be addressed. More suitable lighting environments and fully functional workstations and seats should be provided for employees with prolonged computer usage.

4.5. Research limitation and future study

This study is subject to several limitations. Firstly, the investigation period was restricted to autumn; therefore, the seasonal variations across an annual cycle were not explored. Future research should focus on the varying impacts of seasonal changes. Secondly, as this study concentrated on multi-sensory IEQ comfort factors, indoor air quality was not incorporated into the research. Future studies should establish specific investigation methods for air quality comfort and explore its associated influences. Furthermore, as this research involved SEM validation, the analysis was conducted using a sample size that met the requirements for model construction. Future work could involve selecting a larger number of samples over a broader range to expand the database, thereby enhancing the stability of the conclusions and allowing for a comparison of pathway differences across various factors. Furthermore, as this study utilizes cross-sectional data for analysis, the results are presented as associational conclusions rather than causal ones. Future research could conduct experimental analyses integrating various sensory IEQ comfort factors and CUT with IEQ preference to further investigate and establish causal evidence. Finally, future research needs to prioritize the benefits generated by a wider array of IEQ comfort factors.

5. Conclusions

This study conducted a comprehensive investigation into sensory IEQ comfort, TECV, WESA, WSA, and LSA within office environments, while also accounting for personal traits such as CUT, age, gender, and work stress. By establishing a multi-group SEM incorporating spatial interactions, the research explored the influence pathways of the WS and LS to clarify the underlying mechanisms through which IEQ comfort impacts LSA. The following conclusions were drawn:

(1) The multi-group SEM revealed that in the sub-space level SEM, both the WS and LS demonstrated that sensory IEQ comfort effectively influences WESA, with direct effects on LSA observed specifically within the LS. However, in the overall office SEM, the influence of WESA was diminished, and the direct impact on LSA was eliminated. Consequently, significant differences exist in the effects of IEQ comfort on WESA and LSA across multidimensional office spaces. Future investigations should first prioritize employee perceptions to define spatial boundaries and extract relevant factors before conducting targeted explorations.

(2) In the overall office SEM, TECV within the WS was only able to exert a direct effect on WSA, whereas TECV in the LS influenced both WESA and WSA. Specifically, TECV (LS) effectively promotes WESA, while WSA serves as a vital pathway through which IEQ comfort enhances LSA.

(3) CUT was identified as a core factor influencing TECV (LS), WESA, and WSA, exerting a severe impact on LSA. Future research should prioritize the expansion of studies into CUT and its related variables to clarify the pathway mechanisms affecting multiple types of comfort, satisfaction, and well-being. Furthermore, the impact of CUT on WS factors requires further clarification. However, no significant differences in IEQ comfort were found in this study; additional related factors should be explored to define their benefits. Notably, no significant influence of work stress on these variables was observed in this study.

This research integrated comfort and satisfaction to propose a mechanistic pathway framework influencing employee well-being. It successfully identifies the key pathways for enhancing well-being in office environments and clarifies the critical roles of TECV and CUT.

These findings provide guiding conclusions for the development of more comprehensive, health-promoting environmental designs.

Data Availability: The data presented in this study are available on request from the corresponding author.

Additional Information

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Abbreviations: The following abbreviations are used in this manuscript:

Abbreviation	
IEQ	Indoor Environmental Quality
WESA	Work Environmental Satisfaction
WSA	Work Satisfaction
LSA	Life Satisfaction
WS	Work Space
LS	Leisure Space
CUT	Computer Usage Time
TECV	Total Environmental Comfort Vote
TCV	Thermal Comfort Vote
NLCV	Natural Light Comfort Vote
ALCV	Artificial Light Comfort Vote
ACV	Acoustic Comfort Vote
VCV	Visual Comfort Vote
TPV	Thermal Preference Vote
LPV	Light Preference Vote
APV	Acoustic Preference Vote
SWLS	Satisfaction with Life Scale
WWR	Window-to-wall Ratio
SEM	Structural Equation Model
CB-SEM	Covariance-based SEM
PLS-SEM	Variance-based Partial Least Squares SEM
RMC	Reflectively Measured Constructs
FMC	Formatively Measured Constructs
CFA	Confirmatory Factor Analysis
AVE	Average Variance Extracted
CR	Composite Reliability
DF	Degrees of Freedom
IFI	Incremental Fit Index
CFI	Comparative Fit Index
RMSEA	Root Mean Square Error of Approximation

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