https://doi.org/10.36375/prepare_u.iiche.a417

Effects of Indoor Plants on Occupants' Perceptions of Indoor Climate, Sick Building Syndrome (SBS), Emotional State, Self-Assessed Performance, and Overall Space Satisfaction: A Systematic Review

Mukesh Budaniya[a*] and Mani Sankar Dasgupta[a]
[1]Department of Mechanical Engineering, BITS Pilani, Pilani, 333031, India
*Email: mukesh.budaniyai@pilani.bits-pilani.ac.in

Abstract

This systematic review analyses the impact of indoor plants on various aspects of indoor environments and occupants' perceptions using bibliometric tools. The use of tool helps in identification, classification, and trend of research related to indoor plants effect on occupants' perception based on published manuscripts. Analysis brings out that a prominent number and quality publications from various research groups have offered evidence that indoor plants can have prominent impact on feelings of emotional states, self-assessed performance, and overall space satisfaction, as well as the impression of indoor climate. The published works encompassed scholarly articles, empirical studies, and surveys that examined the influence of indoor plants. However, some studies similarly did not find any benefits. While some others recommend careful consideration before placing indoor plant because doing so occupies functional space, require initial investment, augment maintenance cost, and also poses challenges with increased humidity, allergens, and the plants' own emission of volatile organic compounds. As a result, choosing to bring indoor plants require careful consideration. The corpus of research on the benefits of indoor plants for interior spaces and occupant perceptions is still lacking in conclusion. A few well-designed studies have been done to look at the effects of indoor plants on occupants in terms of temperature comfort, perception of air quality, sick building syndrome, emotional state, and task performance. To fully understand the impact of indoor plants on interior settings and occupant well-being, more research is necessary and a direction for future research is established through this manuscript using advanced analytical tools.

Keywords: *Indoor plants, bibliometry, air quality, thermal comfort, aesthetics, lighting, noise, Sick Building Syndrome (SBS), emotional state, performance.*

1. Introduction

The indoor environment quality (IEQ) is an major concern for the scientific community because people spend over 80–90% of their life indoors [1]. Numerous factors contribute to shaping the indoor environment within a building, such as indoor air quality (IAQ), thermal comfort, lighting, noise levels, etc.

In pursuit of a sustainable way to enhance the quality of the interior environment, researchers opted for a variety of indoor plants. Their explorations primarily centred around extensive studies probing the phytoremediation (plants use clean up polluted air) effects of plants, specifically targeting the reduction of particulate matter (PM) levels [2–7] and total volatile organic compounds (TVOCs). Commencing with closed chamber experiments in controlled environments [8–14], these studies subsequently transitioned into real-world settings [15–18]. However, the initial findings regarding the efficacy of passive potted plants towards reducing both PM and VOCs were not promising [19,20]. Researchers inferred that achieving notable effects would necessitate a much larger quantity of plants within the indoor space.

To address this challenge of scale, researchers turned their attention to the concept of creating green walls [21]. This innovative approach presented the possibility of accommodating high number of plants that are an order of magnitude larger than what room floor can accommodate. Nevertheless, the implementation of green walls is notably more complicated than the straightforward placement of potted plants [22–24]. It involves a complex setup encompassing various elements such as regular monitoring, irrigation systems, structural support, and they often demand specialized knowledge or training. Moreover, researchers intended the integration of active airflow through these green walls to enhance their efficacy [25–27]. This necessitated the installation of fans alongside the green wall structure, further adding to the complexity of the setup and maintenance.

Lohr et al. [28] used hanging plants also and assessed productivity and stress level in presence and absence of plants and many later scholars have sought to understand their perceived benefits across various dimensions like indoor climate [29–34], sick building syndrome (SBS), emotional state [35–37], self-assessed performance [28,30,34,37,38], and overall space satisfaction. While reviewing the existing studies Bringslimark et al. [39] reported inconsistency in results in the aspects of benefits of indoor plants. Additionally, Han et al. [40] noted in their review that the most prominent effects of indoor plants on participants include heightened positive emotions and diminished negative feelings, with a subsequent reduction in physical discomfort. Further, work by Lee Bak Yeo [41] provide important insights regarding selection of indoor plant species keeping psychological and physiological benefits of plants.

The authors have not come across any recent review paper that has provided a comprehensive analysis of existing studies that proposed a holistic methodology for future researchers to adopt in order to achieve consistent and impartial outcomes. To address this research gap, we conducted a systematic review of available English articles focusing on the effects of indoor plants on occupants' comfort and psychological well-being. Standard bibliometric approaches are employed to comprehensively analyse high-quality journal papers that investigate the integration of indoor plants into indoor settings.

The objective of this review are to:

- Identify the key findings and trends in the literature related to the effects of indoor plants on indoor climate, occupant perceptions, and well-being.
- Critically evaluate the strengths and limitations of existing studies, addressing conflicting results and gaps in the current knowledge.

2. Methodology

To ensure a critical review of the existing literature, we employed a systematic approach to keyword selection. Our search strategy encompassed a range of terms related to occupant perception, indoor climate, and the influence of indoor plants. The keywords included: occupant perception, indoor climate, indoor air quality, thermal comfort, aesthetics, privacy, noise, Sick Building Syndrome (SBS), emotional state, and indoor plants. This broad selection is aimed at capturing a diverse area of the research landscape and facilitate an in-depth bibliometric analysis.

Based on these keywords we gathered a total 1467 articles from various database sources like Web of Science (WoS) and Scoups reported in the past four decades ranged from 1980 to 2023, after removing 315 duplicate articles. Using these collected articles, we generated the density keyword plot (Figure 1) using VOS viewer [42] served as a visual representation of the prevalence and interconnectedness of these keywords, providing insights into the landscape of existing literature.

Observations from the density plot highlighted the inclusion of studies related to phytoremediation, green walls, online surveys, photosynthesis, plant growth, biological control, medical research, bacteria, and also other topics beyond our intended scope. Recognizing the importance of refining our dataset for a more targeted review, we systematically excluded these undesirable papers from our analysis. This process ensured that the remaining articles aligned closely with the key theme of our investigation. Refer to figure 2 for a visual representation of the collecting and screening process.

The final selection include 20 articles, and was based on stringent inclusion criteria, including studies conducted with potted plants in laboratory or field settings, the presence of both control and treatment experiments, and a specific focus on indoor potted plants' effects on occupants' perceptions of their indoor environment and well-being. This selection criteria is aimed at ensuring the relevance, quality, and alignment of the chosen studies with our research objectives.

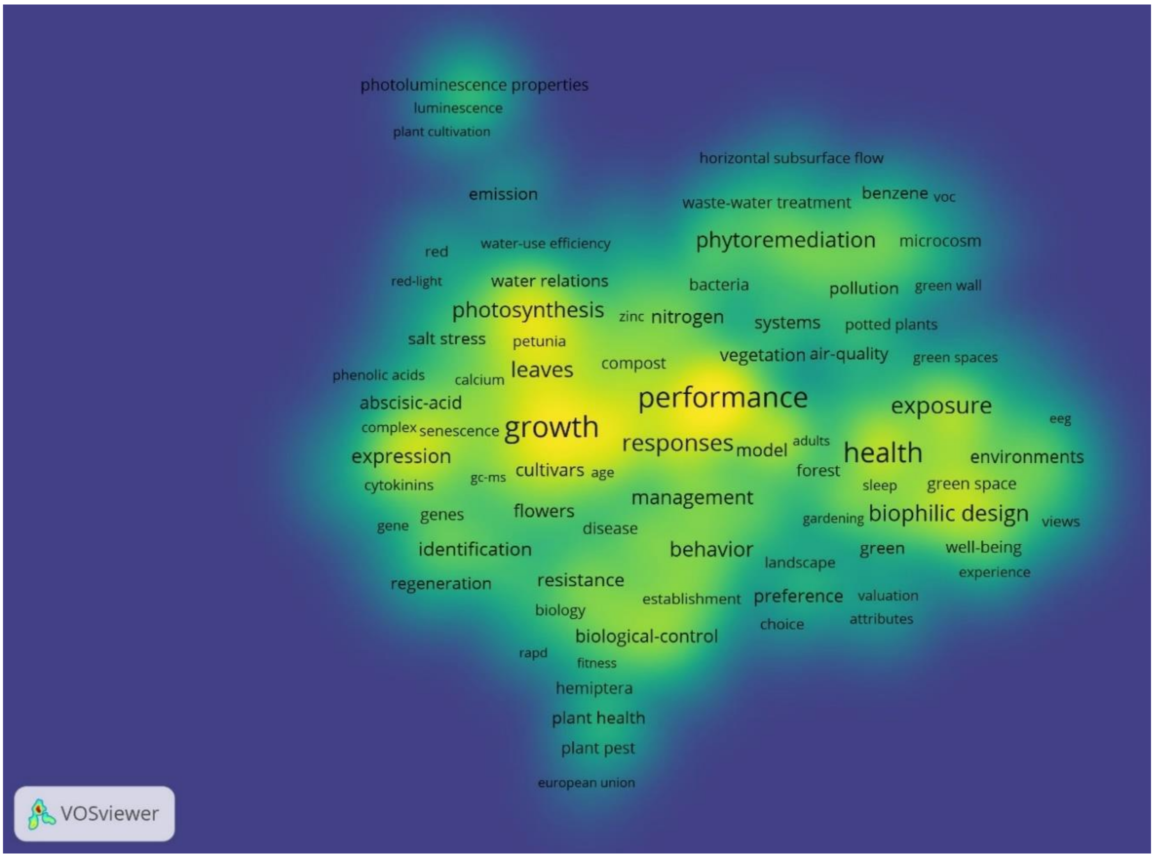

Fig. 1 The density map of frequently of appearance of keywords.

https://doi.org/10.36375/prepare_u.iiche.a417

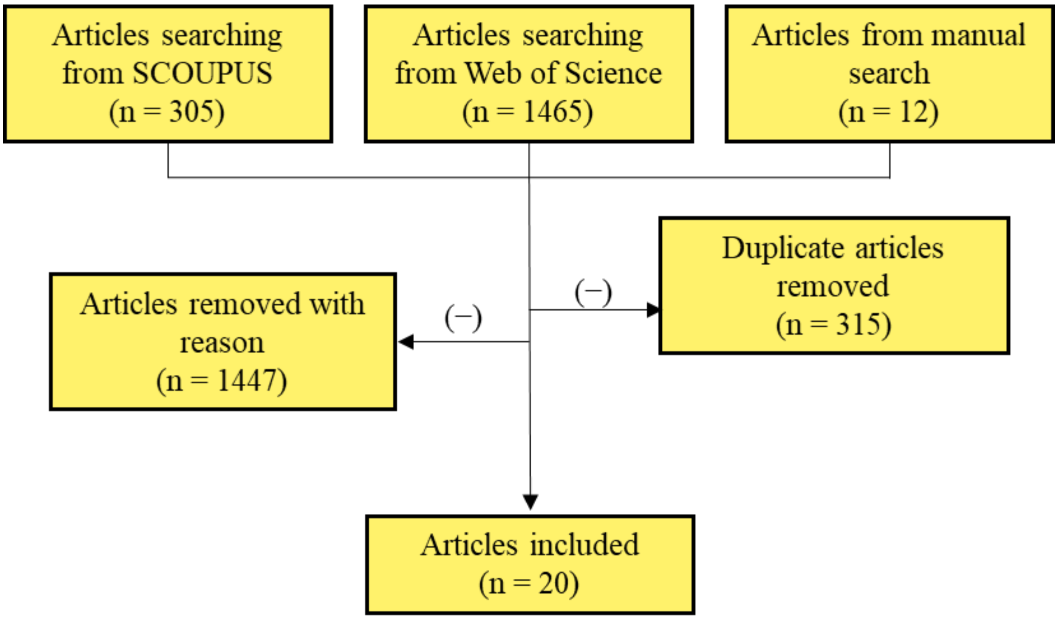

Fig. 2 Collecting and screening process of articles.

3. Results and discussions

3.1. Analysis of keyword frequencies in selected studies

The examination of keywords and their respective frequencies are extracted from the 20 shortlisted studies. This provided valuable insights on common themes and focus points in the field of indoor plants and their impact on the well-being of occupants. Figure 3 shows that "Indoor plants" [34,37,43–48] emerged as the most frequently mentioned keyword, highlighting a substantial focus on the general impact of indoor flora. Additionally, "People-plant interactions" [43,45] and "Human issues in horticulture" [28,43,45,49] surfaced as recurrent themes, indicating a considerable interest in understanding human experiences concerning indoor plants.

Keywords such as "Task performance," [31,44] "Productivity," [28,50] "Mood," [48,51] and "Mental fatigue" [45,48] underscored a notable interest in cognitive aspects, emotional states, and overall well-being influenced by indoor plants. Notably, "Educational building" [46,47] suggested specific research inquiries within educational settings, while "Indoor environment quality" [46,47] depicted an exploration of the overall indoor space quality. Furthermore, the frequencies of terms such as "Repeated measures" [46,52], and "Task reaction time" [34,43,46] pointed towards an experimental approach in assessing the impact of indoor plants on human performance.

These findings collectively highlight a multifaceted research landscape, indicating a substantial interest in understanding of the nuanced relationship between indoor plants, human experiences, and diverse environmental contexts. The prevalent keywords and their frequencies provide valuable insights into the key areas of focus within the literature, setting the stage for a comprehensive understanding of the impact of indoor plants on occupant well-being and indoor environment.

https://doi.org/10.36375/prepare_u.iiche.a417

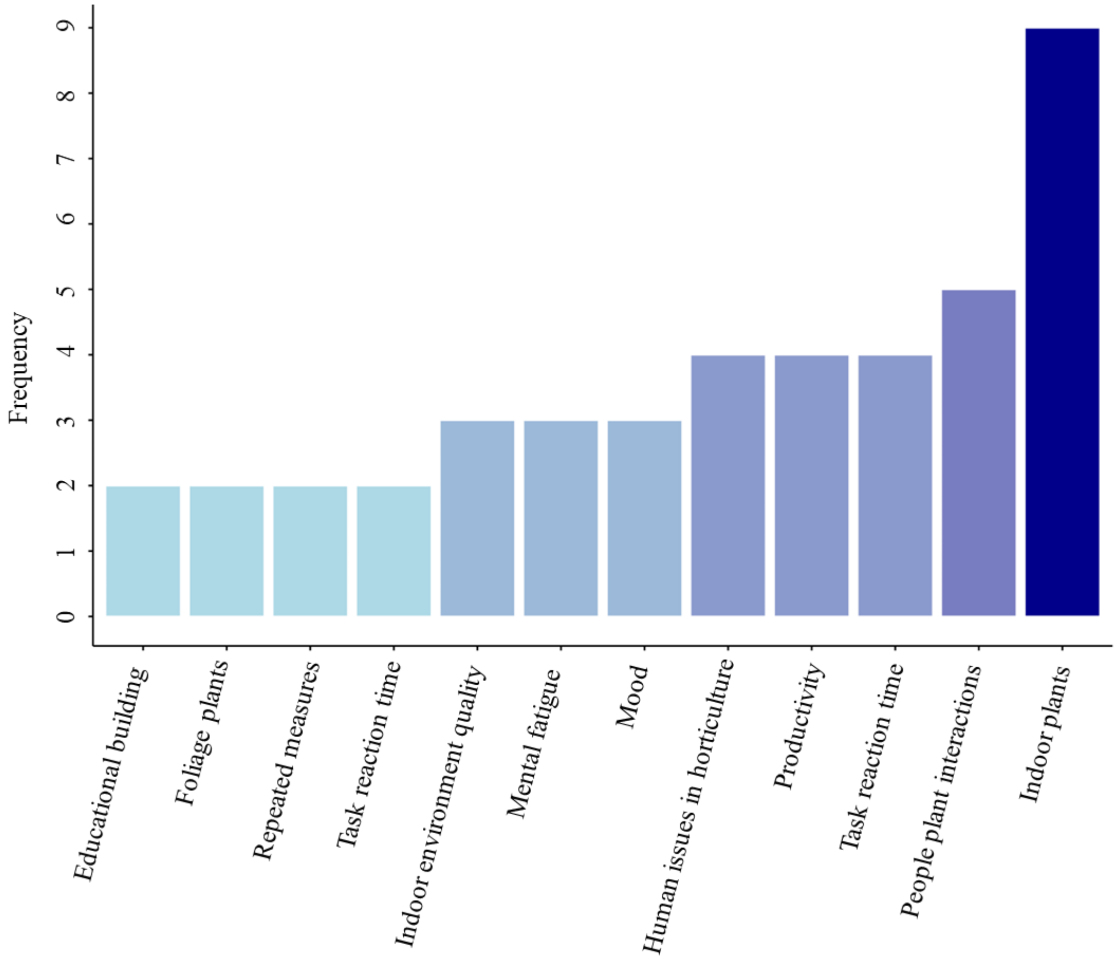

Fig. 3 Frequency of keywords used in twenty shortlisted studies.

3.2. Analysis of studies and citations

Figure 4 presents a compilation of studies on indoor plants and occupant well-being, along with their respective citation counts. The figure showcases a diverse range of studies spanning several decades, from as early as 1995 to recent publications in 2022. Each study is associated with a citation count, providing insights into its impact within the academic sphere. Upon analyzing figure 4, it becomes evident that some authors and studies consistently appear across multiple years. Works authored by S. Shibata et al. [44,48,53] span multiple years, so is by R.K. Raanaas'et al. [45,50] . The highest cited study includes by Larsen et al. [51] and M Niwuwenhuis [30] , and are influential within the dataset, in terems of their relevance relevance.

Recent studies, such as those by P. Archary et al. [34] , A. Thatcher et al. [54] , and S. Sugano et al. [55] , indicate ongoing research endeavors in the field. Additionally, the presence of multiple studies from the year 2021 underscores sustained interest and contributions during that period. The spred in publication years and citation counts among the compiled studies depicts an evolving landscape of research within the domain of indoor plants and occupant well-being. These findings highlight the diverse array of studies and their respective impacts, providing valuable insights into the historical evolution and contemporary relevance of research in this field.

In terms of Instutional affiliation of the prominent aiuthors, we find researchers from esteemed institution like Washington State University, Pullman; Toyohashi University of Technology, Japan; University of Malaya,

https://doi.org/10.36375/prepare_u.iiche.a417

Malaysia; Ajman University; University of the Witwatersrand, Johannesburg, South Africa; Bunkyo Women's University, Japan; Norwegian University of Life Sciences, Norway; Agricultural University of Norway; Delft University of Technology, The Netherlands; Waseda University, Japan; Vrije Universiteit Amsterdam, the Netherlands; Bunkyo Gakuin University, Japan; Kansas State University; Cardiff University; and the University of Michigan. All of these works enrich the ever-changing field of research in this area, adding some local preference and prominence.

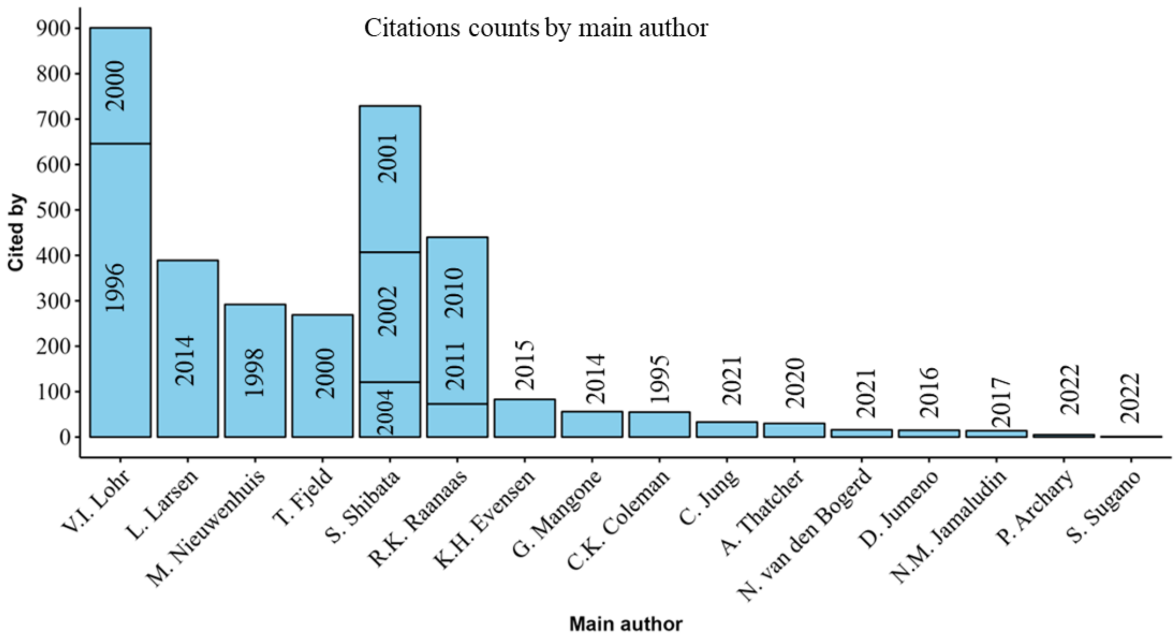

Fig. 4 Prominent authors and their citations

3.3. Geographic distribution of indoor plant studies

The analysis of indoor plant studies based on authors' and co-authors' countries reveals a diverse and global engagement in the research domain. A comprehensive examination of the dataset illustrates a broad geographic representation of studies on indoor plants and occupant well-being. Figure 5 indicate that studies originating from Japan, including works by D. Jumeno et al. [46] , S. Shibata et al. [53], stand out, indicating Japan's significant involvement and contributions to this field. Studies by authored T. Fjeld et al. [55], R.K. Raanaas et al. [45], and others, portray active participation in indoor plant research from Norway, often in collaboration with countries like Sweden and the USA. Concurrently, multiple studies from the USA, such as those by V.I. Lohr et al. [34], highlight the country's sustained engagement in this area of study. Moreover, contributions from regions like Malaysia, South Africa, United Arab Emirates, Netherlands, Canada, United Kingdom, and Indonesia reflect a global interest.

https://doi.org/10.36375/prepare_u.iiche.a417

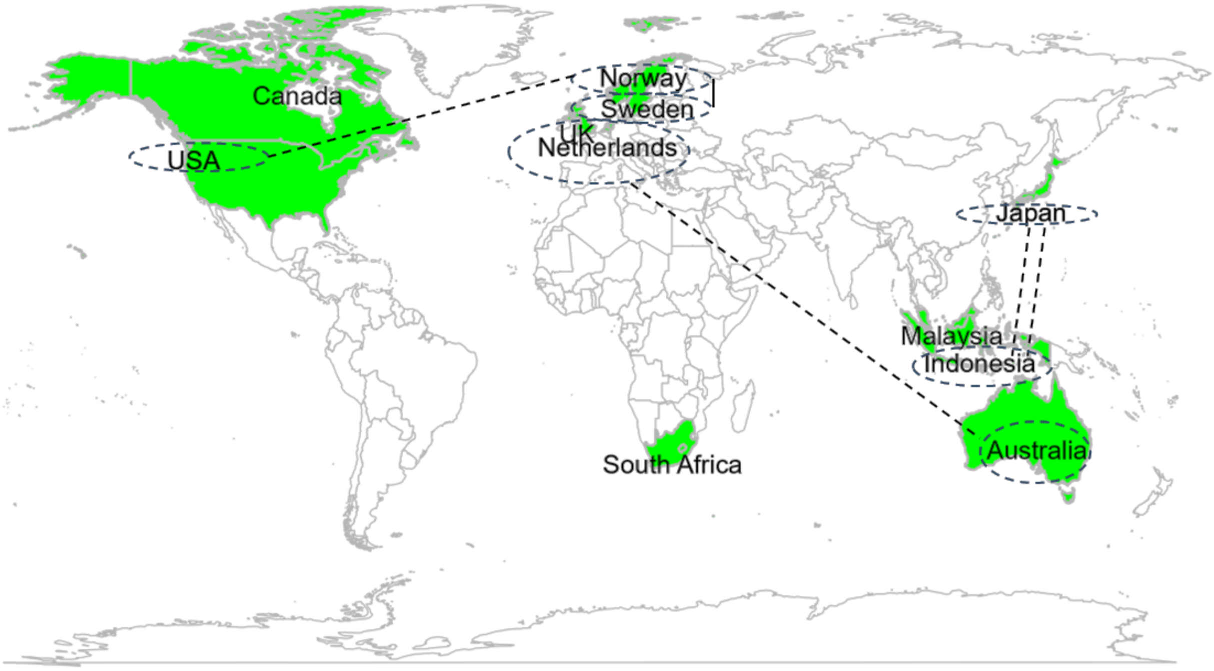

Fig. 5 Indoor plant studies by regions.

3.4. Diversity of plants used in indoor studies

Table 1 displays a diverse array of plants utilized in indoor studies related to occupant well-being. Certain plants have been commonly utilized in numerous investigations, however, there are others that are comparatively underrepresented in the dataset. Plants such as *Dracaena fragrans* (Janet Craig), *Epipremnum aureum* (Money plant), and *Schefflera arboricola* (Dwarf umbrella tree), emerge as the most frequently used species, each featured in six studies. Similarly, *Aglaonema* (Chinese Evergreen), and *Philodendron scandens* (Sweetheart Plant) have been employed in five studies, signifying their recurring presence in indoor plant-related research. Several other plant species, including *Spathiphyllum* (Lily), *Dracaena marginata* (Dragon tree), *Chamaedorea seifrizii* (Bamboo palm), among others, are featured in fewer studies, ranging from one to three instances, within the dataset. The dataset demonstrates a rich diversity of plant species utilized in indoor studies.

While certain plants like the Money plant and Dwarf umbrella tree are extensively explored, the inclusion of a variety of other plant species highlights the breadth of exploration in understanding the effects of diverse indoor plants on occupant well-being. The distribution of plant usage across studies emphasizes the importance of comprehensive assessments encompassing a wide range of plant species. The presence of several plant species offers researchers the chance to investigate a range of plant traits, taking into account elements such as visual appeal and the overall influence on indoor environmental quality and human well-being.

3.5. Investigated aspects in indoor plant studies

The analysis of various studies concerning effect of indoor plant reveals a multifaceted exploration across various domains. Trends of indoor plant studies in different directions can be seen in the table 2.

N.M. Jamaludin et al [34] reported a two-week long study with plants in a classroom's corners, in a non-controlled environment. The research, resembling a laboratory-style design, sampled classroom students and reported that learning was not significantly affected by the presence or absence of plants. The young age of the students was suggested as a reason, indicating their limited susceptibility to indoor environmental qualities and health symptoms. The study did not provide information on effect size or p-values. In year 1996, V.I. Lohr et al. [28] conducted a between-group study in a computer lab, keeping plants in the periphery. Participants reported higher productivity, less stress, and feeling more attentiveness in presence of plants. However, the study did not report the effect size, and a 10% alpha level was chosen for analysis. Similarly, C. Jung et al. [47] conducted a between-group study in two classrooms with plants, sampling classroom students. The study duration in the running classroom was not specified. Students perceived fresher IAQ, reported fewer complaints of SBS symptoms, and demonstrated increased focus on learning. However, the study did not report the effect size.

R.K. Raanaas et al. [50] in year 2019, assessed the impact of an indoor plant on patients of coronary and pulmonary desease. They reported improved subjective well-being and overall improvements in physical and mental health during the program, while the addition of plants did not further enhance these benefits. In a separate a between-group study in the year 2010 also conducted in an office setting by Raanaas et al. [50], examining the impact of indoor plants, they did not provide information about environmental control. Performance was assessed three times during a one-hour session both with and without plant conditions. Participants in the plant condition exhibited improved performance from the first to the second assessment. However, neither group showed improvement from the Isecond to the third assessment. Furthermore, Evensen et al. [56] examined the restorative effects of indoor plants on participants with and without window conditions. The study included three experiment conditions: live plants, inanimate objects, and a control, all with and without a window view. The presence of plants resulted in greater perceived fascination. However, they did not report any significant performance improvement.

S. Shibata et al. [44,48,53] reported a series of studies: In 2001, they reported that plants had no impact on self-reported fatigue [48]. However, plants showed a greater stress-reducing effect during breaks compared to task performance. In 2002, their findings revealed that one plant had a significant positive effect on the performance of a creative task but not on a concentration task. The positioning of the plant in front of the participant had a greater impact than when it was positioned at the side [53]. In 2004, they found that self-reported mood significantly improved in the presence of plants, positive effects were more observed in females [44]. However, they did not provide a thorough analysis of the indoor circumstances in their trial. Thatcher et al. [38] conducted three studies, first a laboratory study and the other two field studies conducted at a call center setup. Laboratory study showed positive outcomes, howecer, those findings could not be observed in the their field studies. The field studies used various proxy measures of performance and well-being, productivity, physical and psychological health, work engagement, job satisfaction, and work environment. Notably, they have not reported the effect size in their analysis. Additionally, Larsen et al. (1998) [51] explored the impact of plant density (number of plants) on productivity, attitudes, and perceptions. Participants reported improved mood, appreciation for office decoration, and increased comfort when plants were present. However, productivity was reported to be lowest with the highest plant density, while moderate plant density yielded the highest productivity scores.

https://doi.org/10.36375/prepare_u.iiche.a417

Table 1: Trends of plant species used in research

Plant species ↓ / Preferred by Author's →	V I lohr (1996)	D. Jumeno (2016)	N.M. Jamaludin (2017)	C. Jung (2021)	V I lohr (2000)	P Archary (2022)	S Shibata (2001)	R K Raanaas (2010)	S Shibata (2002)	T. Fjeld (1998)	G. Mangone (2014)	S Sugano (2022)	A. Thatcher (2011)	N. van den (2021)	S. Shibata (2004)	R K Raanaas (2011)	K.H. Evensen (2015)	C K Coleman (1995)
Dracaena fragrans (Janet Craig)	■		■					■		■	■			■	■			
Epipremnum aureum (Money plant)	■	■	■					■	■	■								
Aglaonema (Chinese Evergreen)	■				■			■			■					■	■	
Philodendron scandens (Sweetheart plant)	■				■		■			■						■	■	
Schefflera arboricola (Dwarf umbrella)		■						■						■		■	■	
Chamaedorea seifrizii (Bamboo palm)	■				■	■												
Dracaena marginata (dragon tree)	■										■		■					
Sansevieria (Snake plant)	■		■											■				
Spathiphyllum (Lily)		■	■															
Dracaena reflexa (Song of Jamaica)								■			■							
Dracaena surculosa (Spotted dracaena)								■			■							
Dypsis lutescens (Areca palm)				■														
Howea forsteriana (Paradise Palm)											■							
Livistona palm (Fountain Palm)														■				
Phycorapis Singaporensis (stick palm)							■											
Rhapis excelsa (lady palm)								■			■							
Ficus carica (Common fig)						■												
Aloevera (Burn plant)														■				
Anthurium (Flamingo flower)											■							
Asparagus (Satawar)											■							
Chlorophytum comosum (Spider)			■															
Dieffenbachia (dumb cane)														■				
Ficus elastica (Rubber fig)											■							
Ficus umbellata (Umbrella Tree Fig.)												■						
Liriope muscari (blue lily turf)								■										
Monstera (Swiss cheese plant)														■				
Polyscias fabian (Aralia Fabian)											■							
Strelitzia nicolai (wild banana)							■											
Tripogandra serrulata (Purple Scimitars)																		■
Zamioculcas (ZZ Plant)														■				
Syngonium podophyllum (Syngonium)	■																	
Scindapsus pictus (Argyraeus)	■																	
Hoya sp. (axplant)	■																	

C.K. Coleman, et al. [36] investigated influence of indoor plants on human stress in a classroom divided into three compartments to isolate treatments. Each compartment, having three participants, represented different conditions: one with a live foliage plant, another with a life-sized photo of the plant, and the third serving as a control with a metal stool. The experiment involved four stages, including the plant in front of the subject, a photo of the plant, the stool alone, and a baseline with neither plant nor stool. However, due to the small number of participants, no significant conclusions could be drawn. D. Jumeno et al. [46] explored the impact of the number and size of indoor plants on perceived air quality, mood, attention, and productivity. Experimentation was carried out with two variations on the number of plants and three variations on the plant size. Findings indicats that rooms with 3 small and medium-sized plants provided the highest mood, while rooms with 1 small plant, 3 medium-sized plants, and 3 large plants returned the smallest reaction time. The room with 1 small plant exhibited the highest productivity, and the room with 3 small plants recorded the highest perceived air quality. Overall, the study concluded that the number of plants had a positive impact on subjects' mood, with larger numbers correlating with better mood.

Table 2: Trends of indoor plant studies in different directions

Study	Indoor climate (air quality, thermal comfort)	Performance	Working environment (aesthetics, privacy, illumination, and noise)	Emotional state	SBS
V.I. Lohr, et al. (1996) [28]		■		■	
D. Jumeno, et al. (2016) [46]	■	■	■	■	
N.M. Jamaludin, et al. (2017) [34]	■	■			■
C. Jung, et al. (2021) [47]	■	■			■
V.I. Lohr, et al. (2000) [49]	■				
P. Archary, et al. (2022) [57]		■		■	
S. Shibata, et al. (2001) [48]		■	■	■	■
R.K. Raanaas, et al. (2010) [45]					■
S. Shibata, et al. (2002) [53]		■		■	
T. Fjeld, et al. (1998) [55]					■
G. Mangone, et al. (2014) [31]	■				
S. Sugano, et al. (2022) [58]		■			
A. Thatcher, et al. (2020) [54]			■		
N. van den, et al (2021) [37]	■	■	■	■	
S. Shibata, et al. (2004) [44]		■		■	
R.K. Raanaas, et al. (2011) [50]		■			
K.H. Evensen, et al. (2015) [59]		■			
C.K. Coleman, et al. (1995) [36]				■	
M. Nieuwenhuis, et al. (2014) [30]	■	■	■		
L. Larsen, et al. (1998) [51]	■	■	■	■	

N. van den Bogerd et al. [37] conducted a quasi-experimental study and assessed the impact of introducing potted plants in a university library on students' well-being and performance. Although students preferred the room with plants, improvements in mood and cognitive performance were not observed. While students found the room with plants more attractive and comfortable, they did not report effect on mood and cognitive performance. M. Nieuwenhuis, et al. [30] conducted three experiments in large commercial offices in to explore the impact of plants. All three experiments consistently reported positive impact on workers' well-being and productivity. G. Mangone, et al. (2014) [31] conducted a quasi-experiment to evaluate the impact of indoor plants on the thermal comfort of office workers in an office building. Thermal comfort improved by 1.79 to 1.95 times more when plants were present than they were not, findings suggest that incorporating a substantial quantity of plants in office buildings could contribute to reduced energy consumption that may be obtained by offsetting the air conditioning device.

T. Fjeld et al. [55] reported a study to investigate the impact of plants in office spaces on the health and discomfort symptoms of office workers. Participants responded a questionnaire covering neuropsychological, mucous membrane, and skin symptoms. In the with-plant condition, participants reported 23% lower score sum of symptoms, indicating a significant reduction in neuropsychological and mucous membrane symptoms. In addition, conditions related to cough, fatigue, and dry/hoarse throat were reduced by 37%, 30%, and 23% respectively. S. Sugano et al. [58] explored a mechanisms by which indoor plants improve human cognitive function. Thirty students participated in cognitive tasks across four desktop conditions: no objects, real plants, artificial plants, and books. Results revealed that viewing real plants led to lower cognitive effort and better restoration of attention capacity. Female participants, in particular, exhibited higher scores under the real plant condition compared to the no-object condition, indicating potential gender differences in the cognitive benefits of plants.

3.6. Limitations and future research

As recommendations for future research, it is crucial to develop standardized protocols considering some factors like: 1) Intention-to-treat analysis, 2) ensure demographic parity, 3) conduct a priori and post-hoc power calculation, 4) participant blinding to intervention, and 5) maintaining indoor conditions. Considering these limitations are crucial for conducting more unbiased researc

4. Conclusion

The scarcity of well-designed research articles in prominent databases, and concentration studies in a limited number of countries and a complete absence of standard publications from India, emphasizes the need for a more diverse and comprehensive global research effort. Additionally, non-inclusion of various social demographics among study groups creates challenges in achieving a complete understanding of the impacts of indoor potted plants on human occipants.

Furthermore, the absence of a study planned with a priori estimate of statistical power undermines the study's validity and dependability. The lack of participant blinding to interventions (indoor plant) introduces the potential for bias, and oversight in reporting specific indoor conditions further complicates nuanced interpretations of effects. The limited availability of studies, particularly in exploring multiple dimensions with holistic approach such as emotions, cognition, thermal comfort, and overall satisfaction with space influenced by indoor plants, highlights a gap in the current research landscape.

Acknowledgment

Authors thankful to Birla Institute of Technology and Science Pilani (Pilani Campus) for providing the sophisticated analytical instrumental facilities.

References

[1] N.E. Klepeis, W.C. Nelson, W.R. Ott, J.P. Robinson, A.M. Tsang, P. Switzer, J. V Behar, S.C. Hern, W.H. Engelmann, The national human activity pattern survey (NHAPS): a resource for assessing exposure to environmental pollutants, J. Expo. Sci. Environ. Epidemiol. 11 (2001) 231–252. https://doi.org/10.1038/sj.jea.7500165.

[2] T. Pettit, P.J. Irga, F.R. Torpy, Towards practical indoor air phytoremediation: a review, Chemosphere. 208 (2018) 960–974. https://doi.org/10.1016/j.chemosphere.2018.06.048.

[3] A. Aydogan, R. Cerone, Review of the effects of plants on indoor environments, Indoor Built Environ. 30 (2021) 442–460. https://doi.org/10.1177/1420326X19900213.

[4] A. Prigioniero, D. Zuzolo, Ü. Niinemets, C. Guarino, Nature-based solutions as tools for air phytoremediation: a review of the current knowledge and gaps, Environ. Pollut. 277 (2021) 116817. https://doi.org/10.1016/j.envpol.2021.116817.

[5] R.J. Leonard, C. McArthur, D.F. Hochuli, Particulate matter deposition on roadside plants and the importance of leaf trait combinations, Urban For. Urban Green. 20 (2016) 249–253. https://doi.org/10.1016/j.ufug.2016.09.008.

[6] S. Janhäll, Review on urban vegetation and particle air pollution - deposition and dispersion, Atmos. Environ. 105 (2015) 130–137. https://doi.org/10.1016/j.atmosenv.2015.01.052.

[7] V.I. Lohr, C.H. Pearson-Mims, Particulate matter accumulation on horizontal surfaces in interiors: Influence of foliage plants, Atmos. Environ. 30 (1996) 2565–2568. https://doi.org/10.1016/1352-2310(95)00465-3.

[8] N.R. Jeong, K.J. Kim, J.H. Yoon, S.W. Han, S. You, Evaluation on the potential of 18 species of indoor plants to reduce particulate matter, J. People, Plants, Environ. 23 (2020) 637–646. https://doi.org/10.11628/ksppe.2020.23.6.637.

[9] Y. Cao, F. Li, Y. Wang, Y. Yu, Z. Wang, X. Liu, K. Ding, Assisted deposition of PM2.5 from indoor air by ornamental potted plants, Sustain. 11 (2019) 1–10. https://doi.org/10.3390/su11092546.

[10] J. Ryu, J.J. Kim, H. Byeon, T. Go, S.J. Lee, Removal of fine particulate matter (PM2.5) via atmospheric humidity caused by evapotranspiration, Environ. Pollut. 245 (2019) 253–259. https://doi.org/10.1016/j.envpol.2018.11.004.

[11] J.-S.C. Bo-Kook Jang, Kyungtae Park, Sang Yeob Lee, Hamin Lee, Soo Ho Yeon, Boran Ji, Cheol Hee Lee, Screening of particulate matter reduction ability of 21 Indigenous Korean evergreen species for indoor use, Int. J. Environ. Res. Public Health. 18 (2021) 1–10. https://doi.org/10.3390/ijerph18189803.

[12] J.-W. Yoon, K.-C. Son, D.S. Yang, S.J. Kays, Removal of indoor tobacco smoke under light and dark conditions as affected by foliage plants, Korean J. Hortic. Sci. Technol. 27 (2009) 312–318.

[13] G.Y. Gong, J.S. Kang, K.J. Jeong, J.H. Jeong, J.G. Yun, Effect of several native moss plants on particulate matter, volatile organic compounds and air composition, J. People, Plants, Environ. 22 (2019) 31–38. https://doi.org/10.11628/ksppe.2019.22.1.031.

[14] S. Panyametheekul, T. Rattanapun, M. Ongwandee, Ability of artificial and live houseplants to capture indoor particulate matter, Indoor Built Environ. 27 (2018) 121–128. https://doi.org/10.1177/1420326X16671016.

[15] P.N. Pegas, C.A. Alves, T. Nunes, E.F. Bate-Epey, M. Evtyugina, C.A. Pio, Could houseplants improve indoor air quality in schools?, J. Toxicol. Environ. Heal. - Part A Curr. Issues. 75 (2012) 1371–1380. https://doi.org/10.1080/15287394.2012.721169.

[16] A.J. Ghazalli, C. Brack, X. Bai, I. Said, Alterations in use of space, air quality, temperature and humidity by the presence of vertical greenery system in a building corridor, Urban For. Urban Green. 32 (2018) 177–184. https://doi.org/10.1016/j.ufug.2018.04.015.

[17] T. Pettit, P.J. Irga, F.R. Torpy, The in situ pilot-scale phytoremediation of airborne VOCs and particulate matter with an active green wall, Air Qual. Atmos. Heal. 12 (2019) 33–44. https://doi.org/10.1007/s11869-018-0628-7.

[18] S.-H. Hong, J. Hong, J. Yu, Y. Lim, Study of the removal difference in indoor particulate matter and volatile organic compounds through the application of plants, Environ. Health Toxicol. 32 (2017) e2017006. https://doi.org/10.5620/eht.e2017006.

[19] M. Budaniya, A.C. Rai, Effectiveness of plants for passive removal of particulate matter is low in the indoor environment, Build. Environ. 222 (2022) 109384. https://doi.org/10.1016/j.buildenv.2022.109384.
[20] B.E. Cummings, M.S. Waring, Potted plants do not improve indoor air quality: a review and analysis of reported VOC removal efficiencies, J. Expo. Sci. Environ. Epidemiol. 30 (2020) 253–261. https://doi.org/10.1038/s41370-019-0175-9.
[21] X. Meng, L. Yan, F. Liu, A new method to improve indoor environment: combining the living wall with air-conditioning, Build. Environ. 216 (2022) 108981. https://doi.org/10.1016/j.buildenv.2022.108981.
[22] T. Pettit, P.J. Irga, P. Abdo, F.R. Torpy, Do the plants in functional green walls contribute to their ability to filter particulate matter?, Build. Environ. 125 (2017) 299–307. https://doi.org/10.1016/j.buildenv.2017.09.004.
[23] P.J. Irga, N.J. Paull, P. Abdo, F.R. Torpy, An assessment of the atmospheric particle removal efficiency of an in-room botanical biofilter system, Build. Environ. 115 (2017) 281–290. https://doi.org/10.1016/j.buildenv.2017.01.035.
[24] A.L. Morgan, F.R. Torpy, P.J. Irga, R. Fleck, R.L. Gill, T. Pettit, The botanical biofiltration of volatile organic compounds and particulate matter derived from cigarette smoke, Chemosphere. 295 (2022) 133942. https://doi.org/10.1016/j.chemosphere.2022.133942.
[25] M. Mannan, S.G. Al-Ghamdi, Active botanical biofiltration in built environment to maintain indoor air quality, Front. Built Environ. 7 (2021) 1–8. https://doi.org/10.3389/fbuil.2021.672102.
[26] F. Torpy, M. Zavattaro, Bench-study of green-wall plants for indoor air pollution reduction, J. Living Archit. 5 (2018) 1–15. https://doi.org/10.46534/jliv.2018.05.01.001.
[27] J. Sowa, J. Hendiger, M. Maziejuk, T. Sikora, L. Osuchowski, H. Kamińska, Potted plants as active and passive biofilters improving indoor air quality, IOP Conf. Ser. Earth Environ. Sci. 290 (2019). https://doi.org/10.1088/1755-1315/290/1/012150.
[28] V.I. Lohr, C.H. Pearson-Mims, G.K. Goodwin, Interior plants may improve worker productivity and reduce stress in a windowless environment, J. Environ. Hortic. 14 (1996) 97–100. https://doi.org/10.24266/0738-2898-14.2.97.
[29] D. Jumeno, H. Matsumoto, The effects of indoor foliage plants on perceived air quality, mood, attention, and productivity, J. Civ. Eng. Archit. Res. 3 (2016) 1359–1370.
[30] M. Nieuwenhuis, C. Knight, T. Postmes, S.A. Haslam, The relative benefits of green versus lean office space: three field experiments, J. Exp. Psychol. Appl. 20 (2014) 199–214. https://doi.org/10.1037/xap0000024.
[31] G. Mangone, S.R. Kurvers, P.G. Luscuere, Constructing thermal comfort: investigating the effect of vegetation on indoor thermal comfort through a four season thermal comfort quasi-experiment, Build. Environ. 81 (2014) 410–426. https://doi.org/10.1016/j.buildenv.2014.07.019.
[32] R. Elnaklah, I. Walker, S. Natarajan, Moving to a green building: indoor environment quality, thermal comfort and health, Build. Environ. 191 (2021) 107592. https://doi.org/10.1016/j.buildenv.2021.107592.
[33] J. Qin, C. Sun, X. Zhou, H. Leng, Z. Lian, The effect of indoor plants on human comfort, Indoor Built Environ. 23 (2014) 709–723. https://doi.org/10.1177/1420326X13481372.
[34] N.M. Jamaludin, N. Mahyuddin, F.W. Akashah, Assessment on indoor environmental quality (IEQ) with the application of potted plants in the classroom: case of university Malaya, J. Des. Built Environ. 17 (2017) 1–15. https://doi.org/10.22452/jdbe.vol17no2.1.
[35] D.L. Rich, Effects of exposure to nature and plants on cognition and mood: a cognitive psychology perspective, Cornell University, New York, 2007.
[36] C.K. Coleman, R.K. Mattson, Influences of foliage plants on human stress during thermal biofeedback training, Horttechnology. 5 (1995) 137–140. https://doi.org/10.21273/horttech.5.2.137.
[37] N. van den Bogerd, S.C. Dijkstra, S.L. Koole, J.C. Seidell, J. Maas, Greening the room: a quasi-experimental study on the presence of potted plants in study rooms on mood, cognitive performance, and perceived environmental quality among university students, J. Environ. Psychol. 73 (2021) 101557. https://doi.org/10.1016/j.jenvp.2021.10155

7.
[38] A. Thatcher, K. Adamson, L. Bloch, A. Kalantzis, Do indoor plants improve performance and well-being in offices? Divergent results from laboratory and field studies, J. Environ. Psychol. 71 (2020) 101487. https://doi.org/10.1016/j.jenvp.2020.101487.
[39] T. Bringslimark, T. Hartig, G.G. Patil, The psychological benefits of indoor plants: a critical review of the experimental literature, J. Environ. Psychol. 29 (2009) 422–433. https://doi.org/10.1016/j.jenvp.2009.05.001.
[40] K. Han, Effects of indoor plants on self-reported perceptions: a systemic review, Sustainability. 11 (2019) 4506. https://doi.org/https://doi.org/10.3390/su11164506.
[41] L.B. Yeo, Psychological And Physiological Benefits Of Plants In The Indoor Environment: A Mini And In-Depth Review, Int. J. Built Environ. Sustain. 8 (2020) 57–67. https://doi.org/10.11113/ijbes.v8.n1.597.
[42] N.J. Van Eck, L. Waltman, Manual VOSviewer, Univeristeit Leiden. (2021) 54.
[43] S. Sugano, M. Tazaki, H. Arai, K. Matsuo, S.I. Tanabe, Effects of indoor plants on occupants' cognitive functions: a systematic review, 17th Int. Conf. Indoor Air Qual. Clim. INDOOR AIR 2022. (2022).
[44] S. Shibata, N. Suzuki, Effects of an indoor plant on creative task performance and mood, Scand. J. Psychol. 45 (2004) 373–381. https://doi.org/10.1111/j.1467-9450.2004.00419.x.
[45] R.K. Raanaas, G.G. Patil, T. Hartig, Effects of an indoor foliage plant intervention on patient well-being during a residential rehabilitation program, HortScience. 45 (2010) 387–392. https://doi.org/10.21273/hortsci.45.3.387.
[46] D. Jumeno, H. Matsumoto, The effects of indoor foliage plants on perceived air quality, mood, attention, and productivity, J. Civ. Eng. Archit. Res. 3 (2016) 1359–1370.
[47] C. Jung, J. Awad, Improving the IAQ for Learning Efficiency with Indoor Plants in University Classrooms in Ajman, United Arab Emirates, (2021).
[48] S. Shibata, N. Suzuki, Effects of Indoor Foliage Plants on Subjects' Recovery from Mental Fatigue, N. Am. J. Psychol. 3 (2001) 385–396.
[49] V.I. Lohr, C.H. Pearson-Mims, Physical discomfort may be reduced in the presence of interior plants, Horttechnology. 10 (2000) 53–58. https://doi.org/10.21273/horttech.10.1.53.
[50] R.K. Raanaas, K.H. Evensen, D. Rich, G. Sjøstrøm, G. Patil, Benefits of indoor plants on attention capacity in an office setting, J. Environ. Psychol. 31 (2011) 99–105. https://doi.org/10.1016/j.jenvp.2010.11.005.
[51] L. Larsen, J. Adams, B. Deal, B.S. Kweon, E. Tyler, Plants in the workplace the effects of plant density on productivity, attitudes, and perceptions, Environ. Behav. 30 (1998) 261–281. https://doi.org/10.1177/001391659803000301.
[52] S.H. Park, R.H. Mattson, Effects of flowering and foliage plants in hospital rooms on patients recovering from abdominal surgery, Horttechnology. 18 (2008) 563–568. https://doi.org/10.21273/horttech.18.4.563.
[53] S. Shibata, N. Suzuki, Effects of the foliage plant on task performance and mood, J. Environ. Psychol. 22 (2002) 265–272. https://doi.org/10.1006/jevp.2002.0232.
[54] A. Thatcher, K. Adamson, L. Bloch, A. Kalantzis, Do indoor plants improve performance and well-being in offices? Divergent results from laboratory and field studies, J. Environ. Psychol. 71 (2020). https://doi.org/10.1016/j.jenvp.2020.101487.
[55] T. Fjeld, B. Veiersted, L. Sandvik, G. Riise, F. Levy, The effect of indoor foliage plants on health and discomfort symptoms among office workers, Indoor Built Environ. 7 (1998) 204–209. https://doi.org/10.1177/1420326X9800700404.
[56] K.H. Evensen, R.K. Raanaas, C.M. Hagerhall, M. Johansson, G.G. Patil, Restorative Elements at the Computer Workstation: A Comparison of Live Plants and Inanimate Objects With and Without Window View, Environ. Behav. 47 (2015) 288–303. https://doi.org/10.1177/0013916513499584.
[57] P. Archary, A. Thatcher, Affective and cognitive restoration: comparing the restorative role of indoor plants and guided meditation, Ergonomics. 65 (2022) 933–942. https://doi.org/10.1080/00140139.2021.2003873.
[58] S. Sugano, M. Tazaki, H. Arai, K. Matsuo, S. ichi Tanabe, Characteristics of eye movements while viewing indoor plants

and improvements in occupants' cognitive functions, Japan Archit. Rev. 5 (2022) 621–632. https://doi.org/10.1002/2475-8876.12284.

[59] K.H. Evensen, R.K. Raanaas, C.M. Hagerhall, M. Johansson, G.G. Patil, Restorative Elements at the Computer Workstation: A Comparison of Live Plants and Inanimate Objects With and Without Window View, Environ. Behav. 47 (2015) 288–303. https://doi.org/10.1177/0013916513499584.