Final Report

Part 1 of Healthy Homes Index project

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Project Number: NY16008

NY16008

This project has been funded by Hort Innovation using the research and development Nursery levy and funds from the Australian Government.

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ISBN 978 0 7341 4342 6

Published and distributed by:
Hort Innovation
Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

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Content

Summary

For over 50 years research has demonstrated that plants deliver benefits for urban citizens by reducing air pollution and supporting well-being. As cities in Australia increase their density it is important to understand how plants can benefit people in denser spaces, such as apartments. A range of research shows the benefits of plants in indoor and outdoor settings for remediating air pollution, improving mental health and concentration. In this project, our aim was to draw on this literature and systematically review and synthesise this knowledge to derive a scale of plant benefits. The intention is a scale optimised for easy integration into a smart device application (app) that interactively asks users to rate and improve their spaces using plants and by doing so encourages them to understand the benefits that plants bring.

To increase the reliability of the outcome the project applied a limited Delphi expert panel focus group process. The expert group met and iteratively contributed to the rating. The outputs of the research include a literature review with a summary document, recordings of the discussions amongst the expert panel, and scales of plant benefits that can be integrated into the app. During the process, to gain consensus among the expert panel members we have subscribed to the Best Available Scientific Evidence (BASEline) approach. As much as possible we used high quality science to determine the relevant relationships but, where information was not adequate to contribute to the index, the research team estimated the most likely relationships. In the spirit of the Delphi method, which was developed to provide answers in the face of inadequate information or time, we have aimed to provide best available input into the app while acknowledging the gaps in the research. We anticipate that the identification of these gaps will guide future research that will contribute to the broader understandings initiated in this project.

Keywords

Indoor plants; indoor air quality; well being; Delphi methods

Introduction

Our society has an innate emotional affiliation to other living organisms in nature (Edward O. Wilson). However, human beings are spending less and less time in nature. Current estimates indicate that urban dwellers spend 90% of their time in indoor environments (USEPA 2007). In addition to being disconnected from nature we are exposed to indoor contaminant compounds. Both conditions are detrimental to our psychological and physiological health. For instance, Kaplan's (1995) attention restoration theory explains that nature's complexity can naturally avert the fatigue resulting from the prolonged mental effort; in an indoor environment this could be explained by a both our instinctive inclination to nature (biophilia) or by the plants' ability to remove the contaminants from the air.

Over the past 50 years, research has explored the potential role of nature to improve our mental and physical well-being by incorporating the experience of nature within the built environment and its role in improving indoor air quality. In particular, immersive active experiences in nature (i.e. running, vacationing) are regarded as highly restorative (Bratman et al. 2015; Korpela et al. 2017); however, there is also evidence that passive experience of nature (i.e. indoor plants, views out windows, etc.) can have a strong positive impact (Bringslimark et al. 2009). The benefit depends on the individual preferences of the person experiencing nature (Hartig et al. 2003; Morton et al. 2017).

The exposure to indoor pollutants can lead to adverse health outcomes such as pulmonary diseases and Sick Building Syndrome (SBS), these result from exposure to Particulate Matter (PM) and Volatile Organic Compounds (VOC) respectively. Common symptoms include tiredness and drowsiness without an apparent reason, difficulty breathing, restlessness, inability to concentrate or focus, irritation of the eyes, throat, and nose. Furthermore, the effects disappear when leaving the room. The likelihood that an individual will be affected by the presence of a contaminant depends upon: the contaminant concentrations and the individual's sensitivity to that contaminant; the current state of their psychological and physical health; and, the duration and frequency of exposure. In severe cases, high levels of contaminants can lead to disability, disease, and death.

The relationship between indoor plants and their benefits is difficult to quantify as it is a complex process mediated by the interaction of a wide range of variables. Research studies generally focus on single elements to explore the direct correlation between the analysed variable and the observed effect. While this is the key to rigorous research, it also leads to partial understandings of the system. The aim of the literature review within this project was to gain an holistic understanding of the physiological and psychological benefits of plants through a systematic approach.

Table 1: Example of VOC found indoors, their average levels and their detrimental health effects. This table was extracted from Guieysse et al. 2008

Compound	CAS[a]	Priority list			Indoor concentration ($\mu g\ m^{-3}$)			Recommended values ($\mu g\ m^{-3}$)	IARC[c]	Health effects	References
		EPA	OQAP[b]	WHO	Min	Max	Average				
Acetaldehyde	75-07-0	×	HP		3.24	119 78.0	18.9 12.0	LFC[d]	2B	Respiratory disorders, irritation of the eyes	Weisel et al. (2005) Mosqueron and Nedellec (2002)
Benzene	71-43-2	×	HP	×	0.48	364 141	2.90 1.57	0.17 LFC[d]	1	Immunological disorders, leukemia, neurological effect	Weisel et al. (2005) Edwards et al. (2001)
Dieldrin	60-57-1	×	P			6.00×10^{-4}	7.00×10^{-5}	–	3	Neurological effect, cancer of the liver	Mosqueron and Nedellec (2002)
Dichlorvos	62-73-7	×	HP			2.24	0.455	–	2B	Neurological effect, cancer of the liver	Mosqueron and Nedellec (2002)
Formaldehyde	50-00-0	×	HP	×	11.2	53.8 62.3	20.1 33.0	1000 (1 h) 60[e]	2A	Respiratory disorders, irritation of the eyes	Weisel et al. (2005) Edwards et al. (2001)
Naphthalene	91-20-3	×		×	2.20	90.1		–	2B		Mosqueron and Nedellec (2004)
Tetrachlorethylene	127-18-4	×	P	×	0.10	20.9 73.6	0.56 1.38	250 LFC[d]	2A	Neurological effect, renal disorder	Weisel et al. (2005) Mosqueron and Nedellec (2002)
Toluene	108-88-33	×	P	×	2.83	122 247	10.1 14.6	260	3	Neurological effect	Weisel et al. (2005) Edwards et al. (2001)
Trichlorethylene	79-01-6	×	P	×	0.04	7.84 41.8	0.12 0.86	2.3 LFC[d]	2A	Neurological effect, cancer of the testicles	Weisel et al. (2005) Mosqueron and Nedellec (2002)

[a] Chemical Abstract Service.
[b] HP: High Priority, P: Priority.
[c] International Agency for Research on Cancer (IARC) classification: Group 1: agent carcinogenic to humans, group 2A: agent probably carcinogenic to humans, group 2B: agent possibly carcinogenic to humans, Group 3: agent not classifiable as to humans, group 4: agent not carcinogenic to humans, ns: non-study.
[d] NIOSH recommended for the carcinogenic Lowest Feasible Concentration.
[e] Canada (1987).

Methodology

Literature Review

For the analysis of the relevant literature, we adopted the methodology of Bringslimark et al. (2009) comparing papers based on the following characteristics: study subjects, methodology, exposure to stimuli, outcome measure, and findings. The approach was widened by including the project's scope (indoor, outdoor), the scale (small, medium, large) and the description of the plants in terms of species, age and soil characteristics as reported by the authors.

Delimiting relevant literature for academic rigour

We located the material for review through standard methods including electronic databases and snowballing (e.g. one paper referring to another). To enhance the reliability of the data, we focused on research papers, conference proceedings and official reports with a clear experimental or a quasi-experimental methodology. Furthermore, we assessed the methodology to ensure studies established a baseline level by the inclusion of a no-plant control or a repeated measures approach (before vs. after plant treatment). Informal publications such as science communication magazines, papers and blogs were excluded from the study.

Literature analysis

After an initial categorisation according to a range of benefits, the papers were classified according to two broad benefits: air quality and well-being. In particular, air quality was defined as studies assessing a plant's ability to affect the concentration of airborne compounds (inorganic and organic compounds) and/or particulate matters (PM). Meanwhile, well-being was defined as any direct (i.e. improved mood, concentration) or indirect benefit (i.e. productivity, prosocial behaviour) that could be attributed to the presence of plants. Based on the details above, a total of 101 articles were included (43 for air quality, 57 for well-being and 1 for both). Of these, the data of 76 articles were read from the original source while the remaining articles (25) were included from a secondary source. In the latter cases, the original source could not be found within the project's timeframe and the secondary source was detailed enough to meet the information criteria as described above. These studies were summarised and included from reviews.

Transforming the literature into a Plant-life balance index

Air Quality Removal Rate Meta-analysis

To enhance the understanding of the literature, we took data from relevant research papers for further analysis, we specifically performed an air quality meta-analysis. This analysis compiled all reported plant species, contaminant removal rates, and air volume for studies that utilised a sealed air chamber; when available, we also compiled plant's leaf area, aesthetic category (i.e. foliage, fern, woody), and authors' categorization of the plant as a high, medium, or low contaminant removalist. Studies that did not provide enough information were eliminated from the aggregation. this includes experiments conducted outside of sealed chambers, compounds with insufficient data for analysis (i.e. NOx, aldehyde, ozone), articles reporting aeromycota and PM.

The removal rates reported on the selected 15 studies were compiled and re-analysed. These studies specifically reported removal rates for CO_2, formaldehyde and VOC. More specifically, VOC studied and included in the meta-analysis are benzene, toluene, octane, TCE and xylene. To ensure that the studies were comparable to each other, we converted the units to **μg/hour/m^3 of air/m^2 of leaf area**. To convert the study units, we ran the database in R Version 3.4.1. This information was used to explore the relationship between removal rates of different contaminants and the relationship between plant size and removal rate. For the meta-analysis, we developed a python program in Jupiter

Notebook.

Categorising plants based on the efficiendy of removal

There are three key studies to determine removal efficiency category. Yang et al. (2009) who measured the removal rate of 28 different species for five different VOC; Liu et al. (2007) who measured benzene removal rates of 73 species, and Kim et al. (2008) who measured the effectivity of formaldehyde removal of 86 different indoor plant species.These studies were used to establish the range of values that determine the efficiency category. In particular, the first study provided a categorization of the plants based on their efficiency to remove total VOC. These values were validated with the second study. The removal efficiency category for formaldehyde was established by the reviewers (Marco Amati, Dominique Hes and Cris Hernandez) utilising the third study as an example. Unfortunatley, to the best of our knowledge, no study has determined said parameters.

Deliberation through a Delphi Methodology

The Delphi method assumes that expert group judgments are more valid than individual judgments. The Delphi method was developed at the beginning of the Cold War to forecast the impact of technology on warfare (Custer et al. 1999). Since then the methodology has been used when there is need to provide direction and synthesis of existing research without the time or resources to do primary research. In this project, the research on the benefits of plants was summarized, presented, and discussed with the aim to provide a way to be able to simplify the benefits of plants. This project adopted a modified Delphi methodology appointing an expert panel to aid in the literature review and the valuation method of the index. The core team, comprised by Marco Amati, Dominique Hes and Cristina Hernandez conducted the literature review, created an initial benefit table based on the findings and gained ethics approval from RMIT University's Human Research Ethics Committee (DSC CHEAN A 20793-04/17). We had a total of three different meetings for planning, review, and deliberation. The expert panel also reviewed the present report to ensure it was representative of the topics discussed.

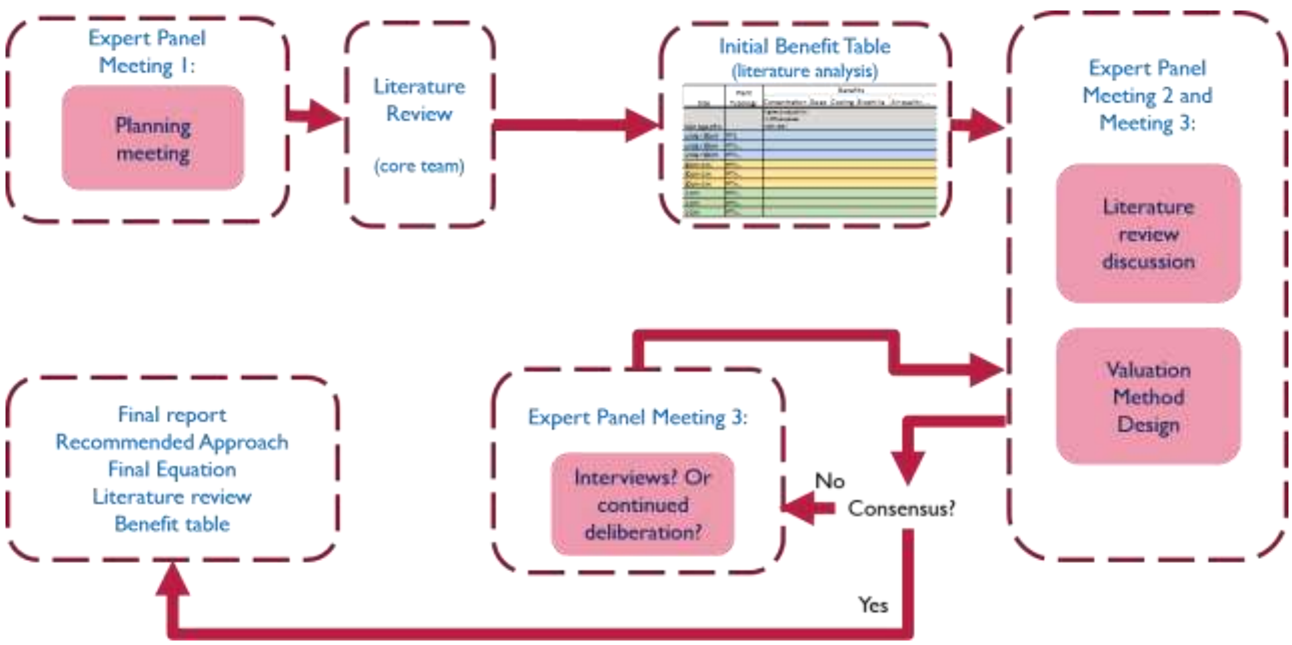


Figure 1: Methodology as applied by this project

Expert Panel

A key part of the project was to appoint a panel with the necessary expertise and networks to conduct the Delphi study. At all stages of the panel discussion and throughout the development of the index, the project leads guided the knowledge transfer process using the following questions:

- *Is the scale robust and defensible from a scientific point of view?*
- *Is the scale developed relevant to all of the stakeholders in the project?*
- *Does it provide enough information when used in an app context?*

Name	Area of Expertise	Institution
A/Prof Sara Wilkinson	Mental health and greenery, green roofs	University of Technology, Sydney
A/Prof Cheryl Desha	Hospitals and green spaces. Health and plants	Griffith University
Dr Jana Soderlund	Greenspaces and Biophilia	Curtin University
A/Prof Nick Williams	The benefits of plants and green spaces in an urban environment such as green roofs	University of Melbourne
A/Prof Kathryn Williams	The psychological benefits of plants and the environment	University of Melbourne

Outputs

The outputs can be subdivided into three sections:

Holistic understanding of the benefits of plants

- A holistic literature review summarising the key findings and patterns emerging from 43 studies on air quality and 57 studies on well-being (Appendix 1).
- A preliminary meta-analysis of air quality studies reporting removal rates for inorganic and organic compounds (Appendix 2). This meta-analysis led to:
    - Identification of toluene and/or benzene as a proxy for VOC removal rate categorization.
    - Parameters for VOC removal rate categorization based on benzene, toluene, TCE, and xylene (emerging from literature).
    - Confirmation that there is no relationship between removal rates and leaf area for different species
    - Confirmation that there is no relationship between removal rate of formaldehyde and other VOCs
    - Identification of a list of plants that have been screened during air quality tests and their removal category based on current research (Appendix 3).
- Benefit table listing the 101 articles reviewed through this research (Appendix 4).
- Recommendations for further research.

Plant-life Balance Index

(formerly known as Healthy Home Index)

- An equation based on the current BASEline.
- A simplified equation for use in the app while acknowledging information gaps
- A clear understanding of the information gaps and areas where the expert panel gave responsibility to the core team to estimate information for the equation.

Communication

- Frequent communication with the Plant Life Balance Index Team providing research updates and recommendations for the app development. Key meetings included:
    - Planning meeting to align the research, app development and communication strategy timelines.
    - Physical meeting in Sydney to present initial findings from the literature review.
    - Ongoing email communication providing feedback for the index equation.
    - Webinar sharing a presentation with preliminary meta-analysis results.
- List of limitations of the Plant Life Balance App.
- Recommendations for future app development.

Outcomes

The outcomes of this project can be divided according to short, medium, and long-term goals:

Short term goals:

Validating the index that runs the app to improve the market messaging of the app

A key short-term outcome was to allow the effective summation and translation of a broad range of scientific understanding about the benefits of plants into an easy to apply index. The outcome is a seamless integration of knowledge into the app so that the user can understand both the possibilities and the limitations of the science around the benefits of indoor plants.

Medium term goals:

An evaluation of the limits and benefits of using a Delphi process in guiding Augmented Reality Environments

Augmented reality environments, such as the one developed in this project, call for rich and precise information so they can be called 'augmented reality' and not 'augmented fantasy'. Yet scientific knowledge is scattered among a range of sources and generated using very different means that might not be in dialogue with one another. In such situations of asymmetric and uncertain information, a consensus process using the Delphi method can help to identify areas where information is imprecise for users and identify gaps for further research. A specific output of this exercise has been the development of a BASEline (Best Available Scientific Evidence) of understanding (suggested during the discussions by one of the expert panel members).

Long term goals:

A greater understanding among the research community of the benefits of plants in indoor environments.

This research has identified key gaps in the literature, pointing to the need for further research in the following areas:

- Further research to identify the extent to which different plants are able to remove air pollutants. For example, it is clear from the meta-analysis that there is a lack of research on the rate of formaldehyde removal compared to VOCs such as benzene. While it is possible to categorise different plants according to their removal efficiency for VOCs this is not possible for formaldehyde (Appendix 2). Air pollution removal efficiency may be related to soil micro-organisms and stomata number as well as plant size, but it is not possible to know the extent without further research.
- The impact of a complex array of plants versus a monocultural array on well being
- Whether the relationship between plant benefits and the number of plants is different from that for air pollution

Evaluation and discussion

This project drew upon literature exploring the benefits of plants in indoor and outdoor settings through experimental and quasi-experimental approaches. We found and categorised 101 different articles. Aside from articles examining Kaplan's (1995) attention restoration theory, the literature focused on topics relevant to indoor and outdoor environments. For the well-being evaluation, this included window views, art, plant props and the use of real plants within indoor environments. We argue that these apply to outdoor settings in dense urban environments that are similar to outside living areas such as balconies and patios. The articles were summarised and provided to the expert panel for discussion. The key aim of the panel was to consider the research to date and to provide a series of recommendations for the development of an index assessing the benefits of plants.

Development of a Plant-Life Balance Index

The Plant-Life Balance app is a mobile application for users to optimise the use of plant for their physical and mental well being within and close to their homes. The app user can understand their current situation and then choose more plants to enhance the benefit for them. The research team and the expert panel would like to acknowledge that our role within this project was to establish the BASEline based on literature and provide recommendations for the development of the index. To achieve this purpose, we made the following assumptions:

- The app will be used for residential spaces. Following Australian standards, we assume a density of 2.2 – 2.6 residents per dwelling.
- There is strong evidence indicating that plants can improve indoor air quality and human well-being; however, to the best of our knowledge, research has not been conducted within residential spaces. This report draws on research from office spaces, laboratory settings and a few immersive experiences in vast natural environments and brings these learnings to the household. However, further research is needed within the residential setting proposed for use by the app.
- For indoor air quality, research shows that contaminant removal efficiency changes for each species. In particular, the gram negative microorganisms associated with the root system remove the highest proportion of organic compounds suggesting that larger pots will lead to higher contaminant removal. However, at this stage, this knowledge cannot be transferred to the app. It is, however, highly recommended that the information is shared with the users via a pop-up message, social media or other means available. The same research suggests that the type of substrate can lead to differences in removal efficiency. This topic requires further research. At this stage, the expert panel assumes that plants introduced to the residential settings will be planted in traditional potting soil mix. In addition, in outdoor settings any plants are likely to have a minimal impact on air pollution remediation because of air movements.
- We assume that the users of the app will provide a minimum standard of care to the plants such as access to adequate light and water.
- Although healthy plants, should not lead to an increase of aeromycota (Torpy et al. 2013), we do not recommend to place plants in closed areas (i.e. bedrooms). Thus, the app is valid for leaky indoor spaces such as a lounge or living room. For outdoor environments it only assesses well-being at the same scale for indoor spaces.
- We assume that the environmental conditions are kept at a relatively constant level. Either through natural climactic processes or with the plants placed within a constantly air conditioned environment, the temperature, humidity and light levels of the space are constant.
- Lastly, we assume that this report will be used as the first iteration of the Plant Life Balance App but that the process will allow for continued improvement of the index, the list of plants available and the knowledge of the plants.

BASEline equation

Based on the research BASEline, the benefits can be grouped into one of two categories: increased air quality and enhanced well-being. The separation of the benefits into two scales arose from the recommendations by the expert panel.

Air quality benefits emerge from plants' ability to act as a passive filter of particulates (PM) and their ability to actively remove contaminants. Plants can be categorised based on their efficiency to remove contaminants (high, medium or low). The BASEline indicates that at least three categories are needed: 1) PM removal ability, 2) VOC removal, and 3) formaldehyde removal. The leaf structure is the main element determining PM removal capacity (Dzierzanowski et al. 2011; Treesubsuntorn & Thiravetyan 2012) while VOC and formaldehyde are primarily driven by the microorganisms living within the root system (Orwell et al. 2004; Wood et al. 2006; Kim et al. 2008; Xu et al. 2011; Torpy et al. 2013). Other elements mediating organic compound removal are the number of stomata and wax in the leaves (Ugrekhelidze et al. 1997). At this stage, inorganic compounds such as NOx, SOx and CO have not been explored in sufficient depth. Based on our meta-analysis, there is no evidence that the removal capacity of plants is related to the plant size for different species, however it is related to plant size when one species is considered simply because a larger plant is likely to have more stomata to absorb pollutants.

To quantify indoor air quality benefits based on BASEline research, we suggest the following equation:

$$AQ = \sum_{i=1}^{n} (\beta VOC_i + \beta For_i + \beta PM_i)$$

Where AQ is the air quality benefit for *i* plant, β is the benefit weighting value for each assessed contaminant considering the removal efficiency for three different contaminants: VOC, formaldehyde (FOR) and particulate matter (PM). These three contaminants would be assessed based on plant's removal efficiency categorised as high, medium, or low. In particular, PM would then be separated based on the size of the particulates (PM_{10}, $PM_{2.5}$, UPM) being assessed but further research is required to further specify the most relevant paterns for PM. The number of plants are weighted by a plant multiplier (M) generated based on the size of the plant following a generic recommendation of **1 high air pollution removalist plant every 2m^2**.

Well-being benefits emerge from the plant's ability to act as a group. The index rates the group of plants based on their ability to fascinate or activate (complexity) and their ability to foster relaxation (de-stress). While identity, preference, and a sense of control over your own environment are all key elements to increase well-being, the team and the expert group believe these elements are addressed indirectly as the app user is choosing the plants based on looks. At a BASEline level, we suggest the following equation:

$$WB = \sum_{i=1}^{NP} \mathrm{M_i} * \sum_{i=1}^{C} p_i^2$$

Where the well-being (WB) is measured through the total number of plants (NP) and the complexity of the group (C). The complexity is assessed by weighting the number of species weighted by their proportion (p_i^2). The value for M is as follows: a small plant has a value of 0.3, a medium sized plant has a value of 1, a large plant has a value of 1.5. These values were extracted based on the leaf area of the assessed plants and the number of plants that would be needed to fill 1m^2 of leaf area (Figure 2).

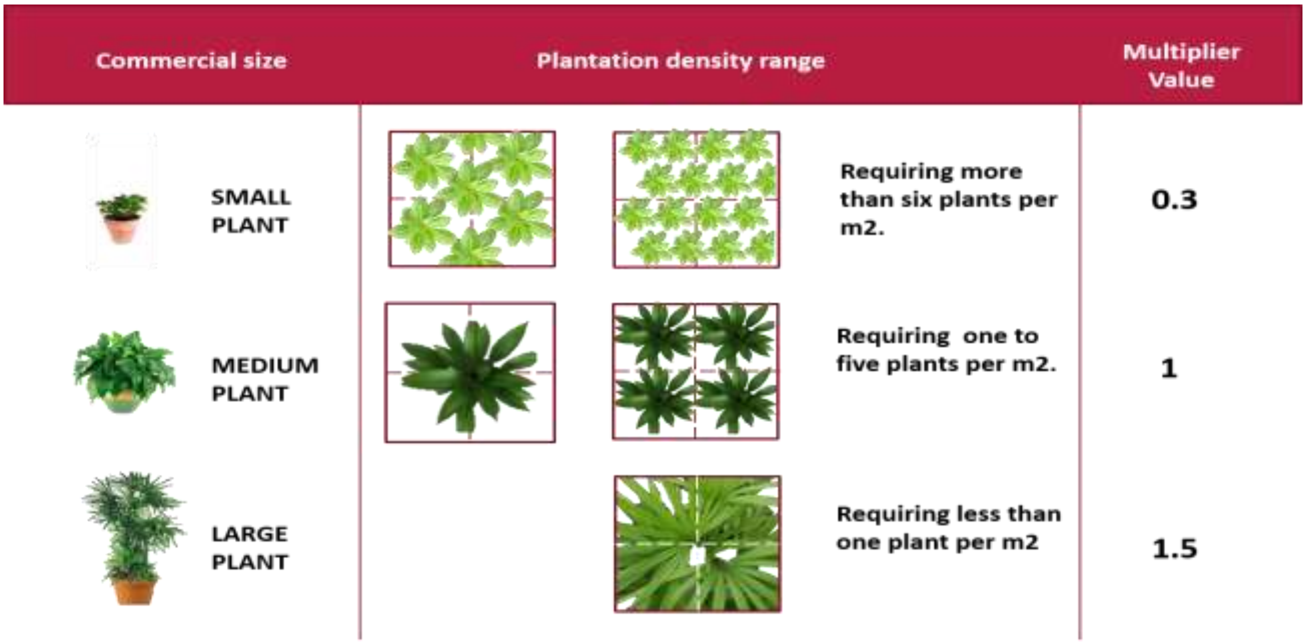


Figure 2: Size in relation to plantation density and the multiplier value. For instance, each medium sized plant would be equivalent to 3-4 small plants, thus, the multiplier for small plants is 0.3

Limitations in the use of the above index

Acknowledging that this equation cannot be used in an Augmented Reality environment such as the one proposed, the above is considered an 'ideal' equation were information available to satisfy the BASEline information from the literature. The key elements that prevent the adoption of the above are:

- only 130 species have been categorised as high, medium or low based on their contaminant removal efficiency; the current list of species (Appendix 3) includes VOC and formaldehyde categories with minimal species overlap;
- there is little overlap between the screened species and the current list of species proposed for the app;
- a subsequent literature or experimental research is needed to determine the β for each contaminant;
- the design of the app precludes the user from using species in the initial assessment of their home.

Simplified equation

Acknowledging the need to generate options that the app developers can use, the core team decided to make the following adaptations to the formula:

$$PB = AQ + WB$$

$$AQ = \sum_{i=1}^{NP} \mathrm{M_i}$$

$$WB = \sum_{i=1}^{NP} \mathrm{M_i} * (p_i = 1 \rightarrow 0.2)\hat{}(p_i < 1 \rightarrow 1)$$

The principal differences between the BASEline and the simplified equation for use in the app, is firstly, the Plant Benefits (*PB*) can be summed whereas in reality this relationship is unlikely to be able to be summed in a simple way. [Well-being benefits are mainly psychological, air quality benefits are mainly physiological. Secondly, in the BASEline equation the number of plant varieties (p_i) affects the complexity whereas in the simplified equation if the proportion of a given plant variety is the same (i.e. $p_i = 1$) then the benefits are reduced by multiplying by 0.2. If the number of plant varieties are more than 1 (i.e. $p_i < 1$) then the well-being benefits remain the same. The value of 0.2 was estimated by the team but no BASEline information is available to confirm this.

AQ and WB are both primarily assessed by the total number of plants (NP) weighted by a plant multiplier (M) generated based on the size of the plant. The generic recommendation is slightly modified to **1 medium sized plant every 2m^2.** The value for M is as follows: a small plant has a value of 0.3, a medium sized plant has a value of 1, a large plant has a value of 1.5. These values were extracted based on the leaf area of the assessed plants and the number of plants that would be needed to fill 1m^2 of leaf area (Figure 2). For well-being the difference with the BASEline equation shows that instead of p_i representing the proportion of species, instead it represents the proportion of plant sizes. This was done as the app users may not be able to provide the species of plants already available at their home but can provide a breakdown of plant sizes.

The equation used above is able to be used in the app but is not consistent with the BASEline established from the literature review, and is seen as a first step. In addition, for outdoor settings the Expert Panel agreed that the air quality part of the equation should not be included as the quantity of contaminants tends to be lower than indoors particularly with respect to VOCs and formaldehyde. The exception to this would be particulate matter, which is important outdoors, but the literature did not show enough information to conduct further analysis and draw conclusions.

Further suggestions in the development of the app

The expert panel felt that the following topics were relevant for the long-term development of the app. For well-being, assigning a single ideal number of plants is a reductive approach. It is understood that different people have different preferences not only regarding the species they choose but how many are needed to gain the maximum level of well-being. This was discussed over a minimalist scenario where the recommended level of 1 medium sized plant every 2m^2 may be too much for some people or too little for others. Some expert panel members felt that it would be a better use a decision tree allowing users the choice based on their preferred level of complexity (from minimalist to standard to forest). Similarly, the current version of the app does not allow the user to prioritise between air quality and wellbeing benefits.

All members of the core team and the panel of experts know that the light levels will be key to the success of the plants. As such, a generic inquiry on how much sunlight enters the room can help filter the plant choices before they begin their search for plants. Although it has been indicated that this information will be provided to the user when they receive the full list of plants they chose, we believe that failing to filter the plants ahead of time will lead to a sub-optimal process of plant choice. Some expert members suggested this could appear as a pop-up message to educate the users ahead of time. Another approach suggested was to ask the user to install a free light levels app and use that data to assess the light levels of the room.

There was also disagreement regarding the plant options with some members stating a desire to avoid any weeds in the list while other members believing that, if the plants remain indoors, it is not of great consequence. Of course, often plants from indoors environments end up in landfill or garden, so this is a consideration.

The expert panel believes that further research is needed based on plant typologies (leaf structure, standard leaf areas, etc). Research suggests that plant typology is more critical in understanding the benefits of plants but the expert panel acknowledges that this type of research is limited and requires longer time frames.

The research on well-being is vast and very diverse in nature. A vast literature exists on the relationship between plants and well-being in outdoor environments, but none on balconies and patios using potted plants. A large amount of literature exist on the well-being benefits of indoor plants. However, no standard measure of well-being has been developed. Well-being factors are highly interrelated, to one another and, from the existing research, only directional factors can be incorporated. The panel agreed on the following:

a. A plant is better than a picture of a plant, which is better than a plant colour, which is better than nothing.
b. More plants are better than fewer plants.
c. More diverse is better than less diverse (the relationship between different plants, shapes) but dependent of a cohesive look. Organised complexity.
d. Green foliage is better than other foliage.
e. Flowers are better than no flowers.
f. Air quality-plant relationship are valid for the app in indoor spaces, well-being-plant relationships are valid for outdoor and indoor spaces.

Recommendations

Recommendations for the App Development Process

The team involved in this process identified that a significant knowledge gap exists between the simplified equation and the BASEline research. Further research should be invested in understanding the contaminant removal efficiency per species included in the app and migrating to the BASEline equation. The differences between the equations is summarized in the diagram below:

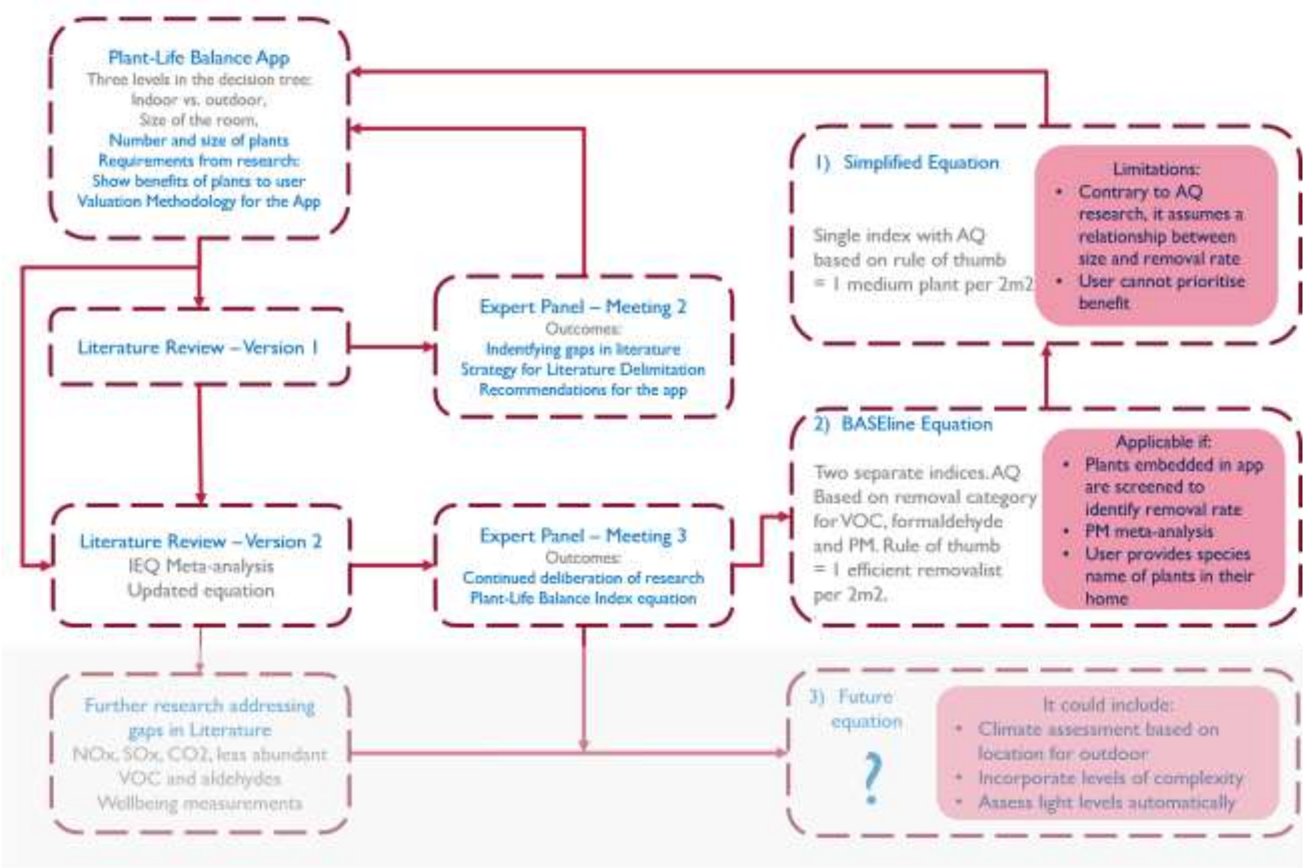


Figure 3: Summary diagram outlining the method used to generate knowledge in the project and the difference between the BASEline equation generated from the literature and the simplified equation to be used for the app.

Recommended topics for pop-up messages.

The literature tables can be used to extract many quick facts to create a 'did you know?' pop-up approach. Some topics that should be incorporated are:

- The relevance of microorganisms in the soil as key purifiers of the air.
- Recommendations on when to transplant and the benefits of doing so through allowing the root system to grow.
- Happy plants make for happy people. The plants need to be healthy to provide well-being benefits; unhealthy plants on the other hand can have a negative impact.

Recommendations for future research

There are three ways to improve research and current BASEline levels:

Conduct studies within a residential environment. To the best of our knowledge, most studies exploring well-being effects are done at office spaces, hospitals, schools, care centres or through immersive experiences in a natural environment.

Conduct a higher number of field studies for air quality. In particular, studies assessing existing levels of contaminants and adding plants until saturation would be ideal to test the variable of how many plants to include per m^2 of area.

Conduct a higher quantity of plant screening tests to enhance the knowledge of our plants. Research exploring the relationship between plant traits, air quality and well-being are highly desirable. It is also important to report the full list of species including those that did not have an impact on these benefits.

Scientific refereed publications

None to report

Intellectual property/commercialisation

No commercial IP generated

References

Bratman, G. N. et al. (2015) The benefits of nature experience: Improved affect and cognition, Landscape and Urban Planning 138: 41–50

Bringslimark et al. (2009) The psychological benefits of indoor plants: A critical review of the experimental literature, Journal of Environmental Psychology 29: 422–433

Dzierżanowski K, et al. (2011) Deposition of partic- ulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. Int J Phytoremediation;13(10):1037–46.

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Ga¨rling, T. (2003). Tracking restoration in natural and urban field settings. Journal of Environmental Psychology, 23, 109–123.

Kaplan, S. (1995). The restorative benefits of nature: toward an integrative framework. Journal of Environmental Psychology, 15, 162–182.

Kim, K. J. et al. (2008) Efficiency of Volatile Formaldehyde Removal by Indoor Plants: Contribution of Aerial Plant Parts versus the Root Zone, J. AMER. SOC. HORT. SCI. 133(4):521–526.

Korpela, K. et al. (2017) Nature at home and at work: Naturally good? Links between window views, indoor plants, outdoor activities and employee well-being over one year, Landscape and Urban Planning 160: 38–47

Liu, Y.-J. (2007) Which ornamental plant species effectively remove benzene from indoor air? Atmospheric Environment 41: 650–654

Morton et al. (2017) Seeing our self reflected in the world around us: The role of identity in making (natural) environments restorative, Journal of Environmental Psychology 49: 65-77

Orwell, R. L. (2004) REMOVAL OF BENZENE BY THE INDOOR PLANT/ SUBSTRATE MICROCOSM AND IMPLICATIONS FOR AIR QUALITY, *Water, Air, and Soil Pollution* 157: 193–207

Torpy, F. R. et al. (2013) Do indoor plants contribute to the aeromycota in city buildings? Aerobiologia 29: 321–331

Treesubsuntorn, C. Thiravetyan, P. (2012) Removal of benzene from indoor air by Dracaena sanderiana: Effect of wax and stomata, Atmospheric Environment 57: 317-321

Ugrekhelidze, D. et al. (1997) Uptake and Transformation of Benzene and Toluene by Plant Leaves, ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY **37,** 24–29

USEPA, (2007) The EPA Cost of Illness Handbook U.S. Environmental Protection Agency, Washington, D.C (2007)

Wood, R. A. (2006) THE POTTED-PLANT MICROCOSM SUBSTANTIALLY REDUCES INDOOR AIR VOC POLLUTION: I. OFFICE FIELD-STUDY**,** *Water, Air, and Soil Pollution* 175: 163–180

Xu, Z. et al. (2011) Formaldehyde removal by potted plant–soil systems, Journal of Hazardous Materials, 192: 314–318

Yang, D.-S. et al. (2009) Screening Indoor Plants for Volatile Organic Pollutant Removal Efficiency, HORTSCIENCE 44(5):1377–1381.

Acknowledgements

The team would like to thank the expert panel without whose generosity with time and intellectual property this project would not have been possible. In addition, Ben Peacock, Lucy Jackson, Alexis Clarke, Alex Marshall and Claire Tindale-Penning all contributed ideas and useful insights in the development of the review and index. All errors and omissions remain the authors.

Appendices

Appendix 1: Holistic literature review on the benefits of plants

Appendix 2: Organic compound removal rate meta-analysis

Appendix 3: List of plants per revoval category

Appendix 4: Benefit table – for literature review

Appendix 1: Holistic literature review on the benefits of plants

The purpose of this review is to provide a holistic overview of the research exploring the benefits of plants with a particular interest in a benefit for indoor spaces. The review is separated into two sections based on the benefit: Air Quality or Wellbeing, with each of them, subdivided in response to the literature analysis.

Methodology

For the analysis of the relevant literature, we adopted the methodology of Bringslimark et al. (2009) comparing papers based on the following characteristics: study subjects, methodology, exposure to stimuli, outcome measure, and findings. The approach was expanded by including the project's scope (indoor, outdoor), the scale (small, medium, large) and the description of the plants in terms of species, age and soil characteristics as reported by the authors.

Delimiting relevant literature for academic rigour

We located the material for review through standard methods including electronic databases and snowballing (e.g. one paper referring to another). To enhance the reliability of the data, we focused on research papers, conference proceedings and official reports with a clear experimental or a quasi-experimental methodology. Furthermore, we assessed the methodology to ensure study established a baseline level by the inclusion of a no-plant control or a repeated measures approach (before vs. after plant treatment). Informal publications such as science communication magazines, papers and blogs were excluded from the study.

Literature analysis

The papers were categorised into two broad benefits: air quality and well-being. In particular, air quality was defined as studies assessing a plant's ability to affect the concentration of airborne compounds (inorganic and organic compounds) and/or particulate matters (PM). Meanwhile, well-being was defined as any direct (i.e. improved mood, concentration) or indirect benefit (i.e. productivity, prosocial behaviour) that could be attributed to the presence of plants. Based on the details above, a total of 101 articles were included (43 for air quality, 57 for well-being and 1 for both). Of these, the data of 76 articles were read from the original source while the remaining articles (25) were included from a secondary source. In the latter cases, the original source could not be found within the project's timeframe and the secondary source was detailed enough to meet the information criteria as described above. These studies were summarised and included from reviews.

For the case of air-quality, we also enhanced the existing literature by conducting a meta-analysis. In general terms, this comprises a compilation and re-analysis of removal rates reported by previous authors. This analysis was conducted to strengthen the index development and recommendations provided by the expert panel For more details on the methodology of this meta-analysis please refer to Appendix 2.

Indoor air quality review

Over the last 35 years, researchers have accumulated evidence that plants can improve our indoor air quality (Guieysse et al. 2008; Girman et al. 2009; Hartig et al. 2014). This direction of research began in the 1980's when Wolverton et al. (1984) showed that plants had the ability to remove formaldehyde. Since then, research has expanded to include removal capacity for other airborne contaminants such as PM (i.e. Tiwary et al. 2009; Beckett et al. 2000; Ottelé et al. 2010), CO2 (Fujii et al. 2005; Park et al. 2010; Makido et al. 2012), NOx (Fujii et al. 2005) and volatile organic compounds (VOC) such as benzene, toluene, trichloroethylene (TCE), and xylene amongst many others (Wolverton et al. 1989, 1993; Wood et al. 2006; Tarran et al. 2007; Wetzel & Doucette 2015).

In general terms, these studies indicate that plants can remove 75%-90% of pollutants depending on the plant and the specific contaminant being assessed. This research has earned plants a the reputation of an affordable bioremediation system that can support mechanical systems that remove pollutants from indoor air (Tarran et al. 2007; Pipal et al. 2012). For example, air filtration systems studied by Shaughnessy et al. (1994) were unsuccessful in removing formaldehyde, whereas various studies included in this review highlight the ability of different plant species to provide this service. However, most results have been achieved within the controlled setting (sealed chamber) and by analysing each contaminant separately. Field studies are limited and often show more conservative numbers of 10-15% (Pegas et al. 2012) making some researchers believe that the change is of little benefit (Girman et al. 2009).

This review assessed 43 different studies which met the academic rigour criteria described in the methodology. Figure 1 summarises the findings of these studies and how our understanding of the benefit of plants has evolved over the past 35 years. In general terms, the research topics can be subdivided into four categories. The air quality review is divided into four subsections in response to these four categories:

1. Uptake mechanism of organic and inorganic compounds: Studies which explored the strategies through which the plant and its root system are able to purify the air.
2. Compound removal response to local conditions: Studies which explored the external factors influencing removal rates (i.e. light levels, temperature, concentration or airborne molecules, etc).
3. Plant species screening for airborne compound removal rates: where the key objective of the study was to compare the differences amongst plant species.
4. Particulate Matters (PM): Studies exploring the elements determining the variation of dust or PM in response to plant presence.

Table 1 summarises the number of articles that explore each category as well as the specific contaminant used for their study. Some studies addressed more than one of the above-mentioned topics and or contaminants.

When relevant, species' contaminant removal rates for airborne compounds were collated for the meta-analysis. The analysis was limited to the contaminants with enough data. For instance, ozone, NOx and SOx were addressed by a limited number of studies and a small number of plant species and were thus excluded from the meta-analysis. Meanwhile, PM studies have been separated into a different section as they respond to different mechanisms of the plant. The results of this analysis are briefly discussed in subsection 3 while the complete meta-analysis is available in Attachment 2.

Table 1: Category of study, authors and number of studies for each contaminant

Measured element				
Inorganic Compounds	CO_2	Uptake mechanisms by soil or leaves	(Irga et al. 2013)	6
		Removal response to local condition	(Fujii et al. 2005; Park et al. 2010; Pegas et al. 2017; Torpy et al. 2014)	
		Plant screening	(Torpy et al. 2014)	
	NOx	Removal response to local condition	(Fujii et al. 2005)	1
	Ozone	Removal response to local condition	(Abbass et al. 2017)	2
		Plant screening	(Papinchak et al. 2009)	
Organic Compounds (Part A)	Formaldehyde	Uptake mechanisms by soil or leaves	(Kim et al. 2008; Aydogan & Montoya 2011)	4
		Plant screening	(Wolverton et al. 1984; Kim et al. 2010)	
	Aldehydes	Uptake mechanisms by soil or leaves	(Tani & Hewitt 2009)	1
Organic Compounds (Part B - VOC)	TVOC		Wetzel & Douchette 2015	
	Benzene	Uptake mechanisms by soil or leaves	(Ugrekhelidze et al. 1997; Wood et al. 2002; Orwell et al. 2004; Treesubsuntorn & Thiravetyan 2012; Pegas et al. 2012; Torpy et al. 2013; Irga et al. 2013)	10
		Removal response to local condition	(Orwell et al. 2004)	
		Plant screening	(Wolverton et al. 1989; Liu et al. 2007; Yang et al. 2009)	
	Toluene	Uptake mechanisms by soil or leaves	(Ugrekhelidze et al. 1997; Pegas et al. 2012; Kim et al. 2014)	6
		Removal response to local condition	(Orwell et al. 2006; Sriprapat et al. 2014)	
		Plant screening	(Yang et al. 2009; Sriprapat et al. 2014)	
	Xylene	Uptake mechanisms by soil or leaves	(Kim et al. 2014)	4
		Removal response to local condition	(Orwell et al. 2006; Sriprapat et al. 2014)	
		Plant screening	(Yang et al. 2009; Sriprapat et al. 2014)	
	TCE	Plant screening	(Wolverton et al. 1989; Yang et al. 2009)	2
	Octane	Plant screening	(Yang et al. 2009)	1
	n-hexane	Plant screening	(Wood et al. 2002)	1
Particulate Matter		Particle capture mechanisms	(Terzaghi et al. 2013; Przybysz et al. 2014; Gawronska & Bakera 2015; Chen et al. 2017)	9
		Local conditions	(Lohr & Pearson-Mims 1996; Tiwary et al. 2009; Wania et al. 2012; Chen et al. 2017)	
		Plant screening	(Lin et al. 2012; Sæbø et al. 2012)	
Risks	Aeromycota	No significant effect	(Fjeld 2002; Torpy et al. 2013; Irga et al. 2013)	3
	VOC emission	Emission	(Georgieva et al. 2005)	1

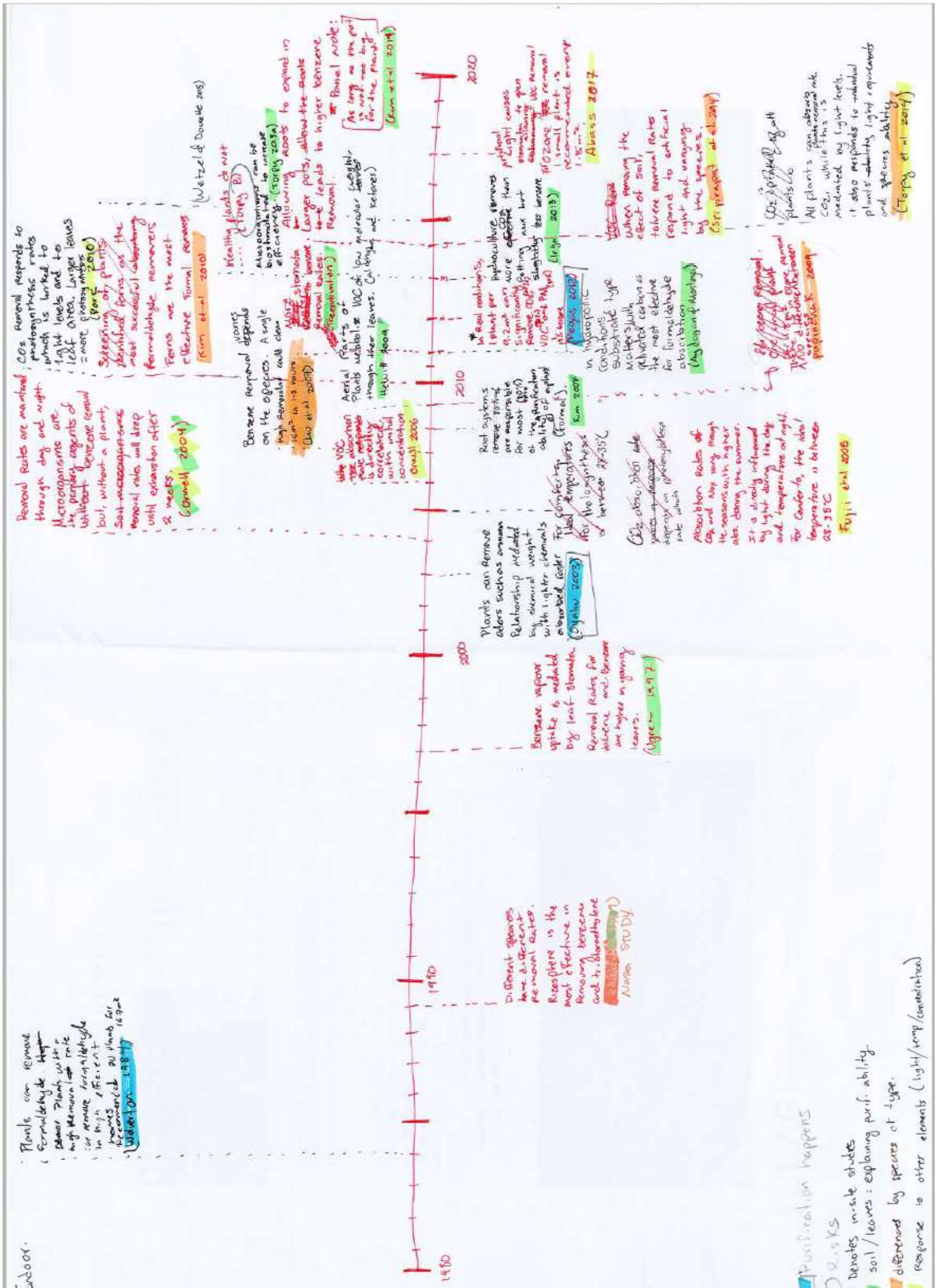


Figure 1: Timeline of research insights

UPTAKE MECHANISMS OF ORGANIC AND INORGANIC COMPOUNDS

Wolverton et al. (1989; 1991; 1993) were not only the first to research the potential use of plants for indoor air quality, but also the first to suggest that the process could be regulated by the plant and the microorganisms associated with the soil. It was later confirmed that microorganisms in the root system as responsible for as much as 80% or the removal efficiency of a plant (Kim et al. 2008; Orwell et al. 2004). More specifically, species with a higher proportion of gram-negative bacteria can remove organic compounds more effectively (Wolverton & Wolverton 1993). Gram-negative bacteria (i.e. *Pseudomonas*) are characterised by having a cell wall formed by peptidoglycan and have been previously reported for their effectivity degrading organic chemicals (Wolverton & Wolverton 1993; Guieysse et al. 2008; Pipal et al. 2012).

Kim et al. (2014), analysed this relationship through a limited number of plant species (n=8) finding that similarly-sized individuals of the same species, can increase their removal efficiency if they are transplanted into bigger pots. This allows the root system to expand, thus, the effect is correlated to the root size, not the pot size. Similarly, the efficiency increases through time suggesting that the microorganisms adapt to the contaminant enhancing their own ability to metabolise the contaminant (Wolverton & Wolverton 1993). This is in line with (Torpy et al. 2013) who claim that biostimulation resulted in a 15% increase of benzene removal rates.

Hydroponic systems are also effective mediums for the growth of microorganisms responsible for inorganic and organic compound removal (Irga et al. 2013; Aydogan & Montoya 2011). Shifting from potting soil to hydro culture medium will shift the removal efficiency of the species. For instance, *Syngonium podophyllum* grown under a hydroponic system led to higher CO2 removal but was also less effective for benzene (Irga et al. 2013). The efficiency may also vary depending on the substrate analysed. for instance, activated carbon is the best medium for formaldehyde removal (Aydogan & Montoya 2011).

The key role of the plant itself is primarily to keep that microbiota alive; by itself, the soil system is prone to exhaustion within 2 weeks without the plant (Orwell et al. 2004). In addition to the soil, the plants themselves also have an ability to uptake contaminants (~20% of total uptake) (Tani & Hewitt 2009). In particular, Treesubsuntorn & Thiravetyan (2012) found that the number of stomata on the leaf surface is correlated with the ability of *Dracaena sanderiana* to remove benzene. This was also explored by Ugrekhelidze et al. in 1997 who found that younger leaves of *Acer campestre*, *Malus domestica*, and *Vitis vinifera* are more effective in removing toluene and benzene. In a more recent study, the presence of hexadecanoic acid in the wax of the leaves was highlighted as the most plausible explanation for toluene and ethylbenzene adsorption (Sriprapat et al. 2014). For formaldehyde, the activity is mediated by the formaldehyde dehydrogenase from the leaves (Xu et al. 2011).

For inorganic compounds, research on the uptake mechanisms by plants is sparse. Fujii et al. (2005) indicate that vegetation might be also used to remove CO_2 and other inorganic air emissions (e.g. NOx, Sox, CO). But the effectiveness might depend on the local conditions.

COMPOUND REMOVAL RESPONDS TO LOCAL CONDITIONS

It is clear that removal rate will vary depending on the species and the contaminant in question, but there are also other factors mediating the response based on local conditions. For instance, the removal rate changes based on the concentration of the contaminant (Orwell et al. 2006). In this study, Orwell et al. screened 2 different species at four different concentrations. He highlighted the plant's ability to remove toluene and xylene at ‘high’ (10ppm) and ‘low’ (0.20ppm) concentrations, however, the removal rate varied accordingly showing slower removal rates at lower concentrations. The 'low' concentration of this study is equivalent to levels that would be commonly found in office spaces, while the 'high' concentrations correspond to levels where the occupants will show sick building syndrome symptoms. The observed phenomenon can explain the differences between studies conducted within chambers and field experiments in schools and office settings.

CO_2 absorption is mediated by photosynthesis (Park et al. 2010; Fujii et al. 2005; Torpy et al. 2014). Thus, it varies through the seasonality and in response to temperature. Fujii et al. (2005) indicate that for *Juniperus conferta*, is most efficient when the temperature is between 30-35`C. Similarly, they found that the same plant will absorb the most amount of CO_2 during spring and early summer when the removal rates are approximately five times higher than that of autumn or winter. This observation is supported by those of other authors stating that growing plants are the most effective removing CO_2. Removal rates of CO_2 also vary in response to light (Park et al. 2010; Torpy et al. 2014). In general terms, the light requirements by each plant are correlated to the light levels at which they will be most effective in removing CO_2 (Torpy et al. 2014).

Finally, Park et al. (2010) suggest that, for CO_2 removal, the leaf area is also an important element as the surface of gas exchange increase (n=5 species), however, this relationship was not verified by our meta-analysis comparing 10 different species. We would suggest that size is of importance within the same species as it increases the surface of air exchange. Further research would be needed to significantly expand the number of species that have been screened for CO_2 and to explore the removal rate changes with increased leaf area within individuals of the same species.

For VOC, authors have found that removal rates are active through night and day with only a slight change of efficiency (Orwell et al. 2004). This can be explained by the microorganisms in the soil, which are active through 24 hours, meanwhile, the aerial portions of the plant will vary their contaminant removal rates in response to light. Light causes the stomata in the leaves to open (Abbass et al. 2017), thus enabling the plant to remove VOC and ozone (Treesubsuntorn & Thiravetyan 2012; Abbass et al. 2017). In a laboratory experiment, Sriprapat et al. (2014) found that plants respond to artificial light in a similar way than to natural light.

PLANT SPECIES SCREENING

When a plant is exposed to a contaminant, each plant may or may not uptake the contaminant. For instance, Liu et al. (2007) found 23 species (out of 73 species screened) that did not alter benzene concentration. As explained before, this depends upon the specific characteristics of the plant (number of stomata), the type of microorganisms associated with its root system (gram-negative bacteria) and the local conditions (i.e. temperature, light, etc).

In 2008 Kim et al. explored if the formaldehyde removal efficiency of various indoor plants was correlated with the plant typology. More specifically, they screened 86 plant species and categorised them as Korean native plants, ferns, herbaceous foliage plants, woody foliage plants and herbs. Of these, they stated that ferns were the most effective removalists. Figure 2 corresponds to a visualisation created by our research team to visualise the effect reported by Kim et al. (2008); we found that, although some fern species do showcase the largest removal ability, it is not enough to conclude that plant typology is related to removal efficiency. Further research would be needed to further explore the relationship between plant typology and removal abilities. Furthermore, a similar study would need to be conducted with other contaminants.

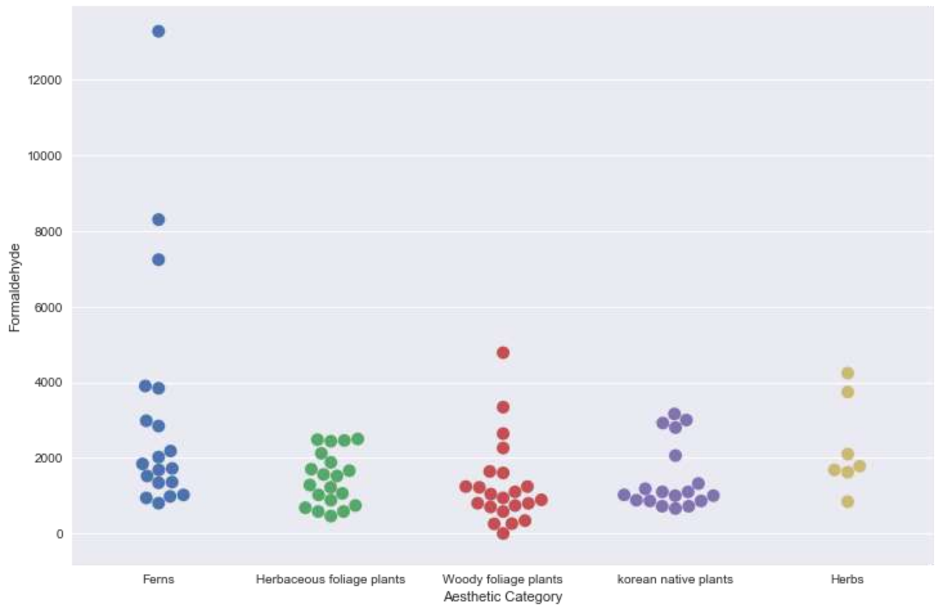


Figure 2: Formaldehyde removal rate based on plant typology. This figure draws upon the research by Kim et al. (2008)

Air quality Meta-analysis, a summary of Attachment 2

The removal rates of 15 different studies were compiled and re-analysed. These studies specifically reported removal rates for CO_2, formaldehyde and VOC. More specifically, VOC included within the study are benzene, toluene, octane, TCE and xylene. The specific objective of the meta-analysis was to guide the research team and panel of experts into the best strategies to develop a the plant-life balance index. This was achieved through the following questions:

1) given individuals of the same species, what is the relationship between the removal rates of different contaminants?
2) Is there a relationship between the size of a plant and their removal rate?

In total, 130 different plant species have been screened for at least one of the aforementioned contaminants. Table 2 indicates the number of species screened for each contaminant with 99 species emerging from two key studies: Yang et al. (2009) measured the removal rate of 28 different species for five different VOC and Kim et al. (2008) measured the effectivity of formaldehyde removal of 86 different indoor plant species.

Table 2: Number of species screened for each contaminant in the meta-analysis

Contaminant	Formaldehyde	Benzene	Toluene	TCE	Octane	Xylene	CO_2
No. of species	91	51	36	34	28	28	10

For full details on the meta-analysis please refer to the Appendix 2. For a list of plants and their removal category please refer to Appendix 3.

How many plants should I use?

Different authors recommend different numbers of plants per floor area. These differences are expected as they are based on a number of species studied as well as the specific contaminant screened. Below is a brief list of the recommended levels by different authors. Subsequently, this research critically assessed the rationale behind the reported set of recommendations and then provided our own recommendation based on the BASEline.

Gathering researcher's recommendations.

- 70 plants in a 167m2 house to remove formaldehyde (Wolverton et al. 1984); equivalent to 1 high removalist per 2.2 m2.
- 1 small plant per 1.8m2 to clean ozone (Abbass et al. 2017)
- 1 highly efficient removalist per 10m2 to remove benzene (Liu et al. 2007)
- 1 plant per 9.2m2 to reduce benzene, PM and CO_2 (Pegas et al. 2012).

Aside from Pegas et al. (2012), the recommendations provided come directly from the author's research. They were calculated based the most efficient species assessed in sealed chambers, thus generating recommendations under the assumption that every plant will be a 'high' removalist. Other assumptions vary from one study to the next.

Wolverton et al. (1984) assumed a typical house size (167m2), calculated the amount of formaldehyde that will be emitted by a new house (based on average formaldehyde concentration of 240μg/m^3), added emissions through resident's activity (i.e. cooking) and calculated the number of spider plants (*Chlorophytum related*) needed to meet the purification needs of that household. Their recommendation is equivalent to one formaldehyde high removalist plant every 2.2m^2 for a new home. Older houses would require fewer plants or would allow for a mixture or low, medium and high removalist species to achieve similar results.

This level of detail was not considered by the remaining studies. Abbass et al. (2017) and Liu et al. (2007) assumed a room with a 2.5m in height but did not consider the typical emissions of said room and the activities that occur within. Abbass et al. (2017) recommendation are based on low and high ozone removalists based on a 0.9-9% removal respectively. Meanwhile, Liu et al. 2007 are based on the length of time (under 5 hours) that the top 10 benzene removalist species take to purify low concentrations of benzene. screened different plant species within a sealed chamber. Thus, we would recommend at a minimum, the double amount of plants.

In contrast, Pegas et al. 2012 designed their study based on recommendations by the Associated Landscape Contractors of America. The study was conducted in a single classroom with 25 students over a nine-week period. The first three weeks were used to establish a pollution baseline while the remaining six weeks plants were introduced. The plants used in this study were all highly efficient removalists as per Wolverton et al. (1989, 1993). The results reported for VOC are more conservative than studies in sealed chambers. We will take a closer look at one of the values monitored. Australian standards recommend that indoor levels of CO2 are maintained under 600ppm. During a real-life experiment, Pegas et al. (2012) found that a single plant every 9m^2 removed 45% of CO_2 in a classroom (from 2004+/-580 to 1121ppm+/-600 of CO2). The mean concentration of CO_2 during the treatment period is still above recommended air quality standards indicating that two to three plants per 9m^2 might be a better recommendation given a classroom setting. These new numbers would also result in higher purification rate for benzene and toluene.

Based on the BASEline

Given the literature assessed to this date, and assuming that only highly efficient removalists are chosen, the research team would recommend **1 plant every 2.2m2 to remove formaldehyde and 1 plant every 3m2 to remove VOC which would result in a final number of approximately 0.80 plants per m^2**. However, given the current state of research, we know of at least plant species that simultaneously remove both contaminants, as such, the number above is high. We also know that there is no correlation between formaldehyde and VOC removal rates for a plant; there are slim chances that a single plant will be high removalists for both contaminant. Considering both factors, the research team suggest that, as a rule of thumb, **one high removalist plant be introduced every 2m²**.

PARTICULATE MATTER

PM is a widespread air pollutant, consisting of a mixture of solid and liquid particles suspended in the air (dust is an example). As their physical and chemical characteristics vary widely, they are usually described in terms of the mass concentration of particles with a diameter of less than 10 µm (PM_{10}), fine particles with a diameter of less than 2.5 µm ($PM_{2.5}$) and ultrafine particles (UFP) with a diameter less than 0.1 µm.

Using plants as a PM removal strategy has been tested in many studies. For instance, within an indoor setting, (Lohr & Pearson-Mims 1996) found that a room with plants had 1 mg lower PM levels per m^2 than a room without plants. Researchers have also made an effort to identify the species best species to use to remove PM of diverse sizes. Lin et al. (2012) identified *Cupresus leylandii* and *Pinus sylvestris* to be the most effective filters out of the species included in their study whereas *Pinus*, *Taxus*, *Stephandandra incisa* and *Betula pendula* were highlighted as efficient by (Sæbø et al. 2012).

The particles are caught within the surface of the leaves and its wax (Dzierzanowski et al. 2011). The composition of particles captured also changes in response to these characteristics. Species that remove high levels of large PM (PM_{10}) generally have large amounts of trichomes and/or deep grooves that capture the particles tightly (Chen et al. 2017). Meanwhile, the wax in the leaves traps the UFP (Gawronska & Bakera 2015) through PM cuticular encapsulation (Terzaghi et al. 2013). Whereas the leaf area is not directly correlated with PM removal when comparing different species, a larger surface of a plant with the necessary leaf structure would be able to capture more particles before reaching a saturation point (Przybysz et al. 2014; Chen et al. 2017).

The effectiveness also depends on the local conditions. For instance, in a study conducted within a classroom, the plants that were placed in active areas (i.e. near the door) capture higher amounts of PM than those placed in the room corner (Lohr & Pearson-Mims 1996). It is highly accepted that plants improve the indoor and outdoor air by removing PM. Researchers modelling the effects at larger scales have found that the effects could help prevent at least two lives each year (Tiwary et al. 2009)

However, researchers also recommend proceeding with caution as, under different conditions, the plant could end up adding more PM. For example, when the particles are released as the wind changes strength or direction (Chen et al. 2017) or by reducing air speeds ultimately causing PM to remain in the space (Wania et al. 2012).

AIR QUALITY RISKS OF INTRODUCING INDOOR PLANTS

One of the elements preventing the introduction of indoor plants is the perceived risk of plants increasing the fungi spores in the air leading to respiratory illness. Elevated counts of fungi within enclosed settings has been linked to respiratory illness and sick building syndrome (Engelhart et al. 2009). Some authors have proposed that indoor plants can studies have proposed indoor plants as plausible sources of fungi (Meyer et al. 2005; Takeda et al. 2009). The reviewed literature states that there is no evidence to suggest that healthy indoor plants increase the aeromycota levels (Fjeld 2002; Torpy et al. 2013; Irga et al. 2013). This highlights the importance of providing a good level of care to the plant species by providing sufficient amount of light and water as per the species requires.

Similarly, Georgieva et al. (2005) state that some species may contain VOCs in their flowers or leaves releasing them into the air. This study was performed on five Gentiana species of which 3 contained low concentrations of aliphatic hydrocarbons in their flowers. This statement is counterbalanced by the wealth of literature included in this and other reviews. In short, the uncertainty of some species emitting a small quantity of a VOC is far surpassed by plants ability to remove some of the most noxious contaminants polluting our indoor air.

Although small, these risks do exist, however, they can be easily managed by providing proper basic care to the plant and maintaining a well-ventilated space.

Wellbeing Review

Research indicates the proximity of plants, natural views or immersion in natural environments provide a diverse range of sensations that cascade into a higher state of well-being. This includes evidence that plants can:

- Improve physical health (Fjeld et al. 1998; Fjeld 2002; Nielsen & Hansen 2007)
- Reduce levels of stress and anxiety – stress reduction theory (Ulrich et al. 1991; Dijkstra et al. 2008; De Vries et al. 2013; Ikei et al. 2014)
- Provide a sense of fascination that energises us or activates us – attention restoration theory (Kaplan 1995; Nejati et al. 2016)
- Promote sense of social cohesion (De Vries et al. 2013; Wei et al. 2014)

This all results in an enhanced level of self-perceived long-term life satisfaction or well-being (Shoemaker et al. in Bringslimark et al. 2009; Dravigne et al. 2008). Well-being is defined as a consistent state of wellness, satisfaction or contentment that emerges from individual perception of good physical, mental and social condition. It is not a state of perpetual happiness, rather the satisfaction that emerges from enjoying the good times and the confidence that you have the ability to cope with the issues that lie ahead. This is the basis of the salutogenesis theory which encourages processes to identify and support the elements that enhance mental and physical health (Becker et al. 2010; Stickley & Hoare 2015). It is grounded in the belief that health support is a better preventive approach than minimizing risks.

This review began by identifying research which measured any direct (i.e. improved mood, concentration) or indirect (i.e. productivity, prosocial behaviour) benefit that could be attributed to the presence of plants. We identified 53 different studies which met the academic rigour criteria described in the methodology. In general terms, the experiments addressed a wide variety of benefits through diverse experimental designs and measures making any sort of comparison among them difficult. Some of the benefits observed include reduced stress, productivity and creativity, nature restoration, pro-social behaviour, and academic performance. Due to the wide variety of experimental designs and measurement, it is not possible to fully compare the studies based on the benefit addressed.

Key benefits of nature

The reviewed literature includes 18 studies with research relevant for the inclusion of nature in our outdoor spaces, 33 studies for indoor spaces and 2 relevant for both. These studies included nature simulation experiments, individuals engaging in an immersive experience and passive experience of a natural environment. Passive experience included outdoor view and well-being benefits gained by the presence of indoor plants.

Nature simulation vs. nature immersion

In 1991, Ulrich et al. exposed people to a set of videos where the first one was designed to put them in a place of enhanced stressed and the second one to relax them through exposure to nature or urban images. They found that nature simulation led to faster recovery from a stressful event, an observation that was measured through self-reported levels of positive emotional state and well as through monitoring their physical tests. Faster stress recovery was also experienced by the participants of an immersive study where the participants went for a walk at a nearby woodland or within an urban environment – besides a road or at the city centre (Hartig et al. 2003; Tyrväinen et al. 2014; Bratman et al. 2015).

Keller et al. (2015) found that while simulation and immersive experiences of nature are both effective for stress relief, immersive experiences are more effective. Immersion in nature also restores peoples ability to concentrate enhancing their productivity. For example, people vacationing in the wilderness, return with a heightened ability to concentrate than people who did not take a time off or visited a city instead (Hartig et al. 1991 in Kaplan 1995). This supports the concept of forest bathing a practice to enhance our emotional wellbeing (Korpela et al. 2014) or to aid the recovery processes of patients (Mao et al. 2017).

The effects of Indoor plants

The reviewed literature shows a strong correlation between the presence or availability of indoor plants and enhances productivity. This is mostly analysed through study subject's task performance with tasks varying from proofreading, shape recognition tasks, sorting tasks, memory assessments, etcetera. Their conclusions include:

1. Higher rate of correct responses completing (Shibata & Suzuki 2002)
2. Indoor plants lead to 12 % faster reaction time while completing a shape recognition task. (Lohr & Pearson-mims 2000)
3. Introducing plants within a classroom can increase 11-14% performance in math and science (Daly et al. 2010).
4. 12% higher consideration of long-term goals (Matsuoka 2010)
5. 5% better attention capacity leading to better performance in high concentration tasks – i.e. proofreading, multitasking (Raanaas et al. 2011)

The increased productivity or performance listed above is partly influenced by plants presence leading to 15-35% lower rates of sick leave and symptoms within the classroom and office settings (Fjeld et al. 1998; Fjeld 2002; Smith et al. 2011) and their ability to reduce tiredness or fatigue (Fjeld et al. 1998). In particular, Raanaas et al. (2011) found that the restorative power of indoor plants is equivalent to a 5-minute break. This can lead to positive experiences of the space and higher levels of satisfaction (Dravigne et al. 2008). It has been theorised that these positive effects are related to the presence of fractal patterns in nature and the ability of these patterns to restore our attention, however, in experimental settings, plants outperform other sources of fractal patterns -i.e. geometrical forms (Shibata & Suzuki 2004; Berto 2005) where sometimes, these patterns result intrusive to the ability of the subject to perform the desired task (Shibata & Suzuki 2004). Furthermore, the positive effect of indoor plants is still present, though to a lower extent, even when the plants are not within sight (Shibata & Suzuki 2002; Shibata & Suzuki 2001 in Bringslimark et al. 2009). The extent of the benefit is mediated by external factors such as how long the individual spends indoors, their individual preferences, the health of the plant amongst others.

The importance of natural views

Access to windows with natural views can also have significant positive impacts on our physical and mental wellbeing. For instance, in hospital settings, it has been registered that window views are linked to faster recovery rates and an increase in pain tolerance - measured by the length of hospital stay and pain-killers intake by patients (Lohr & Pearson-mims 2000; Park & Mattson 2008).

The benefits are not exclusive to people in recovery but can be perceived across the whole population. For example, students with access to natural views express 20% higher levels of self-discipline (Taylor et al. 2002) and a higher academic performance (Matsuoka 2010) than students without an access to nature views. Meanwhile, nurses with access to a break room with natural view show higher levels of wellbeing, and self-perceived energy levels or restfulness (Nejati et al. 2016). The access to natural views also led to the consideration of long-term goals such as higher rates of students graduating high school and with college plans (Matsuoka 2010). In this study, the authors compared different high schools and categorised the 'naturalness' level of the views from various windows. When comparing different types of view, both studies highlighted that the more natural the view, the higher the benefits (Matsuoka 2010; Nejati et al. 2016). Furthermore, a sense of being able to leave the built environment and 'step outside' through a balcony showed the highest levels of restorative potential for the nurses rating higher in restorative potential than the presence of indoor plants (Nejati et al. 2016).

Vegetation shifting perception of a space

Using vegetation also improves the perception of a space (Aitken & Palmer 1989). White & Gatersleben (2011) found that, when comparing different looks for the same house, houses with green facades were considered more beautiful.

Meanwhile, when plants are placed inside a room, space is regarded as more attractive and this indirectly reduces stress perception of the space (Larsen & Adams 1998; Dijkstra et al. 2008; Smith et al. 2011). These conceptual shifts attributed to plants is the direct mechanism that leads to the increased productivity of office workers, students and academic staff and the faster recovery rates that have been observed in hospital and recovery centre patients (see sections above for specific references). The effect is stronger when the people who use the space participated in the decoration decisions by choosing what to include and where (Knight & Haslam 2010).

Vegetation leading to social connection

Nielsen & Hansen (2007) found that accessibility to green spaces was correlated to lower obesity index. This effect was not linked to the amount of physical activity performed by the individuals, thus, they propose that the character of the neighbourhood is conducive to outdoor activities. This suggests that the presence of outdoor and indoor greenery can indirectly enhance mental health by leading to higher social cohesion – reduced loneliness (Maas et al. 2009). This concept is supported by Wei et al. (2014) and Zang et al. (2017) who found that people feeling more connected to nature and with a higher well-being showed pro-social behaviour. The participants in this category were described as more empathic, agreeable, friendly and willing to help.

The relationship between nature exposure and pro-sociality was stronger when the participants were exposed to 'beautiful' nature (Zang et al. 2017). The health status of the plant is a key component of defining 'beauty'. For example, a streetscape affected by a plague was negatively correlated with the long-term life satisfaction of the residents (Jones 2017).

Factors that enhance the benefit

How much we benefit from the experience is mediated by three key factors: the length of the nature-based experience (Hartig et al. 1991 in Kaplan 1996), the nature of the activity - passive vs. active (Korpela et al. 2017) and our individual preferences as determined by our identity (Hartig et al. 2003; Morton et al. 2017). For instance, Tyrväinen et al. (2014) found that visitors to an urban park and a woodland were equally recovered from stress after their visit, however the visitors of the woodland self-perceived the visit as more restorative than the remaining participants. In opposition, Gilchrist et al. (2015) found that longer visits to a natural environment are more effective for long-term satisfaction than shorter but more frequent visits to urban parks.

In urban settings, quantity and quality of greenery are also important. The quality of the green space was found to be stronger in mediating an increase in perceived general physical and mental health; the ability of the green space to aid in stress reduction and conducive to social activities were the stronger mediators of this relationship (De Vries et al. 2013). Thus, spaces that are restorative, reduce stress and are conducive to social interaction (i.e. gardening) are regarded as 'quality' spaces. In terms of vegetation choices, a study on a green roof highlighted a bias for vegetation of higher structural complexity and species diversity as the preferred characteristics for space (Lee et al. 2014).

How many plants should I use?

Through the reviewed literature, the number of plants used in each study varied widely from a single plant to 30 plants in a single room. When considering plants per floor area ratio, the relationship varied from 1-14 plants per $10m^2$. To the best of our knowledge, no research to date has been conducted to develop a general guideline of the ideal number of plants to promote the highest amount of well-being. That type of study would be highly complex it is known that the benefits are tightly correlated to our identity and the number of plants required to saturate well-being will vary based on personal preferences.

Responding to BASEline research, we know that there is a directional trend of 'plants increase well-being' under an assumption that more plants will produce higher benefits until the number of plants reaches the limit of what the individual likes. Thus, as a baseline, we began by simulating what is the maximum number of plants that would be practical to introduce to space and recommend 1 medium-sized plant every $2m^2$. This recommendation is very similar to the one proposed for air-quality with the difference that it focuses more emphasis on the size of the plant allowing the number of plants to change in response to the structural complexity of the plants introduced into said space. Finally, we acknowledge that this number should vary in response to personal preferences and encourage people to introduce plants based on their personal preferences adding less or more plants that the recommended baseline.

Conclusion

Wellbeing is a complex concept determined by a wide range of personal characteristics and the location. In alignment with salutogenesis theory, wellbeing can be promoted if people believe that they understand a problem (comprehensibility), feel that they have resources available (manageability), and possess internal (i.e. motivation) and external (i.e. social cohesion) mechanisms to cope. Thus, we conclude that the inclusion of plants at indoor and outdoor spaces is an effective strategy to promote well-being. Either present at an outdoor or an indoor setting, plants are able to significantly aid the stress recovery process and generate a sense of mental restoration. Indirectly, their air quality purification ability

This response can be explained by the innate emotional affiliation we have with nature; a deep-rooted connection that has evolved throughout human history (Biophilia). There is a general trend that higher quantity of plants will enhance well-being by providing sensorial stimuli that remind us of that deep connection with nature; however, there is currently no available research that has successfully explored the relationship between the number of plants and well-being. Exploring this topic is challenging as well-being effects are affected by personal preferences. One common thread is the requirement of 'high' quality green spaces. In general terms, it should possess a high level of **structural complexity** and **diversity**, while remaining coherent. From the literature the following directional trends emerged:

a. A plant is better than a picture of a plant, which is better than a plant colour, which is better than nothing.
b. More plants are better than fewer plants.
c. More diverse is better than less diverse (the relationship between different plants, shapes) but dependent of a cohesive look. Organised complexity.
d. Green foliage is better than other foliage.
e. Flowers are better than no flowers.
f. Air quality-plant relationship are valid for the app in indoor spaces, well-being-plant relationships are valid for outdoor and indoor spaces.

References

Abbass, O.A., Sailor, D.J. & Gall, E.T., 2017. Effectiveness of indoor plants for passive removal of indoor ozone. *Building and Environment*, 119, pp.62–70. Available at: http://dx.doi.org/10.1016/j.buildenv.2017.04.007.

Aitken, J.E. & Palmer, R.D., 1989. *The Use of Plants to Promote Warmth and Caring in a Business Environment*,

Aydogan, A. & Montoya, L.D., 2011. Formaldehyde removal by common indoor plant species and various growing media. *Atmospheric Environment*, 45(16), pp.2675–2682. Available at: http://dx.doi.org/10.1016/j.atmosenv.2011.02.062.

Becker, C.M., Glascoff, M.A. & Felts, W.M., 2010. Salutogenesis 30 Years Later: Where do we go from here? Origins of Salutogenesis. *Electronic Journal of Health Education*, 13, pp.25–32.

Beckett, P., Smith, F. & Taylor, G., 2000. Particulate pollution capture by urban trees: effect of species and windspeed. *Global Change Biology*, 6, pp.995–1003.

Berto, R., 2005. Exposure to restorative environments helps restore attentional capacity. *Journal of Environmental Psychology*, 25, pp.249–259.

Bratman, G.N. et al., 2015. Landscape and Urban Planning The benefits of nature experience: Improved affect and cognition. *Landscape and Urban Planning*, 138, pp.41–50. Available at: http://dx.doi.org/10.1016/j.landurbplan.2015.02.005.

Bringslimark, T., Hartig, T. & Patil, G.G., 2009. The psychological benefits of indoor plants: A critical review of the experimental literature. *Journal of Environmental Psychology*, 29(4), pp.422–433. Available at: http://dx.doi.org/10.1016/j.jenvp.2009.05.001.

Chen, J. et al., 2017. Indoor simulations reveal differences among plant species in capturing particulate matter. *PloS one*, (May), pp.1–22.

Daly, J., Burchett, M. & Torpy, F., 2010. *Plants in the classroom can improve student performance*, Sydney.

Dijkstra, K., Pieterse, M.E. & Pruyn, A., 2008. Stress-reducing effects of indoor plants in the built healthcare environment: The mediating role of perceived attractiveness. *Preventive Medicine*, 47, pp.279–283.

Dravigne, A. et al., 2008. The Effect of Live Plants and Window Views of Green Spaces on Employee Perceptions of Job Satisfaction. *HortScience*, 43(1), pp.183–187.

Dzierzanowski, K. et al., 2011. Deposition of Particulate Mater of Different size fractions on leaf surfaces and in waxes. *International Journal of Phytoremediation*, 13, pp.1037–1046.

Engelhart, S. et al., 2009. Childhood hypersensitivity pneumonitis associated with fungal contamination of indoor hydroponics. *International Journal of Hygiene and Environmental Health*, 212, pp.18–20.

Faber Taylor, A., Kuo, F.E. & Sullivan, W.C., 2002. Views of Nature and Self-discipline: Evidence from inner city Children. *Journal of Environmental Psychology*, 22, pp.49–63.

Fjeld, T. et al., 1998. The Effect of Indoor Foliage Plants on Health and Discomfort Symptoms among Office Workers. *Indoor Built Environment*, 7, pp.204–209.

Fjeld, T., 2002. *The effect of plants and artificial day-light on the well-being and health of office* *workers, school children and health care personnel*,

Fujii, S. et al., 2005. Effects on air pollutant removal by plant absorption and adsorption. *Building and Environment*, 40, pp.105–112.

Gawronska, H. & Bakera, B., 2015. Phytoremediation of particulate matter from indoor air by Chlorophytum comosum L . plants. *Air Quality Atmospheric Health*, 8, pp.265–272.

Georgieva, E. et al., 2005. Comparative analysis of the volatiles from flowers and leaves of three Gentiana species. *Biochemical Systematics and Ecology*, 33, pp.938–947.

Gilchrist, K., Brown, C. & Montarzino, A., 2015. Workplace settings and wellbeing : Greenspace use and views contribute to employee wellbeing at peri-urban business sites. *Landscape and Urban Planning*, 138, pp.32–40. Available at: http://dx.doi.org/10.1016/j.landurbplan.2015.02.004.

Girman, J., Phillips, T. & Levin, H., 2009. Critical Review: How Well Do House Plants Perform as Indoor Air Cleaners? In *Proceedings of Healthy Buildings 2009*. pp. 9–12.

Guieysse, B. et al., 2008. Biological treatment of indoor air for VOC removal: Potential and challenges. *Biotechnology Advances*, 26, pp.398–410.

Hartig, T. et al., 2014. Nature and Health. *Annual Review of Public Health*, 35, pp.207–28.

Hartig, T. et al., 2003. Tracking restoration in natural and urban field settings. *Journal of Enviromental Psychology*, 23, pp.109–123.

Ikei, H. et al., 2014. The physiological and psychological relaxing effects of viewing rose flowers in office workers. *Journal of Physiological Anthropology*, 33(6), pp.1–5.

Irga, P.J., Torpy, F.R. & Burchett, M.D., 2013. Can hydroculture be used to enhance the performance of indoor plants for the removal of air pollutants? *Atmospheric Environment*, 77, pp.267–271. Available at: http://dx.doi.org/10.1016/j.atmosenv.2013.04.078.

Jones, B.A., 2017. Invasive Species Impacts on Human Well-being Using the Life Satisfaction Index. *Ecological Economics*, 134, pp.250–257. Available at: http://dx.doi.org/10.1016/j.ecolecon.2017.01.002.

Kaplan, S., 1995. The Restorative benefits of Nature: Toward an Integrative Framework. *Journal of Environmental Psychology*, (1995), pp.169–182.

Keller, A.A., Fournier, E. & Fox, J., 2015. Minimizing impacts of land use change on ecosystem services using multi-criteria heuristic analysis. *Journal of Environmental Management*, 156, pp.23–30. Available at: http://dx.doi.org/10.1016/j.jenvman.2015.03.017.

Kim, K.J. et al., 2008. Efficiency of Volatile Formaldehyde Removal by Indoor Plants: Contribution of Aerial Plant Parts versus the Root Zone. *Journal of the American Society of Horticulture Science*, 133(4), pp.521–526.

Kim, K.J. et al., 2010. Variation in Formaldehyde Removal Efficiency among Indoor Plant Species. *Horticulture Science*, 45(10), pp.1489–1495.

Kim, K.J. et al., 2014. Volatile Toluene and Xylene Removal Efficiency of Foliage Plants as Affected by Top to Root Zone Size. *HortScience*, 49(2), pp.230–234.

Knight, C. & Haslam, S.A., 2010. The Relative Merits of Lean, Enriched, and Empowered Offices: An Experimental Examination of the Impact of Workspace Management Strategies on Well-Being and Productivity. *Journal of Experimental Psychology: Applied*, 16(2), pp.158–172.

Korpela, K. et al., 2014. Analyzing the mediators between nature-based outdoor recreation and emotional well-being. *Journal of Environmental Psychology*, 37, pp.1–7. Available at: http://dx.doi.org/10.1016/j.jenvp.2013.11.003.

Korpela, K. et al., 2017. Landscape and Urban Planning Nature at home and at work: Naturally good? Links between window views, indoor plants, outdoor activities and employee well-being over one year. *Landscape and Urban Planning*, 160, pp.38–47. Available at: http://dx.doi.org/10.1016/j.landurbplan.2016.12.005.

Larsen, L. & Adams, J., 1998. Plants in the Workplace: The Effects of Plant Density of Productivity, Attitudes and Perceptions. *Environment and Behavior*, pp.261–281.

Lee, K.E. et al., 2014. Living roof preference is influenced by plant characteristics and diversity. *Landscape and Urban Planning*, 122, pp.152–159. Available at: http://dx.doi.org/10.1016/j.landurbplan.2013.09.011.

Lin, M., Katul, G.G. & Khlystov, A., 2012. A branch scale analytical model for predicting the vegetation collection ef fi ciency of ultra fi ne particles. *Atmospheric Environment*, 51, pp.293–302.

Liu, Y. et al., 2007. Which ornamental plant species effectively remove benzene from indoor air ? *Atmospheric Environment*, 41, pp.650–654.

Lohr, V.I. & Pearson-mims, C.H., 2000. Physical Discomfort may be reduced in the presence of Interior Plants. *Hortechnology*, 10(1), pp.53–58.

Lohr, V.I. & Pearson-Mims, C.H., 1996. Particulate Matter Accumulation on Horizontal surfaces in Interiors: Influence of foliage plants. *Atmospheric Environment*, 30(14), pp.2565–2568.

Maas, J. et al., 2009. Social contacts as a possible mechanism behind the relation between green space and health. *Health & Place*, 15, pp.586–595.

Makido, Y., Dhakal, S. & Yamagata, Y., 2012. Relationship between urban form and CO2 emissions: Evidence from fifty Japanese cities. *Urban Climate*, 2, pp.55–67. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2212095512000132 [Accessed January 15, 2015].

Mao, G. et al., 2017. The Salutary Influence of Forest Bathing on Elderly Patients with Chronic Heart Failure. *Environmental Research and Public Health Public Health*, 14, p.368.

Matsuoka, R.H., 2010. Landscape and Urban Planning Student performance and high school landscapes: Examining the links. *Landscape and Urban Planning*, 97(4), pp.273–282. Available at: http://dx.doi.org/10.1016/j.landurbplan.2010.06.011.

Meyer, H.W. et al., 2005. Molds in floor dust and building-related symptoms among adolescent school children: a problem for boys only? *Indoor Air*, 15(Suppl 10), pp.17–24.

Morton, T.A., van der Bles, A.M. & Haslam, S.A., 2017. Seeing our self reflected in the world around us: The role of identity in making (natural) environments restorative. *Journal of Environmental Psychology*, 49, pp.65–77. Available at: http://dx.doi.org/10.1016/j.jenvp.2016.11.002.

Nejati, A., Rodiek, S. & Shepley, M., 2016. Landscape and Urban Planning Using visual simulation to evaluate restorative qualities of access to nature in hospital staff break areas. *Landscape and Urban Planning*, 148, pp.132–138. Available at: http://dx.doi.org/10.1016/j.landurbplan.2015.12.012.

Nielsen, T.S. & Hansen, K.B., 2007. Do green areas affect health ? Results from a Danish survey on the use of green areas and health indicators. *Health and Place*, 13, pp.839–850.

Orwell, R. et al., 2006. The potted-plant microcosm substantially reduces indoor air voc pollution: ii.

laboratory study. *Water, Air and Soil Pollution*, 177, pp.59–80.

Orwell, R.L. et al., 2004. Removal of Benzene by Indoor plant/substrate microcosm and implications for Air Quality. *Water, Air and Soil Pollution*, 157, pp.193–207.

Ottelé, M., Bohemen, H.D. Van & Fraaij, A.L.A., 2010. Quantifying the deposition of particulate matter on climber vegetation on living walls. *Ecological Engineering*, 36, pp.154–162.

Papinchak, H.L. et al., 2009. Effectiveness of Houseplants in Reducing the Indoor Air Pollutant Ozone. *Hortechnology*, 19(June), pp.286–290.

Park, S.-A. et al., 2010. Comparison of Indoor CO2 Removal Capability of Five Foliage Plants by Photosynthesis. *Kor. J. Hort. Sci. Technol.*, 28(5), pp.864–870.

Park, S. & Mattson, R.H., 2008. Effects of Flowering and Foliage Plants in Hospital Rooms on Patients Recovering from Abdominal Surgery. *Hortechnology*, 4(October-December), pp.563–568.

Pegas, P.N. et al., 2017. Could Houseplants Improve Indoor air Quality in Schools ? , 7394(May).

Pegas, P.N. et al., 2012. Could Houseplants Improve Indoor air Quality in Schools? *Journal of Toxicology and Environmental Health*, A(April 2017), pp.1–27.

Pipal, A.S. et al., 2012. Role of Plants in Removing Indoor Air Pollutants. *Chemestry of Phytopotentials: Health, Energy and Environmental Perspectives*, (January), pp.5–8.

Przybysz, A. et al., 2014. Science of the Total Environment Accumulation of particulate matter and trace elements on vegetation as affected by pollution level, rainfall and the passage of time. *Science of the Total Environment*, 481, pp.360–369.

Raanaas, R.K. et al., 2011. Benefits of indoor plants on attention capacity in an office setting. , 31.

Sæbø, A. et al., 2012. Plant species differences in particulate matter accumulation on leaf surfaces. *Science of the Total Environment*, 427–428, pp.347–354. Available at: http://dx.doi.org/10.1016/j.scitotenv.2012.03.084.

Shaughnessy, R.J. et al., 1994. Effectiveness of Portable Indoor Air Cleaners: Sensory Testing Results. *Indoor Air*, 4, pp.179–188.

Shibata, S. & Suzuki, N., 2004. Effects of an indoor plant on creative task performance and mood. *Scandinavian Journal of Psychology*, 45, pp.373–381.

Shibata, S. & Suzuki, N., 2002. Effects of the Foliage Plant on task Performance and Mood. *Journal of Enviromental Psychology*, 22, pp.265–272.

Smith, A., Tucker, M. & Pitt, M., 2011. Healthy, productive workplaces: towards a case for interior plantscaping. *Facilities*, 29, pp.209–223.

Sriprapat, W. et al., 2014. Ecotoxicology and Environmental Safety Uptake of toluene and ethylbenzene by plants: Removal of volatile indoor air contaminants. *Ecotoxicology and Environmental Safety*, 102, pp.147–151. Available at: http://dx.doi.org/10.1016/j.ecoenv.2014.01.032.

Stickley, T. & Hoare, M., 2015. A review of the concept of Salutogenesis and its significance for promoting mental health recovery through participatory arts. *Journal of Applied Arts and Health*, 6(1), pp.63–75.

Takeda, M. et al., 2009. Relationship between sick building syndrome and indoor environmental factors in newly built Japanese dwellings. *Int Arch Occup Environ Health*, 82, pp.583–593.

Tani, A. & Hewitt, C.N., 2009. Uptake of Aldehydes and Ketones at Typical Indoor Concentrations by Houseplants. *Environmental Science & Technology*, 43(21), pp.8338–8343.

Tarran, J., Torpy, F. & Burchett, M., 2007. Use of Living Pot-plants to clense Indoor Air – Research Review. In *Proceedings of Sixth International Conference on Indoor Air Quality, Ventilation & Energy Conservation in Buildings – Sustainable Built Environment*. Sendai, Japan, pp. 249–256.

Terzaghi, E. et al., 2013. Forest Filter Effect: Role of leaves in capturing/releasing air particulate matter and its associated PAHs. *Atmospheric Environment*, 74, pp.378–384. Available at: http://dx.doi.org/10.1016/j.atmosenv.2013.04.013.

Tiwary, A. et al., 2009. An integrated tool to assess the role of new planting in PM 10 capture and the human health benefits : A case study in London. *Environmental Pollution*, 157(10), pp.2645–2653. Available at: http://dx.doi.org/10.1016/j.envpol.2009.05.005.

Torpy, F.R. et al., 2013. Do indoor plants contribute to the aeromycota in city buildings ? *Aerobiologia*, 29, pp.321–331.

Torpy, F.R., Irga, P. & Burchett, M.D., 2013. Characterization and Biostimulation of benzene biodegradation in the potting-mix of indoor plants. *Applied Horticulture*, 15(November), pp.10–15.

Torpy, F.R., Irga, P.J. & Burchett, M.D., 2014. Urban Forestry & Urban Greening Profiling indoor plants for the amelioration of high CO 2 concentrations. *Urban Forestry & Urban Greening*, 13(2), pp.227–233. Available at: http://dx.doi.org/10.1016/j.ufug.2013.12.004.

Treesubsuntorn, C. & Thiravetyan, P., 2012. Removal of benzene from indoor air by Dracaena sanderiana: Effect of wax and stomata. *Atmospheric Environment*, 57, pp.317–321. Available at: http://dx.doi.org/10.1016/j.atmosenv.2012.04.016.

Tyrväinen, L. et al., 2014. The influence of urban green environments on stress relief measures: A field experiment. *Journal of Environmental Psychology*, 38, pp.1–9. Available at: http://dx.doi.org/10.1016/j.jenvp.2013.12.005.

Ugrekhelidze, D., Korte, F. & Kvesitadze, G., 1997. Uptake and Transformation of Benzene and Toluene by Plant Leaves. *Ecotoxicology and Environmental Safety*, 29, pp.24–29.

Ulrich, R.S. et al., 1991. Sress recovery during exposure to Natural and Urban Environments. *Journal of Environmental Psychology*, 11, pp.201–230.

De Vries, S. et al., 2013. Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Social Science & Medicine*, 94, pp.26–33. Available at: http://dx.doi.org/10.1016/j.socscimed.2013.06.030.

Wania, A. et al., 2012. Analysing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations. *Journal of Environmental Management*, 94(1), pp.91–101. Available at: http://dx.doi.org/10.1016/j.jenvman.2011.06.036.

Wei, J. et al., 2014. An occasion for unselfing: Beautiful nature leads to prosociality. *Journal of Environmental Psychology*, 37, pp.61–72. Available at: http://dx.doi.org/10.1016/j.jenvp.2013.11.008.

Wetzel, T.A. & Doucette, W.J., 2015. Plant leaves as indoor air passive samplers for volatile organic compounds (VOCs). *Chemosphere*, 122, pp.32–37. Available at: http://dx.doi.org/10.1016/j.chemosphere.2014.10.065.

White, E. V & Gatersleben, B., 2011. Greenery on residential buildings: Does it affect preferences and perceptions of beauty? *Journal of Environmental Psychology*, 31(1), pp.89–98. Available at:

http://dx.doi.org/10.1016/j.jenvp.2010.11.002.

Wolverton, B.C., Johnson, A. & Bounds, K., 1989. Landscape Plants for Indoor Air Pollution Abatement. , pp.1–27.

Wolverton, B.C., McDonald, R.C. & Watkins, E.A., 1984. Foliage Plants for Removing Indoor Air Pollutants from Energy-efficient Homes. *Economic Botany*, 38(2), pp.224–228.

Wolverton, B.C. & Wolverton, J., 1993. Plants and Soil Microorganisms: Removal of Formaldehyde, Xylene and Ammonia from the Indoor Environment. *Journal of the Mississippi Academy of Sciences*, 38(2), pp.11–15.

Wood, B.R.A. et al., 2002. Potted-plant/growth media interactions and capacities for removal of volatiles from indoor air. *The Journal of Horticultural Science and Biotechnology*, 77(1), pp.120–129.

Wood, R.A. et al., 2006. The potted-plant microcosm substantially reduces indoor air voc pollution: I. office field-study. *Water, Air and Soil Pollution*, 175, pp.163–180.

Xu, Z., Wang, L. & Hou, H., 2011. Formaldehyde removal by potted plant – soil systems. *Journal of Hazardous Materials*, 192(1), pp.314–318. Available at: http://dx.doi.org/10.1016/j.jhazmat.2011.05.020.

Yang, D.S. et al., 2009. Screening Indoor Plants for Volatile Organic Pollutant Removal Efficiency. *HortScience*, 44(5), pp.1377–1381.

Zang, Z. et al., 2017. Impact of landscape patterns on ecological vulnerability and ecosystem service values: An empirical analysis of Yancheng Nature Reserve in China. *Ecological Indicators*, 72, pp.142–152.

Appendix 2: Organic compound removal rate meta-analysis

The literature review, by itself, was unable to respond some of the key questions required to develop the plant-life balance index. Thus, we performed a meta-analisis to re-analyse a large number of studies of varied scope.

Methodology

To enhance the understanding of the literature, we took data from relevant research papers for further analysis, we specifically performed an air quality meta-analysis. This analysis compiled all reported plant species, contaminant removal rates, and air volume for studies that utilised a sealed air chamber; when available, we also compiled plant's leaf area, aesthetic category (i.e. foliage, fern, woody), and authors' categorization of the plant as a high, medium, or low contaminant removalist. Studies that did not provide enough information were eliminated from the aggregation. this includes experiments conducted outside of sealed chambers, compounds with insufficient data for analysis (i.e. NOx, aldehyde, ozone), articles reporting aeromycota and PM.

The removal rates reported on the selected 15 studies were compiled and re-analysed. These studies specifically reported removal rates for CO_2, formaldehyde and VOC. More specifically, VOC studied and included in the meta-analysis are benzene, toluene, octane, TCE and xylene. To ensure that the studies were comparable to each other, we converted the units to **μg/hour/m³ of air/m² of leaf area**. To convert the study units, we ran the database in R Version 3.4.1. This information was used to explore the relationship between removal rates of different contaminants and the relationship between plant size and removal rate. For the meta-analysis, we developed a python program in Jupiter Notebook.

Categorising plants based on the efficiendy of removal

There are three key studies to determine removal efficiency category. Yang et al. (2009) who measured the removal rate of 28 different species for five different VOC; Liu et al. (2007) who measured benzene removal rates of 73 species, and Kim et al. (2008) who measured the effectivity of formaldehyde removal of 86 different indoor plant species.These studies were used to establish the range of values that determine the efficiency category. In particular, the first study provided a categorization of the plants based on their efficiency to remove total VOC. These values were validated with the second study. The removal efficiency category for formaldehyde was established by the reviewers (Marco Amati, Dominique Hes and Cris Hernandez) utilising the third study as an example. Unfortunatley, to the best of our knowledge, no study has determined said parameters.

Results

A total of 130 species have been screened for at least one of the aforementioned contaminants. Table 1 indicates the number of species screened for each contaminant with 99 species emerging from two key studies: Yang et al. (2009) who measured the removal rate of 28 different species for five different VOC and Kim et al. (2008) who measured the effectivity of formaldehyde removal of 86 different indoor plant species.

Table 1: Number of species screened for each contaminant in the meta-analysis

Contaminant	Formaldehyde	Benzene	Toluene	TCE	Octane	Xylene	CO_2
No. of species	91	51	36	34	28	28	10

Relationship between the removal rates of different contaminants.

In 2009, Yang & Son completed a plant screening of VOC removal efficiency utilising 28 indoor plants. They quantified the removal rates for benzene, toluene, octane, TCE, and a-pinene and, based on these, calculated the total VOC (TVOC) removal efficiency. Lastly, the authors assigned each plant a removal efficiency category based on the TVOC removed by it. Based on this data, we explored the relationship, if any, between the plant's removal ability for different contaminants (Figure 1). We found that there is a clear relationship between most of the assessed VOC. In particular, toluene, benzene and TCE show a linear relationship. The hue of colour on Figure 1 represents the removal efficiency category assigned by Yang & Son (2009). Aside from octane, the categories for TVOC removal efficiency also match with the removal efficiency of individual contaminants. These categories were also compared with the results reported by Liu et al. (2007) study on benzene removal and was found to match.

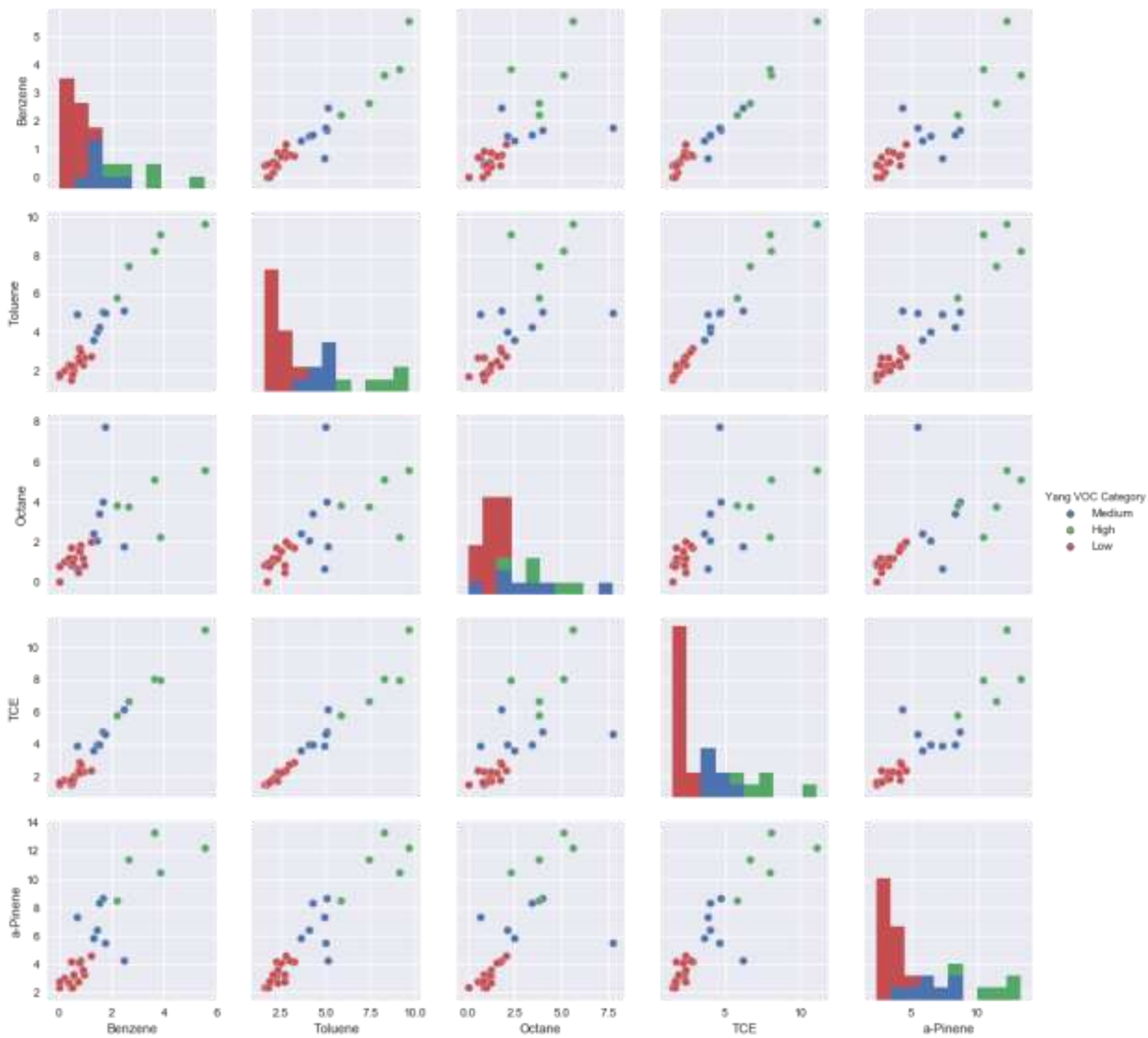


Figure 1: VOC removal efficiency based on Yang & Son 2009

We then identified species that had also been assessed for formaldehyde finding fourteen species in common (Figure 2). There seems to be no correlation between the removal efficiency of TVOC and formaldehyde, indicating the need for a second removal category based on formaldehyde. This observation was also supported individual assessments exploring the relationship of formaldehyde with benzene (23 species), toluene (22 species) and TCE (20 species).

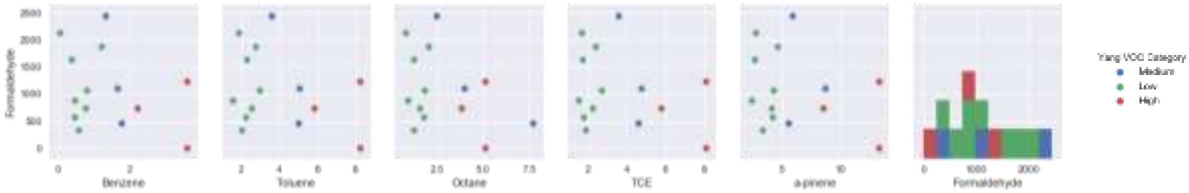


Figure 2: Comparison between Formaldehyde and VOC removal rates.

Based on the visualisations above, there is an indication that toluene, benzene, TCE and a-pinene can be used as a proxy for TVOC removal. The range of values for each category is available on Table 2. Similarly, the research team proposed a series of ranges to categorise formaldehyde given that there is no research available that has set these parameters. Further research will be needed to ensure the validity of these categories. These ranges were used to create the table in Appendix 3.

Table 2: Range of removal rates for each removal efficiency category

Contaminant used as proxy	Null	Low	Medium	High	Units for removal rate value:
Toluene	0	0.1-3.5	3.5-5.5	5.5+	**µg /hour /m³ of air /m² of leaf area.**
Bencene	0	0.1-0.6	0.6-2.5	2.5+	
TCE	0	0.1-3.0	3.0-5.5	5.5+	
a-pinene	0	0.1-4.5	4.5-8.5	8.5+	
Formaldehyde	0	0.01-2500	2500-5500	5500+	

Relationship between removal rates and plant size.

Delimiting size in small, medium and large plants

All data was standarised on removal rate per m² of leaf area, however, depending on the size of the plant, you may require a single or multiple plants to gather one m² of leaves. To assess the relationship between removal rates and size, we began by estimating the planting density based on the leaf area reported by the authors. We then created a series of ranges for the plantation density to determine the size of the plant (Figure 3).

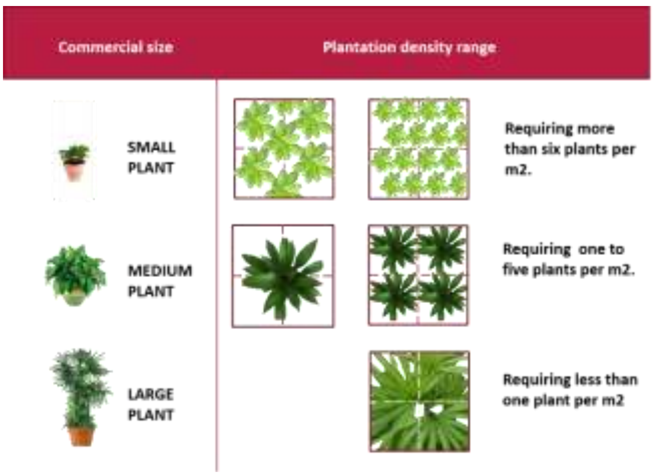
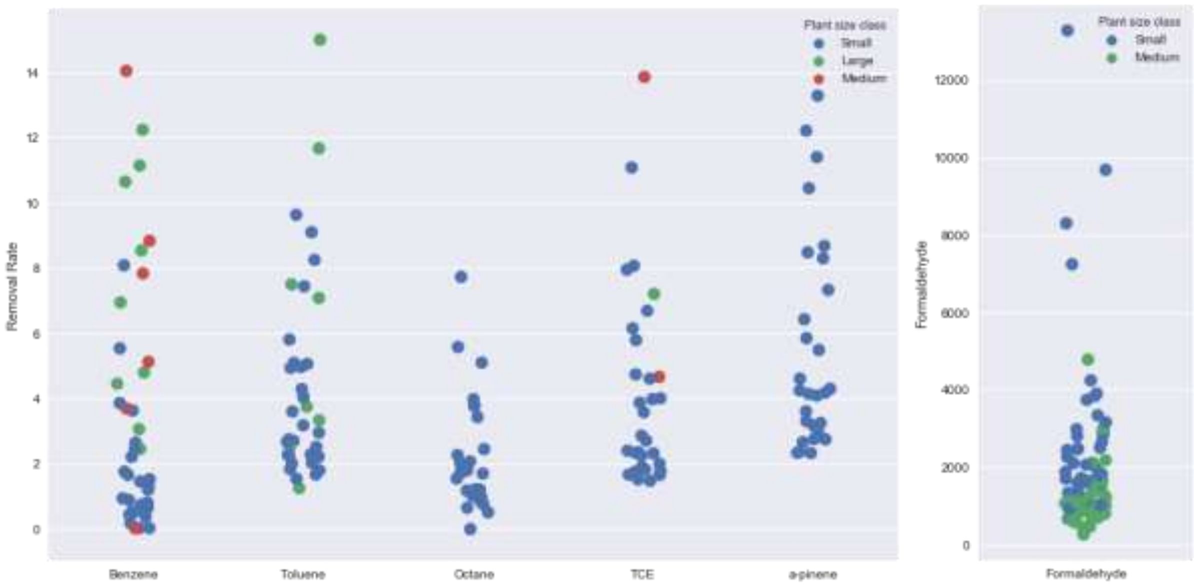


Figure 3: Plantation density and size category

Size analysis

The simplified plant-life balance index proposed for the app development utilises size as a proxy for estimating the number of plants required to gain the maximum air quality benefit possible. Based on the knowledge gathered to this day, research studies evidence that such relationship does not exist; that is, the size of the plant does not influence the contaminant removal efficiency for any of the assessed contaminants (Figure 4). In fact, evidence in the literature review suggests that the number of microorganisms in the soil system (Wolverton & Wolverton 1993; Orwell et al. 2004, 2006; Wood et al. 2006) and the number of stomata on the leaves (Ugrekhelidze et al. 1997; Treesubsuntorn & Thiravetyan 2012) are more important in determining the ability of a plant system to remove noxious compounds from the air.



51 Observations	36 observations	28 observations	34 Observations	28 observations		91 Observations

Figure 4: relationship between contaminant removal rate and plant size

Removal rate per species

Figure 5 shows the plant species that have been screened for VOC. It indicates the removal rate as indicated by researchers and for each contaminant. It also highlights the overlap that exists between the species with 28 plants with measurments for five different contaminants and the remaining species screened for one or two contaminants.

Conclusion

Emerging from this meta-analysis we can conclude:

1) The relationship between different contaminants:
    a. There is no relationship between VOC and formaldehyde removal rates
    b. There is a linear relationship between the removal rates of different VOC.
    c. In order of preference, the following VOC removal rates can be used as proxy of TVOC: toluene, benzene, TCE and xylene.
    d. Further research is needed to perform a meta-analysis on a wider range of contaminants.
2) When comparing different species, there is no correlation between their size and their CO2, formaldehyde or their VOC removal ability.

Figure 5: Removal rates per species per contaminant.

Appendix 3: List of plants per removal category

The table below comprises a list of 130 plants which have been screened for either VOC or Formaldehyde removal potential. To establish VOC removal category this research draws upon research by Yang & Son (2009). In the case of formaldehyde, the meta-analysis highlighted the need for a separate category to rate its removal rate, however, to the best of our knowledge, no standard exists. Some of these plants while delivering benefits for air pollution removal may be categorised as weeds depending on the State in Australia. Users are advised to check the weed status of the plant before using.

Species	Common Name	VOC Rr Efficiency	Formaldehyde Rr Efficiency
Adiantum capillusveneris	Southern maiden hair	Unknown	Low
Aglaonema modestum	Silver evergreen	Unknown	Low
Aglaonema 'Silver Queen'	Chinese evergreen	High	Unknown
Anthurium andreanum	Flamingo flower	Medium	Low
Arachnoides aristata	Pricky shield fern	Unknown	Low
Araucaria heterophylla	Norfork island pine	Unknown	Low
Ardisia crenata	Corlberry	Unknown	Medium
Ardisia pusilla	Japanese fatsia	Unknown	Low
Asparagus densiflorus 'Sprengeri'		High	Unknown
Aspidistra elatior 'Milky Way'		Low	Unknown
Asplenium nidus	Bird's neste fern	Unknown	Low
Botrychium ternatum	Hammock fern	Unknown	Medium
Calathea makoyana	Brain plant	Unknown	Low
Calathea roseopicata		Low	Unknown
Camellia japonica	Common camellia	Unknown	Low
Camellia sinensis	Tea plant	Unknown	Low
Chamaecyparis obtusa	Hinoki false cypres	Unknown	Low
Chrysalidocarpus lutescens	Areca palm	Unknown	Low
Chrysanthemum morifolium	Pot mum	High	Low
Citrus medica var. sarcodactylis		High	Unknown
Clivia miniate	Kaffir lily	Unknown	Low
Clorophytum bichetii	St. Bernanrd lily	Unknown	Low
Clorophytum comosum 'Fire Flash'		Low	Unknown
Codiaeum variegatum		Low	Unknown
Coniogramme japonica	Bamboo fern	Unknown	Low
Crassula portulacea		High	Unknown
Cupressus macrocarpa	Monterey cypress	Unknown	Low
Cycas revoluta	Sago palm	Unknown	Low
Cymbidium Golden Elf		High	Unknown
Cyrtomium caryotideum		Unknown	Low
Cyrtomium falcatum	Holly fern	Unknown	Low

Davallia mariesii	Hare's foot fern	Unknown	High
Species	Common Name	VOC Rr Efficiency	Formaldehyde Rr Efficiency
Dendranthema morifolium		High	Unknown
Dendropanax morbifera	Korean dendropanax	Unknown	Medium
Dieffenbachia amoena	Giant dumbeane	High	Low
Dieffenbachia seguine		Low	Unknown
Dizygotheca elegantissima	False aralia	Unknown	Low
Dracena concinna	Red marginated dracena	Unknown	Low
Dracena deremensis 'Janet Craig'	Janet Craig	High	Unknown
Dracena deremensis 'Variegata'	Striped dracena	Medium	Low
Dracena deremensis 'Warneckei'	Warneckei	High	Low
Dracena fragans	Corn plant	High	Low
Dracena fragans	Corn plant	Low	Low
Dracena 'Janet Craig'	Janet Craig	High	Unknown
Dracena marginata	Marginata	High	Unknown
Dracena massangeana	Mass cane	High	Low
Dryopteris nipponensis		Unknown	Low
Elaeocarpus sylvestris		Unknown	Low
Epipremnum aureum	Golden Pothos	High	Low
Epipremnum aureum	Golden Pothos	Low	Unknown
Eugenia myrtifolia		Unknown	Low
Eurya emarginata		Unknown	Low
Fatsia japonica	Japanese fatsia	High	Unknown
Fatsia japonica	Japanese fatsia	Low	Unknown
Fatsia japonica	Japanese fatsia	Unknown	Low
Ficus benjamina	Weeping fig	Medium	Unknown
Ficus benjamina	Weeping fig	Unknown	Low
Ficus elastic	Rubber plant	Low	Unknown
Ficus elastic	Rubber plant	Unknown	Low
Ficus microcarpa var. fuyuensis		High	Unknown
Fittonia argyroneura		Medium	Unknown
Gardenia jasminoides	Cape jasmine	Unknown	Low
Gerbera jamesonii	Gerbera daisy	High	Low
Guzmania sp.		Medium	Unknown
Haemaria discolor	Jewel orcihd	Unknown	Low
Hedera helix	English ivy	High	Low
Hemigraphis alternata 'Exotica'		High	Unknown
Howea belmoreana	Belmore palm	Low	Low
Howea forsteriana		High	Unknown
Hoya carnosa 'Variegata'	Porcelain flower	High	Low

Hydrangea macrophylla		High	Unknown
Species	Common Name	VOC Rr Efficiency	Formaldehyde Rr Efficiency
Ilex crenata	Box leaved holly	Unknown	Low
Jasminum polyanthum	White jasmine	Unknown	Low
Jasminum sambac	Arabian jasmine	Unknown	Low
Laurus nobilis	Bay tree	Unknown	Medium
Lavandula spp.	Sweet lavender	Unknown	Medium
Ligustrum japonicum	Wax leaf privet	Unknown	Low
Maranta leuconeura		Low	Unknown
Mentha guaveolens	Apple mint	Unknown	Low
Microlepia strigosa	Lace fern	Unknown	Medium
Nandina domestica	Heavenly bamboo	Unknown	Medium
Nephrolepsis exaltata 'Bostoniensis'	Boston Fern	High	Unknown
Osmunda japonica	Japanese royal fern	Unknown	High
Pachira aquatica	Guiana chestnut	Unknown	Low
Pelargonium graveolens		Low	Unknown
Pelargonium spp.	Geranium	Unknown	Medium
Peperomia clusiifolia		Low	Unknown
Peperomia clusiifolia	Red edge peperomia	Unknown	Low
Philodendron scandens		Low	Unknown
Philodendron selloum	Lace tree philodendron	Unknown	Low
Phoenix roebelenii	Pigmy date palm	Unknown	Low
Pittosporum tobira	Japanese pittosporum	Unknown	Low
Polypodium formosanum		Unknown	High
Polyscias balfouriana	Balfour aralia	Unknown	Low
Polyscias fruticosa		Medium	Unknown
Polystichum tripteron		Unknown	Low
Psidium guajava	Guava	Unknown	Medium
Pteris dispar		Unknown	Medium
Pteris ensiformis	Silver leaf fern	Unknown	Low
Pteris multifida	Spider fern	Unknown	Medium
Quercus acuta	Japanese evergreen oak	Unknown	Low
Quercus glauca		Unknown	Low
Raphiolepis umbellata	Yeddo hawthorn	Unknown	Low
Rhapis excelsa	Lady palm	Unknown	Medium
Rosmarinus officinalis	Rosemary	Unknown	Low
Saintpaulia ionantha	African violet	Unknown	Low
Sanseveria trifasciata	Snake plant	Medium	Low
Sansevieria laurentii		High	Unknown
Schefflera arboricola 'Variegata'	Umbrella tree	Low	Low
Schefflera elegantissima		Medium	Unknown

Scindapsus aureus	Golden pothos	High	Unknown
Species	Common Name	VOC Rr Efficiency	Formaldehyde Rr Efficiency
Selaginella tamariscina	Spikemoss	Unknown	High
Serissa foetida	Japanese serissa	Unknown	Low
Spathiphyllum 'Petite'	Peace Lily	High	Unknown
Spathiphyllum 'Sensation'	Peace Lily	High	Unknown
Spathiphyllum 'Supreme'	Peace Lily	High	Unknown
Spathiphyllum wallisii	Peace Lily	Low	Low
Stauntonia hexaphylla	Japanese stauton vine	Unknown	Low
Syngonium podophyllum	Arrowhead vine	Low	Low
Thelypteris acuminate		Unknown	Low
Thelypteris decursivepinnata		Unknown	Low
Thelypteris esquirolii		Unknown	Low
Thelypteris torresiana		Unknown	Low
Tillandsia cyanea	Pink quill	Unknown	Low
Trachelospermum asiaticum	Chinese ivy	Unknown	Low
Tradescantia pallida 'Purpurea'		High	Unknown
Vibrunum awabuki	Sweet viburnum	Unknown	Low
Zamia pumila	Jamaica sago tree	Unknown	Medium
Zamioculcas zamiifolia	ZZ plant Aroid palm	Unknown	Low

Appendix 4: Benefit table – for literature review

Reference	Benefit	Relevant pattern	Scope (Outdoor / Indoor)	Scale (landscape vs small)	Subjects of study	Methodology	Exposure to stimuli (type and duration)	Plant description	Outcome measures	Findings
(Torpy et al. 2013)	Air Quality (Aeromycota)	healthy plants do not contribute to unhealthy mould spore concentrations	Indoor	Small	55 office spaces in two 7 storey buildings in Sydney CBD	3 sample days for each season. (1) one peace lily in 200mm pot, (2) 3 peace lilies in 200mm pots, (3) one dracena in 300mm pot, (4) 3 dracenas in 300mm pots, (5) no-plant control. Air samples collected 50 cm above the floor.	Two study periods: Autumn and Spring	Self-watering pots, dead leaves removed.	the surface area of the potting mix, fungi composition, quantity, indoor vs. outdoor	We found that indoor plant presence made no significant difference to either indoor mould spore counts or their species composition. No seasonal differences occurred between autumn and spring samples. Indoor spore loads were significantly lower than outdoor levels, demonstrating the efficiency of the heating, ventilation and air conditioning systems in the buildings sampled. Neither the number of plants nor the species of plant used had an influence on spore loads; however, variations of those two variables offer the potential for further studies.
(Tani & Hewitt 2009)	Air Quality (Aldehydes, Ketones)	Plants uptake and metabolise VOC	Indoor	Small	Peace lily (*Spathiphyllum clevelandii*), Golden pothos (*Epipremnum aureum*)	Four plants of two different species were acclimated to indoor air and then exposed to VOC (ketones and aldehydes); {fumigated within a transparent bag 20-40L}.	Acclimatisation for 1 month.	50-70cm tall with a leaf area 60-150cm2. Two plant species.	CO_2 concentrations, Aldehydes, ketones concentration.	Plants remove C2-C6 aldehydes and C4-C6 ketones. C3 Ketone is not removed by the plant. Concentration uptake ranges from 7-19mmol/m2s and from 2-7mmol/m2s. VOCs are metabolised by the leaf. It takes 20 min to reach 99% equilibrium
(Irga et al. 2013)	Air Quality [Benzene and CO_2]	Hydroculture removes more CO_2 than potting mix but less benzene.	Indoor	Small	*Syngonium podophyllum*	Within sealed chamber. The target species was grown in (1) conventional potting mix (2) hydro culture, (3) control. Tested at two light levels. Starting conditions 1000ppmv CO_2 and 25ppmv benzene	Plants were grown 133 days before testing. (23.0+-1`C). Changes in photosynthesis measured at 1 min intervals for 40 min. every day for 1 week	Potting mix: composted hardwood sawdust, bark fines and coarse river (2:2:1), Hydroculture: mixture of perlite and grade 3 vermiculite (2:1)	Leaf area, fresh and dry weight, VOC removal rate and CO_2 absorption	It can remove up to 61% (based on 1000ppmv) within 40 min. Hydroculture medium removes more CO_2 but slightly less benzene than a conventional potting mix. Both growth strategies remove 25ppmv benzene in 7 days. Control groups show some removal activity during the first 2 or 3 days but quickly decrease afterwards.
(Wood et al. 2002)	Air Quality [Benzene and n-hexane]	Potted plants as a biofilter. Root microorganisms are key.	Indoor	Small	3 plant species: *Howea forsteriana*, *Spathiphyllum wallissii, Dracena deremensis*,	Sealed chamber with one potted, hydroponic or control. Tests at two doses: (a) Dose of 25 ppm benzene or 100 ppm n-hexane. (b) 50 ppm benzene or 150 ppm n-hexane	Measured over 48 hours before topping up VOCs over 24 h intervals. Test duration for 25 days. N-hexane test duration for up to 40 days.	well-established, 12-month-old plants, 0.3-0.4 m tall. In a 150mm pot with standard, well-aerated potting mix, composed of hardwood sawdust, composted bark fines and coarse river sand 2:2:1	Leaf area, VOC removal rate compared between control and hydroponic treatment	VOC's removal comes from the microorganisms of the growth medium. The plant's role is sustaining a healthy population of root microorganisms, transferring the plants to hydroponic system yields same results, All plants able to purify chamber from benzene in 5 days. Approximately 1-2 days faster in hydroponic conditions. 40% reduction of n-hexane in hydroponic conditions. Purified chamber within 10 days for potted plants.
(Wolverton et al. 1989)	Air Quality [Benzene and trichloroethylene]	A pot with plants removes more than control	Indoor	Small	8 common indoor plants	Within sealed chamber plants were monitored	concentrations of 325–2190 µgm−3		VOC Removal rate	the 8 plants tested could remove benzene by 47–90% in 24 h compared to 5–10% in the control tests, and that the rhizosphere zone was the most effective area for removal

(Orwell et al. 2004)	Air Quality [Benzene]		Indoor	Small	7 potted plants	In static test-chambers, high airborne doses of benzene were removed within 24 h, once the response had been stimulated ('induced') by an initial dose. Removal rates per pot ranged from 12–27 ppm d−1 (40 to 88 mg m−3 d−1) (2.5 to 5 times the Australian maximum allowable occupational level). Rates were maintained in light or dark and rose about linearly with increased dose. Rate comparisons were also made on other plant parameters. Micro-organisms of the potting mix rhizosphere were shown to be the main agents of removal.	24hrs rotations over 40 days	Howea forsteriana (Kentia Palm), Spathiphyllum floribundum, var. Petite (Peace Lily), Dracaena deremensis var. Janet Craig (D. 'Janet Craig'), ,S. floribundum, var. Sensation (S. 'Sensation'), Dracaena D. marginata, Epipremnum aureum (Devil's Ivy); and actinophylla var. Amate (Queensland Umbrella Tree)	removal of benzene	The results also showed that, under these test conditions, in these species, it was the rhizosphere micro-organisms in the potting mix that were the significant direct agents of VOC removal. Unused potting mix alone was also found to display some VOC removal activity, although at significantly lower rates than with the plant present, and prone to exhaustion within 2 wks. with plant 40 days in the dark VOC level absorption stayed consistent and increased if the dose was increased.
(Liu et al. 2007)	Air Quality [Benzene]	Benzene removal capacity depends on the species. The single highly efficient plant could clean 10m2 room in 1-5 hours.	Indoor	Small	73 common indoor plants for the first test. The 10 most efficient species chosen for deeper analysis	Within a controlled greenhouse, plants were fumigated 8 hours per day (air containing 150+-6.7ppb benzene) Greenhouse conditions: 25+-10`C, 55+-15% humidity	8 hours per day/X days	Only a few species specified	Benzene levels, Absorption rates, Soil effects.	23 did not alter benzene concentration in air, 13 species removed between 0.1–9.99% of benzene in contaminated air, 17 species removed 10–20% and 17 species removed 20–40%, 3 removed 60–80% of benzene in the experimental air. Assuming a 10m2 room (2.55m high) with 150ppb of benzene [Totalling 13.26mg benzene] and that plants maintain absorption rate the air would be purified in 0.44 h for *Crassula portulacea* [leaf area 1m2], 1.08 h for *H. macrophylla,* 1.19 h for *Cymbidium* Golden Elf, 5.39 h for *Dracaena deremensis* variegate
(Torpy et al. 2013b)	Air Quality [Benzene]	Microorganisms in root system can be bio-stimulated to enhance removal			Spathiphyllum wallisii 'Petite',	Biostimulation of benzene removal was observed within seven chambers (0.216m3). Purified with 70% ethanol solution prior to testing. Chambers injected with 25 ppm of Benzene (5 times higher than recommended levels in Australia); air samples were taken every 24 hours for 14 days. Two top-up injections introduced when 90% of benzene had been removed from the chamber. (1) no bio-stimulant (2) after bio-stimulation	Chamber was cleaned and aired for 24 hours prior to testing. Up to 14 days.	The potting mix contained 5% coco peat: 80% composted pine bark: 15% basalt crusher dust; and small amounts of aglime, dolomite and superphosphate	community level physiological profile (CLPP) - measured using optical density microbes in Biolog EcoPlates. Before and after biostimulation.	removal rates of about 15%, bacterial activity associated with removal of indoor airborne benzene, and could be applied to increase VOC biodegradation rates, augmenting the uses of indoor plants in improving building environmental quality, Bio-stimulated microorganisms remove benzene twice as fast as non bio-stimulated.
(Treesubsuntorn & Thiravetyan 2012)	Air Quality [Benzene]	More stomata increases uptake of benzene	Indoor	Small	8 common indoor plants	Plants were prepared stomata accounted, crude wax and photosynthesis analysed, plants were fumigated with benzene, plants for desiccated and benzene extracted.	72 hrs	Chamaedorea seifrizii, Scindapsus aureus, Sansevieria trifasciata, Philodendron domesticum, Ixoraebarbata craib, Monster acuminate, Epipremnum aureum, and Dracaena sanderiana	Benzene removal	8 ornamental plants, it was found that Dracaena sanderiana had the highest benzene removal efficiency. In a long-term study, 4 cycles of benzene were studied under both 24 h dark and 24 h light conditions. From the 2nd to 4th cycle, benzene uptake by plants under 24 h light condition had a higher intensity than under 24 h dark conditions, and the close of D. sanderiana stomata was found only in 24 h dark condition. At the final cycle, D. sanderiana still survived, and benzene uptake continued.

(Fujii et al. 2005)	Air Quality [CO_2 and NOx absorption and adsorption]	Ideal temperatures between 28-35`C	Indoor	Small	A single species: Conferta - (Juniperus conferta part)	(1) Conferta, (2) Ivy, (3) Control, empty pot. Humidity and temperature rise prevented by a cooling system. CO_2 was raised to 3500-4000 ppm, NOx raised to 1000ppm higher than atmospheric levels.	Results reported as absorption through a day. Unclear if monitored daily for a year or a single day each season.	Placed a Conferta within a sealed chamber (0.5x0.8x0.12 m3)	Illumination intensity, humidity, temperature, CO_2 levels (using non-diffusion infrared absorption method), NOx and NO_2- (using chemiluminescence method)	Removal effects by plants should be considered for absorption and adsorption (from leaves surface). CO2 absorption varies from minimal (0.001mg/min – 27.5mg/day) during winter to up to 0.08 m/min (145.6 mg/day) during late summer. In autumn 77.4 mg/day, Photosynthesis activity is at its highest in late summer. Absorption influence by illuminance of the chamber during daytime and temperature at night time. Temperature between 30-35`C has best results, above temperatures significantly decrease absorption velocity to 0.03 or lower. One day's CO_2 absorption/ emission (approx. 800cm2 leaf area) was 1022.1mg CO_2/day in spring, 1901.1 in early summer, 145.4 in late summer, 252.2 in autumn, and 168.0 in winter.
(Park et al. 2010). Original text in Korean (information for this table from abstract, tables and figures)	Air Quality [CO_2]	Larger total leaf area = more CO_2 removed	Indoor	Small	5 foliage plant species	Within a sealed chamber (size unspecified), each plant was treated with 500 or 1000 ppm CO2. And with different illuminance levels.	Day and night	Planted in 18cm diameter pots.	Photosynthesis rate (based on CO2 concentration before/after). Substrate type, leaf size, light intensity	Plants exposed to higher CO2 concentrations and higher light intensity (200nmol*m2/s) had faster photosynthesis rate. Plants with larger leaves showed higher photosynthetic rate than plants with smaller leaves Released CO2 released at night is very low compared to absorption rates. Substrate difference (peat moss and hydro ball medium) had no effect on the photosynthetic rate.
(Torpy et al. 2014)	Air Quality [CO_2]	More light, higher photosynthesis rate (higher uptake of CO_2).	Indoor	small	8 common indoor plants	Within the sealed chamber, CO_2 set at 400ppm. Illumination gradually increased at intervals of 0,2,10,20,50,100,200,350,1000, 2000 nmol*PAR/m/s. Plants acclimatised to low and high light levels. After experiment plants were dissected and dry weight taken. Co_2 Levels at 1000 ppm	Plants acclimatised for 93 days prior to the experiment. Tests carried out 9:00-5:00. 40 min to complete a test per plant. Light test maintained 3-5 min to stabilise photosynthesis.	12 months of age. Grown in standard potting mixes of hardwood, sawdust, composted bark fines and coarse river sand (2:2:1) in 20 cm diameter pots	Amount of CO_2 absorbed the reduction in parts per million in the chamber (photosynthesis rate), also Table Of plants for square metre needed (leaf area), fresh and dry weight, Light intensity. - See light and CO_2 plant list	This study profiled the CO_2 removal potential of eight common indoor plant species, acclimatised to both indoor and glasshouse lighting levels, to develop baseline data to facilitate the development of indoor plant installations to improve indoor air quality by reducing excess CO_2 concentrations. The results indicate that, with the appropriate choiceofindoorplant species and a targeted increase in plant specific lighting, plantscape installations could be developed to remove a proportion of indoor CO_2 - For best plants see light and CO_2 plant list
(Kim et al. 2008)	Air Quality [Formaldehyde]	Purification ability has a plateau, Root systems responsible for purification properties of the plant.	Indoor	Small	2 plants: Fatsia japonica and Ficus benjamina	Aerial vs. root ball comparison of formaldehyde uptake (2 nL/L) in 1m3 airtight chamber (half the volume of personal breathing space). Control experiment sterilising root system.	5 hours during the day and 5 hours at night.	2-year-old plants. F. benjamina in 19cm diameter pot. (Leaf area 0.11m2), F. japonica in 15 cm pot. (Leaf area 0.13m2), Single main stem, height 40-55 cm.	Formaldehyde removal per total leaf area, time	Initial uptake very fast but slows down as formaldehyde concentration in chamber reduces. Both plants reduce 80% of formaldehyde concentration in a chamber within 5 hours of the experiment. Up to 90% of formaldehyde removal is a result of microorganisms living in the root system. The aerial part of the plant: removes formaldehyde during the day (effect negligible at night), Root zone: removes formaldehyde day and night. Sterile roots reduce efficiency 80%
(Kim et al. 2010)	Air Quality [Formaldehyde]	Ferns are the most effective formaldehyde removals	Indoor	Small	86 species from five groups. Experiments conducted in Korea.	Species divided into five groups and tested in a chamber (90X90X90). Rooms with controlled temperature, light and humidity. Plants compared to a no-plant control. Three replicates.	Measures were taken every hour for five hours.	ferns (20), woody foliage plants (20), herbaceous foliage plants (20), Korean native plants (20), herbs (6).	Formaldehyde concentration per leaf area, time	9 species removed 95% of formaldehyde in 5 hours (osmunda japonica, selaginella tamaricina, davallia mariesii, polypodium formosanum, psidium guajava, lavandula spp, Pteris dispar, Pteris multifida, Pelargonium spp). Plants separated into excellent (over 1.2mg/m3 per cm2 of leaf), intermediate or poor (under 0.6) formaldehyde removal. Ferns were the most effective.

(Aydogan & Montoya 2011)	Air Quality [Formaldehyde]	Substrate type is important (at least in hydroponics)	Indoor	Small	Four common interior species in the hydroponic growing mediums:	Within test chamber (61X30.5X40.6cm). Temperature condition maintained. Artificial lighting (in 12h cycles) outside the chamber. Three growing mediums compared to assess the ability of plants to remove formaldehyde.	Plants acclimated to the interior for 2 weeks and 24 h in a hydroponic condition prior to the testing period. Initial condition inside chamber 1.63ppm formaldehyde. Tests in triplicate (wet medium, dry medium, no plant)	Species: *Hedera helix* (23 cm) *Chrysanthemum morifolium* (38 cm), *Dieffenbachia compacta* (39 cm), *Epipremnum aureum* (27 cm). Under 1 year old. In 15 cm pots. Growing media: grow stone, expanded clay and activated carbon.	CO_2 monitor, formaldehyde levels, leaf surface area (for comparison),	In a 10 hour period: (mean from all plants). Up to 98% reduction using activated carbon (88% wet medium), Up to 62% reduction using expanded clay (26% without plants, Up to 62% reduction in grow stone (17% without plants), The most efficient plant: 95% reduction (D. compacta), followed by 94% (E. aurenum), 88% (H. Helix), 84% (C. morifolium).
(Xu et al. 2011)	Air Quality [Formaldehyde]	Exposed surface of potted plants removes more	Indoor	Small	3 plant species	Sealed chamber (40X40X60cm) pumped with formaldehyde at increasing intervals (starting at 4.0 mg/m3 and increasing 0.5mg/m3 every 5 days). Light intensity also varied, 80,160, 240 nmol/m2*s	Measurements were taken every 3 days until concentration reached the phytotoxicity for each species.	*Clorophytum xosmosum, Aloe vera, Epipremnum aureum.* All in an 18 cm pot.	Formaldehyde levels, Light intensity	Ability to clean comes from formaldehyde dehydrogenase, *C. xomosum* removes 90-95% at increasing light levels. *Aloe* removes 14,20, 53% at increasing light levels, *Epipremnum* removes 34, 56, 84%, Soil account for roughly 50% of the removal achieved by the plant-soil system. Daytime and higher light levels make it more efficient.
(Papinchak et al. 2009)	Air Quality [Ozone]		Indoor	Small	snake plant (*Sansevieria trifasciata*), spider plant (*Chlorophytum comosum*), and golden pothos (*Epipremnum aureum*),	In chambers with a simulated indoor environment. Ozone injected until a 200ppm concentration. (1) plant, separated per species (2) no-plant control. Concentrations recorded every 5, 6 minutes. Experiment replicated six times per plant species.	Until ozone levels reach under 5ppm within the chamber.	Foliage plants of low maintenance.	ozone concentration, time, leaf area, stomatal conduction,	Ozone depletion time from 38 to 120 minutes. No difference between plant species. No difference between the day or evening tests.
(Abbass et al. 2017)	Air Quality [Ozone]	1 plant per 1.8 m2 floor area.	Indoor	Small	five common indoor species. Light levels extracted from a no-window lab, residential apartment, south-facing hallway during a cloudy and sunny day, north-facing office, lamps projected to plants.	two chambers (52L). Air dehumidified and passed through an activated carbon filter to remove VOC's before being dehumidified. Air ozonated at 60 ppb (elevated but commonly found at real-world). (1) ozone removal per plant species. (2) Light. Separate tests to study the effect of light on photosynthesis rate and ozone uptake. Study replicated indoor light conditions based on measurements from 6 rooms. (3) Control. The effect of the chamber and the pot itself were also measured.	8h of ozonated air followed by 16h of non-ozonated air. The cycle repeated 3 times (64 hours in total). For light experiment12.5 hours alternating 2.5 hours with light and 2.5 hours without light.	Peace Lily, Ficus, Calathia, Dieffenbachia, Golden Pothos. Planted in 15 cm pots and passed to a glass breaker with an aluminium cover sheet to minimise interaction with ozone	ozone deposition velocities based on leaf area. Light. Ozone concentration at the inlet and outlet measured every minute.	Ozone deposition velocity increases during each repetition. With a constant supply of ozone, the deposition velocity begins 'fast' but decreases until flattening out between 1-2 hours later. Authors believe the differences between species could be attributed to leaf roughness per species. Light affects ozone removal. with plants opening their stomata when lights are turned on. Ozone removal velocity ranges from 0.9% to 9% for leaf surface area. Requiring 1 plant every1.8m2
(Przybysz et al. 2014)	Air Quality [PM & heavy metals]	cleaning leaves	both	N/A	leaves & levels of particulates & rain events	1yr old plants planted at 3 sites, soil and leave samples taken and analysed	6 months - 3 samples	evergreen species (Taxus baccata L., Hedera helix L. and Pinus sylvestris L.)	the amount of PM, pb cd, Mn, Ni, Cu, Zn,	collected on leaves, largest better, water washed off much, In this study, PM was accumulated on leaves, needles and twigs in increasing quantities in successive terms during the season. Most of the PM accumulated belonged to the large fraction size (10–100 μm) and occurred on the surface of foliage. The highest amounts of PM and TE accumulated on the foliage of Pinus sylvestris L. grown at the most polluted site and protected from direct precipitation.Our trials with simulated rainfall clearly showed that it removed a considerable proportion of deposited PM from the foliage, mostly of the large size fraction, but not of smallest.

(Chen et al. 2017)	Air Quality [PM between 0.01-50nm]		Indoor	Small	5 tree species	Tree planted in a growth chamber. CO_2 kept at 350ppm, relative humidity at 50%, illumination simulating daylight patterns, and temperature variation (11-25C) emulating May in Beijing. (1) aerosol particles of (NH4)2SO4 dispersed with an atomiser (over 106 particles/cm3). Each tree measured individually. (2) no-plant control evaluates particle deposition in the chamber. (3) atmospheric air pumped into the chamber (also a control). Three levels of air flow tested: 2L/min, 4L/min and 12L/min.	Plant given time to adapt to growth conditions. Transplanted from a forest to Beijing Forestry University. 3 weeks outside, 4-6 weeks inside a greenhouse, 1 week in growth chamber prior to testing.	Tree species: *Kerria japonica, Sophora japonica, Philadelphus pekinensis, Gleditsia sinensis, Prunus persica*. All 4 year old. Leaves washed with ionised water before experiment	particle capture rate per leaf area, time, leaf microstructure.	Leaf geometry and surface characteristics (broadness, trichomes and groves) can increase particle capture. Leaf area is not proportional to particle capture. Leaves with rough surfaces capture more than smooth surfaces. Sophora japoinica with a high deposition velocity has deep grooves and hairs on both sides of the leaf. Higher wind speed leads to higher deposition velocity. Capture depends on wind direction (aerodynamics) and it can also get saturated so, in some conditions, it can increase PM under some conditions. Vegetation can reduce particle pollution under some conditions but it is important to consider specific habitat conditions and choosing plants based on their leaf structures and arranging the plants to facilitate air flow.
(Gawronska & Bakera 2015)	Air Quality [PM]	It is not just gravity that allows plants to act as passive filters of PM.	indoor	Small	spider plants	Five different rooms: (1) a dental clinic, (2) a perfume bottling room, (3) suburban house, (4) apartment and (5) office. Rooms are not air conditioning; temperature from 18-23C. With a treatment of (a) PM captured by the plant, (b) aluminium plates used as a control surface.	2 months (Oct-Dec)	*Chlorophytum comosum* (spider plant)	Washable PM and non-washable PM	spider plants accumulate PM trapped in waxes and washable PM. More than gravity forces are involved in PM accumulation. The smallest sizes of PM are accumulated more tightly in the wax of the leaves.
(Ugrekhelidze et al. 1997)	Air Quality [Toluene, Benzene]	purification VOC removal, Benefit for younger leaves?	Indoor	Small	Spinach leaves	In a laboratory, complicated process see paper	See paper	20-day-old plants of spinach (*Spinacia oleracea*), grown under sterile conditions in Knop's nutrient medium, and with leaves and leafy shoots of mature plants: common maple *(Acer campestre*), apple (*Malus domestica*), and vine (*Vitis vinifera*).	The amount of benzene in toluene absorbed	The [1-614C]benzene and [1-14C]toluene vapours penetrate into hypostomatous leaves of *Acer campestre, Malus domestica*, and *Vitis vinifera* from both sides, whereas hydrocarbons are more intensively absorbed by the stomatiferous side and more actively intensively absorbed by the stomatiferous side and more actively taken up by young leaves. benzene vapour is taken up mainly through stomata. It should be noted that under these experimental conditions (high humidity, light), the stomata were mostly open.
(Kim et al. 2014)	Air Quality [Toluene, Xylene]	Bigger pots = bigger roots = more removal. (ideal size 4L)	Indoor	Small	Fatsia japonica and Dracena fragans.	Each plant grown in different-sized pots to provide different root zone volume ratios. Chamber (1m3) with controlled light, temperature, humidity. Three concentrations	12 hours exposed to initial concentration of 1nL/L of each gas	All pots were 20 cm high with 16 cm of soil. The with changed with a 1L, 2L, 4L, 6L, 12L pot. Grown in their pots for 6 months before testing. Leaf area = 3.6-3.9 m2 for D. fragans, 1.3-1.6m2 for F. japonica	Removal of toluene and xylene per root area, time	F. japonica twice as efficient as D. fragans in removing VOCs After 12 hours: Removal efficiency increased as root volume increased (bigger pots). Ideal pot size = 4L for both, 6L for F. japonica. Using leaf area, height or volume is not enough to predict how many plants are needed to remove VOCs
(Sriprapat et al. 2014)	Air Quality [Toluene, Xylene]	purification VOC removal	Indoor	Small	12 plants	Leaf area 0.013m2, Cultures of plants were maintained in plastic pots(0.1 0.1m2) that contained 200g of soil and coco coir (1:1) as growth media. Furthermore, the pot was covered with aluminium foil to avoid other factors such as soil and pot absorption. VOC levels tested in lab conditions	plants placed in chambers with a constant level of gas for 12 hr light-dark cycle.	see methodology	amount VOC absorbed	Of the twelve plant species examined, the highest toluene removal was found in Sansevieria trifasciata, while the ethyl benzene removal from the air was with Chlorophytumcomosum.

(Orwell et al. 2006)	Air Quality [VOC - Toluene and Xylene]	The rate of removal responds to concentration rates of VOC. More concentration, faster removal.	Indoor	Small	Spathiphyllum 'Sweet Chico' and Dracaena deremensis 'Janet Craig'	Four dosage concentrations used: (A) 0.20ppm (medium range of what usually found in office), (B) 1ppm, (C) 10ppm (two concentrations enough to cause complaints: dizziness, loss of focus) and (D) 100ppm (exceeding recommended levels of VOC in Australia). The dosage administered at beginning of day with top-ups. Three test chambers: (1) Toluene, (2) Xylene, (3) Mixture of both. For replicates per treatment.	5 days for each concentration level. Same four replicates used for the four concentration levels with a 3-day rest in between experiments. 5 to 9 VOC injections completed depending on the progressive acceleration rate of VOC removal.	Well established (12 months old), about 40cm in height and in 15 cm diameter pots. Planted in composted hardwood sawdust, composted bark fines and coarse river sand (2:2:1)	Rate of removal, leaf area, dry weight of plant and potting mix,	If concentrations rise, so do rates of removal (up to ten times faster). Removal capacity of Xylene increases with every step up in dosage. Toluene follows similar pattern until the threshold of 100ppm (is it a saturation point or another issue). Synergy interactions of microorganisms when exposed to mixtures of VOC. Authors discussion: Plants become more effective in removal. Reference to other authors indicating a shift in potted microorganisms variety responding to contaminants present in the air.
(Pegas et al. 2012)	Air Quality [VOC, PM, CO_2]	1 plant per 9.2 m achieve 15% less benzene, 30% less PM, 45% less CO_2	Indoor	Small	Single Classroom with ~25 students in a school, Poretugal. School surrounded by commercial and residential buildings and beside it a parking lot and busy road.	Nine-week air pollution monitoring Indoor and Outdoor of a classroom. (1) Classroom with 6 plants hanging from the ceiling (2) no-plant control. The room was 52.5m2 with wooden floor, water based paint on the walls and five windows. Measurements were taken simultaneously inside the classroom and the playground. Windows remain close through study period.	9 weeks in total. 3 weeks without plants and 6 weeks with potted plants. Study conducted from Feb-May 2011	Species as suggested by NASA. Dracena deremensis, Dracena marginata, Spathiphyllum. Number of plants responding to recommendation of Associated Landscape Contractors of America (1 plant per 9.2m2)	Temperature, CO, CO_2, VOC, PM and carbonyls. Relative humidity and air quality measured with portable Indoor Air IQ 610 Quality Probe and a TSI monitor.	Temperature increased by 1 degree when plants introduced in classroom; CO had no significant changes (measurements always low); 45% less CO_2 (from 2004+/-580 to 1121+/-600 ppm); total VOCs –73% (from933+/-577 to 249+/- µg/m3) - this includes a 15% reduction in benzene, 80% reduction of m+p-xylene and o-xylene, a 57% decrease of toluene, etc; carbonyls at -40% ; and PM10 –30%, compared with no-plant rooms. Three exceptions of the closed windows rule during the hottest days. Authors consider effects negligible as they represent 5% of occupancy period.
(Wolverton et al. 1984)	Air Quality [VOC]	plants absorb VOCs through leaves. 70 plants for a 167m^2 home	Indoor	Small	3 plant types	the ability of plants to remove Formaldehyde soil tested to see its impact -	6hrs 24hrs	golden pothos (Scindapsus aureus), nephthytis (Syngonium podophyllum), and spider plant (Chlorophytum elatum var. vittatum)	formaldehyde removed	A sealed, Plexiglas chamber with temperature and humidity control and illuminated externally with wide spectrum grow lights was used to evaluate the ability of golden pothos (Scindapsus aureus), nephthytis (Syngonium podophyllum), and spider plant (Chlorophytum elatum var. vittatum) to effect the removal of formaldehyde from contaminated air at initial concentrations of 15-37 ppm. Under the conditions of this study, the spider plant proved most efficient by sorbing and/or effecting the removal of up to 2.27 ug formaldehyde per cm2 leaf surface area in 6 h of exposure. The immediate application of this new botanical air-purification system should be in energy-efficient homes that have a high risk of this organic concentrating in the air, due to outgassing of urea-formaldehyde foam insulation, particle board,fabrics and various other synthetic materials. 2 pots filled with a commercial potting soil mix demonstrated that the potting soil would absorb formaldehyde from air by reducing the formaldehyde from 15 to 10 ppm in 24 h. Chlorophytume latum var. vittatum seems best at removing VOCs

(Wood et al. 2006)	Air Quality [VOC]	Total VOC higher than 100ppb stimulate efficient removal mechanisms.	Indoor	Small	60 offices (12 per treatment), across three buildings in Sydney. 14 VOC's detected within the office spaces.	Real-world experiment' in single occupant offices between 10-12m2. Weekly measurements of air quality. Ex1: Dracena plants in 300mm pots introduced (1) 3 plants, (2) 6 plants, (3) no-plant control. Ex 2: Similar procedure but with (A) no-plant control and (B) 3 and (c) 6 plants of which 1 was a different species (Spathiphyllum) in 200 mm pot. Offices sampled between 10 am and noon.	5-9 week periods for each treatment	Spathiphyllum 'Sweet Chico' and Dracaena deremensis 'Janet Craig'. Well established and 12 months old.	Air quality, CO_2, CO, relative humidity and temperature	When TVOC loads in reference offices rose above 100 ppb, large reductions, of from 50 to 75% (to <100 ppb), were found in planted offices, under all planting regimes The results indicate that air-borne TVOC levels above a threshold of about 100 ppb stimulate the graded induction of an efficient metabolic VOC-removal mechanism in the microcosm. The findings together demonstrate that potted-plants can provide an efficient, self-regulating, low-cost, sustainable, bioremediation system for indoor air pollution, which can effectively complement engineering measures to reduce indoor air pollution, and hence improve human well-being and productivity.
(Yang et al. 2009)	Air Quality [VOC]	Species diversity is needed	Indoor	Small	28 species, commonly used. Five VOC: benzene, toluene, octane, halogenated hydrocarbon [trichloroethylene (TCE)], and terpene	Individual plants placed in chambers of 10 L and exposed to 10 ppm of the five VOC		plants in 10 cm pots with a growing media of peatmoss, pine bark, and perlite/vermiculite (2:1:1, v/v)	Removal efficiency per leaf area.	Hemigraphis alternata, Hedera helix, Hoya carnosa, and Asparagus densiflorus had the highest removal efficiencies for all pollutants; Tradescantia pallida removed four of the five VOCs (i.e., benzene, toluene, TCE, and a-pinene). Fittonia argyroneura effectively removed benzene, toluene, and TCE. Ficus benjamina removed octane and a-pinene, Polyscias fruticosa, effectively removed octane. The variation in removal efficiency among species indicates that for maximum improvement of indoor air quality, multiple species are needed.
(Wetzel & Doucette 2015)	Air Quality [VOC]	plants absorb VOCs through leaves	Indoor	Small	4 plants types	To investigate the potential use of plants as indoor air VOC samples, a static headspace approach was used to examine the relationship between leaf and air concentrations, leaf lipid contents and octanol-air partition coefficients (Koa) for six VOCs and four plant species	48 hours	Four common houseplants were used in both the laboratory and residential experiments: ficus (Ficus benjamina); golden pothos (Epipremnum aureum); spider fern (Chlorophytus comsosum 'vittatum'); and Christmas cactus (Schlumbergera truncate 'harmony').	Ficus [12.4%]c Log LACF (L Kg 1) Spider [9.30%] Log LACF (L Kg 1) Pothos [6.67%] Log LACF (L Kg 1) Cactus [3.82%] Log LACF (L Kg 1)	van use leaves as VOC samplers, ficus removed most VOCs
(Rihn et al. 2015)	N/A	Reporting air quality benefits increases the probability of purchase.	N/A	N/A	Experiment conducted in Florida	Simulation: 16 scenarios to evaluate: how much are people willing to buy/when information is provided ($10.98, $12.98, $14.98). Scenarios had 5 identical plants. Participants asked to answer considering budget constraints.	30 min during the experiment. Eye-tracker first calibrated to the participant; instructions, example (using tomato plant), experiment with three target species.	three plant species: Dracena marginata, Spathiphyllum wallisii, Guzmania lingulata. All leafy species, indoor plants.	Eye-tracking (Tobii X1 Light Eye Tracker), VOC removal (low, high, no label), production practices (certified organic, organic vs. inorganic), product origin (instate, domestic, imported). Survey: sociodemographic, self-reported barriers to purchase. Purchase likelihood 1-7 scale	Things that increase the likelihood of plant purchase: plant type associated with preference (Dracena more likely to be purchased), certified organic (uncertified organic was also more likely to be purchased than not organic), Either in-state or domestic origin, high VOC removal rating, eye fixation on the highest price and domestic origin. Regarding demographic: female more likely to buy, older age, with children or pets less likely to buy. Self-reported barriers to purchase: maintenance (42%), price, space, light (~30%), feel bad if I kill it (26%), bugs (23%), allergies and toxicity for pets (17%), other (14%), lack of selection (9%), don't like it (4%), toxic for kids (3%)

Reference	Benefit	Relevant pattern	Outdoor / Indoor	Scale (landscape vs small)	Subjects of study	Methodology	Exposure to stimuli (type and duration)	Plant description	Outcome measures	Findings
Shibata & Suzuki, 2001 in (Bringslimark et al. 2009)	Well-being [Academic Performance]	You don't have to look at the plants to experience an increase in performance.	Indoor	Small	70 students; simulated office without windows	Randomised experiment with repeated measures (1) Three plants from 15 to 30 cm, not in sight when working on task, (2) plant control	5 min during task, 3 min break, 5 min during task time for a questionnaire		Key-response task, mood, fatigue, room assessment	Higher rate of correct the response in 2nd task period with plants; no significant effects on mood or fatigue; room with plants rated more silent and smaller
(Shibata & Suzuki 2002)	Well-being [Academic Performance]	Best performance when the plant is visible. Males experience greater performance gains than flames (leafy plants)	Indoor	Small	146 students (83 males) - study conducted in Japan	Students complete a task within a room with covered windows with (1) a plant 145 cm in front of the subject, (2) a plant 145cm to the side of the subject or (3) control. Two tasks: word association (30 words for 20 items - 73 subjects) or card sorting task (180 cards in alphabetical order - 72 subjects)	During test (~30 min): 5 min wait time (alone in room), mood evaluation (baseline), (10 min), task (10 min), mood evaluation	Leafy plants about one meter high. (Epiremnum aureum)	Self-reported measures of mood; task-performance (no. of words generated or no. of cards sorted), room effects, and attention to plant, plant effects	Word association task: Gender is significant with female performing better in all conditions. Men show slightly fewer total words in the no-plant room -best results with the plant-in-front room where the plant was more visible; no significant effect on sorting task or change in the mood from pre- to post-task. The task was the main element affecting mood with sorting task ranked higher in 'concentration demanding' and lower on positive mood feelings; this group also didn't pay attention to the plant. Reviewer comment: sorting task subjects engage in 'flow' and pay attention only to the task at hand.
Khan, Younis, Riaz, & Abbas, 2005 in (Bringslimark et al. 2009)	Well-being [Academic Performance]		Indoor	Small	222 masters and graduate students and 28 teachers at a college	Quasi-experiment with the single post-test measure. Potted plants introduced into classrooms of the college	Class and other working time on up to and perhaps more than 30 work days		Self-reported change in indoor air quality, aesthetics, performance	Large majorities reported that the plants improved air quality, increased pleasantness, and helped improve performance
(Daly et al. 2010)	Well-being [Academic Performance]	Plants improve student performance	Indoor	Small	360 students of Year 6 or 7. 13 classes in 3 schools of Brisbane, Australia.	(1) 3 plants in treatment classroom, (2) no-plant control. Students tested before treatment (base-line) and after 6 weeks of plant presence.	6 weeks	Epipremnum aureum, Dracena fragans, Pathiphyllum sp. Between 250-300mm.	Performance in tests (spelling and math) in all three schools with the addition of reading test in one school and science in another.	Mathematics, Science & spelling scores improved 11–14%, compared with no-plant rooms (True for two of the three schools)
(Knight & Haslam 2010)	Well-being [Academic Performance]		Indoor	Small	Ex1: 112 people (31% students, 61% employed, 8% retired. within the psychology department; Ex2: 47 workers in commercial city office (35% non-management; 30% lower management; 26% middle management; 9% upper management	Productivity comparison under four treatments: (1) lean - tight control over office space, (2) enriched - decorated by a researcher with plants or art, (3) empowered - self-decorated, (4) self-decorated and redecorated by the researcher. In ex1, participants were tested in a 3.5X2m office with no windows or natural light. Temperature and light kept constant. Followed by test time. Ex. 2; same but with the addition of OCB - organisational citizen behaviour task. Carried out in 4.5X6m office	5 min alone in the room + test time	Decorations were six potted plants (35cm) and six pictures hung from the wall (80X80cm). All picture had planted.	Productivity tests included: card-sorting task and vigilance task followed by a questionnaire. Comfort, job satisfaction, Organisational identification, productivity (attention to detail, information processing, information management, organisational citizenship)	Decorated is better than lean; empowered yields best productivity results. Results attenuated if the input is overridden (condition 4). Participants inside a lean office felt disengaged and less autonomous. Indoor plant presence increases productivity, performance, job satisfaction, by >10%, measured by(28-31): > Faster times to complete computer Tasks > Creative task performance > Sorting and editing tasks > Attention capacity > Job satisfaction (on all 10 criteria tested) > Promotes good office relationships.

(Matsuoka 2010)	Well-being [Academic Performance]	The naturalness level of views increases performance.	Indoor	Large (views)	101 public highschools Infomation obtained from the principal, vice-principal of the school through interviews.	Data collected for the 2004-2005 academic year. Control variables: demographic, socioeconomic, school size, building age. Treatment: views, tree density,	Daily through the school year.	Included campus lawns, athletic fields, parking lots.	Behaviour: Crime rates, Performance: graduation rates, performance on standardised tests. Demographic, Views	Views of greater quantities of trees and shrubs from cafeteria increase merit award recipients (4.8%), graduation rates (3.7%) and college plans (12.2%) – percentages= an explanation of the variance. These schools also offered longer lunch periods (40 min). Views from classroom were not significantly associated. Regarding quality of the views: mowed grass and parking lots are associated with lower performance. Higher naturalness = higher performance.
(White & Gatersleben 2011)	Well-being [Aesthetic]	Green facades and meadow roof provide the biggest aesthetic benefit (compared to turf, sedum)	outdoor	Small	188 participants (8 interviews)	Simulation. Participants of an online survey rated a series of photographs of houses with and without vegetation (Study 1). Eight interviews examined preference and installation concerns (Study 2). A total of 24 photos. Four different houses modified in six different versions: turf roof, a sedum roof, meadow roof, ivy facade, brown roof and no-vegetation. Participants randomly assigned one type of vegetation condition.	Not specified. While participants complete online survey.	turf roof, a sedum roof, meadow roof, ivy facade, brown roof. More details not specified.	Preference, beauty, affective quality, perceived restoration.	Houses with vegetation perceived as the most beautiful and restorative. Ivy façade and meadow roof were the preferred methods for vegetation integration. Based on study 2, the biggest barrier to green roof/ facades is the maintenance requirements (15 comments) followed by installation (7 comments)
(Lee et al. 2014)	Well-being [Attention Restoration & Aesthetic]	Preference for diverse, tall, and green.	outdoor	Small	274 office workers. 74% female	Employees rated preference for 41 images. One bare roof and 40 living roof images (with different typologies)	Web survey. Approximately 20 min to complete	Life form: succulent, grassy, mixed. Height: low, tall, mixed. Colour: green, grey, red, mixed	Preference, The restorative potential of best and worst ratings. Connectedness to Nature Scale	All living-roof better (preferred) than the concrete roof. Tall, green, grassy preferred over other forms. All flowering living roof images were more preferred than the original non=flowering image. Moderate levels of diversity preferred to no diversity. They believe they would recover their attention in tall grassy vegetation (9 points mean score).
Hartig et al. (1991). in (Kaplan 1996).	Well-being [Attention Restoration & Stress]		outdoor	Large	Not specified	compared wilderness vacationers with urban vacationers and a non-vacationing control group	unknown	N/A	attention restoration assessed through proof-reading. Happiness score	Following their trip, the wilderness group showed a significant improvement in proof-reading performance, a task that is highly demanding of directed attention. By contrast, the other two groups showed a pre-test-to-post-test decline. Interestingly, the wilderness groups had the lowest overall happiness score at the post-test. At a 3-week follow-up, however, they showed the highest
(Ulrich et al. 1991)	Well-being [Attention Restoration & Stress]	stress relief	outdoor	large	120	stressful movie - colour/sound videotapes of one of six different natural and urban settings. Data concerning stress recovery during the environmental presentations were obtained from self-ratings of affective states and a battery of physiological measures: heart period, muscle tension, skin conductance and pulse transit time, a non-invasive a measure that correlates with systolic blood pressure.	10 min stress video then 10 min video - nature or urban	1 of 6 plants, rest was water, traffic, etc - Setting dominated by trees and other vegetation; some openness among trees; occasional light breeze in the background; no people or animals.	Self-rating and physical tests	nature views reduce stress and its impacts.responses to nature had a salient parasympathetic nervous system component; directional differences in cardiac responses to the natural vs urban settings, suggesting that attention/intake was higher during the natural exposures... Findings were consistent with the predictions of the psycho-evolutionary theory that restorative influences of nature involve a shift towards a more positively-toned emotional state, positive changes in physiological activity levels, and that these changes are accompanied by sustained attention/intake. Content differences in terms of natural vs human-made properties appeared decisive in accounting for the differences in recuperation and perceptual intake.

(Lohr & Pearson-Mims 1996)	Well-being [Attention Restoration & Stress]		Indoor	Small	97 people (81 students)	Students completed a task within a large windowless computer room. (1) with plants (2) decorative (3) control	while completing the task (~15 min)	17 plants distributed around the perimeter of the room. Varied sizes (25-225 cm). Specific species not specified	Shape-recognition task.	12% faster reaction time in a group with plants. BP measures consistent with lower stress reactivity and faster stress recovery Self-reported more attention.
Kim & Mattson, 2002 in (Bringslimark et al. 2009)	Well-being [Attention Restoration & Stress]	Flowering plants have higher impact in women than men	Indoor	Small	150 students; windowless bio-monitoring laboratory	Randomised experiment with repeated measures (1) Flowering geraniums, (2) Geraniums with flowers removed, (3) no-plant control	5 min following a 10 min stress induction procedure	Geranium planted in 15 cm pots. With flowers or removing flowers depending on treatment. Nine plants per room	EEG, EDA, ST, ZIPPERS	Among highly stressed women, flowering geraniums promoted faster and more complete stress recovery, as seen in declines in beta activity and EDA; flowering geraniums also evoked a greater increase in positive affect, less the decline in attentiveness in women generally; no significant effects found for men
(Hartig et al. 2003)	Well-being [Attention Restoration & Stress]	Blood pressure reduced in a room with a view. Restorative effects depend on preferences	outdoor	Large	112 normotensive students	(1) Participants were in first in a room with views and then walking in a natural reserve. (2) room with no views and then a walk through an urban environment. Also dived in (a) completing a demanding task before walk (b) no task	Tests for three months. Drive 10min sitting quietly in the room + BP reading, 50 min walk with assistant (conv. Minimised) + BP and some surveys (halfway through), 10 min final surveys back in lab	Walks in a national park. Well grated dirt road	Ambulatory blood pressure (Accutracker II monitor), emotions (Zuckerman's Inventory of Personal Reactions – attention, fear, sadness, anger, positive), Overall Happiness Scale attention (Necker Cube Pattern Control task)	Blood pressure of people immersed in nature walk is 2mmHg lower than baseline and city immersed people. People completing no-test and walking in nature had the biggest positive shift in emotion but the remaining groups had a negative change self-reporting angrier after the activity. Correlation is weaker than other studies but authors claim the approach prevents self-selection thus providing a better understanding of the influence on people with less affinity to nature.
(Kjellgren & Buhrkall 2010)	Well-being [Attention Restoration & Stress]	Nature simulations also help reduce stress but less effective than immersion in natural environment	outdoor	Large	18 people diagnosed with stress and/or burnout syndrome (from 65 people approached)	Individuals exposed to logical/thinking test to induce stress followed by relaxation period in: (1) sitting in wooden bench in the woods (2) room with single table and chair and a video	30 min after performing stress inducing task (5 min)	Photographs from the simulated environment are from the same woodland as the natural treatment.	Hospital Anxiety and Depression Scale (1-6, normal; 6-10, borderline, 10+, depression/ anxiety). Stress VAS (self-estimated stress), emotional state test, blood pressure	Natural environment resulted in a sense of tranquillity, intensified senses, connection to nature, being in the present, self-reported well-being, renewed energy, Simulated environment resulted in a sense of being cut off from nature, longing to be in 'real' nature, lack of concentration, anxiety, and some positive emotions. Stress levels (measured from physiological and self-estimated stress) reduced in both simulated and natural environment (no differences in treatment. The natural environment has more effects on well-being than the simulated environment.
(Tyrväinen et al. 2014)	Well-being [Attention Restoration & Stress]	Restores, more vital, creative, better mood	outdoor	large	77 people	Seventy-seven participants visited three different types of urban areas; a built-up city centre (as a controlled environment), an urban park, and urban woodland located in Helsinki.	20-30 mins	woodland and park.	psychological (perceived restorativeness, subjective vitality, mood, creativity) and physiological (salivary cortisol concentration), EEG, blood pressure, effects of short-term visits to urban nature environments.	No seasonal differences occurred between

(De Vries et al. 2013)	Well-being [Attention Restoration, Stress, Social Cohesion, Activity]	stress reduction, stimulating physical activity and facilitating social cohesion.	outdoor	large	1641 people from eighty neighbourhoods. Dutch cities.	Data on quantity and quality of streetscape greenery were collected by observations. Data on self-reported health and proposed mediators were obtained for adults by mail questionnaires (N ¼ 1641). Multilevel regression analyses, controlling for socio-demographic characteristics. The average quantity of public green area (i.e., square metres available per residence within a distance of500m)was used to select ten more and ten less green neighbourhoods within each city to ensure variation in the amount of green area.	eighty neighbourhoods - exposure not reported	unclear	mail questionnaire	revealed that both quantity and quality of streetscape greenery were related to perceived general health, acute health related complaints, and mental health. Relationships were generally stronger for quality than for quantity. Stress and social cohesion were the strongest mediators. Total physical activity was not a mediator. Physical activity that could be undertaken in the public space (green activity) was, but less so than stress and social cohesion. With all three mediators included in the analysis, complete mediation could statistically be proven in five out of six cases. In these analyses, the contribution of green activity was often not significant. The possibility that the effect of green activity is mediated by stress and social cohesion, rather than that it has a direct health effect, is discussed.
(Berto 2005)	Well-being [Attention Restoration]	Plants outperform geometrical (fractal) patterns	Indoor	Large	32 undergraduate students evenly distributed in sexes, treatment, and control. New set of students for each experiment	Using restorative and non-restorative images. (1) Restorative effect: Attention test followed by 25 images; then a second attention test (2) Exposed to geometrical patterns (3) time observing pictures measured	Tested within a laboratory	Restorative images tended to be mountain views, lakes, the ocean.	Perceived Restorativeness Scale: being-away, fascination, coherence, scope, and compatibility (0-10 points). Attention capacity (SART paradigm) Response: participant sensitivity, reaction times, correct response rate,	Participants exposed to restorative environments recover attention capacity. Geometrical forms don't improve attention even though they take no effort to analyse.
Raanaas et al. 2011)	Well-being [Attention Restoration]	5-minute breaks are as effective as plants in the room to increase performance	Indoor	Small	34 students. 22 women and 12 men.	(1) Office setting (3.9mX2.1mX3.6m)with four indoor plants (2) control. Attention capacity assessed three times, before beginning, after completing test and after a 5-min break	While taking the test	A mixture of foliage and flowering plants. Two flowering plants by the window (purple flowers) and two large foliage plants beside the desk.	Attention capacity assessed through reading span test, dual processing task. Comparison between baseline level and the subsequent tests.	5% better performance for plant treatment but no change after the 5-min break
(Nieuwenhuis et al. 2014)	Well-being [concentration, satisfaction, productivity]		Indoor	Medium	Office spaces (1) open plan office (4875m2) of a consultancy in London. 153 employees where 67 completed before and after survey. (2) 2 open plan offices (~360m2) from health insurance company. 177 employees with 81 completing 3 surveys. (3) 33 participants in a series of work-stations	3 field experiments: (1) open-plan office subdivided into sections with (a) at least 2 plants within sight from each work station or (b) no plants visible from work station. (2) two open-plan offices selected with three survey periods, before plants; two weeks after the plants and 3.5 months after the plants. (b) control office with no treatment) (3) participants assigned a (a)lean or (b) green condition and completed analytical, processing and intellectual tasks. Workstations	(1) 8 weeks without plants, 3 weeks with plants. (2) 5 weeks without plants, 3.5 months with plants	(1) an average of three plants per five desks. About 90cm in height. (2) one plant per 3 desks, each 90cm in height. (3) 8 plants or about 90cm in height. at least three plants within sight.	self-reported measures of perceived air quality, satisfaction concentration, performance, and (questionnaire before and after plant treatment), productivity (self-reported and objective). Study 2 productivity measured by average call time, on-hold time, the time between calls. Study 3 measures productivity by time and accuracy completing assigned task.	(1) perceived the ability to concentrate, air quality and subjective productivity increased under 'green' condition. Workplace satisfaction increased under both conditions. Multilevel analysis (on 153 employees) confirms a significant relationship between green office, concentration and perceived air quality. (2) in this condition, employees have less autonomy and a lower salary than in study 1. Satisfaction significantly higher after plant treatment (this effect did not decrease in the long-term), Air quality perceived higher. No effect for concentration or objective measures of productivity. Aditional analysis indicates 'disengagement' as a mediator for workplace satisfaction stating that a green office tends to decrease disengagement which in turn has a positive effect on satisfaction. (3) green office rated more positively than lean office; less time to complete the task but the difference in the number of errors was not significant.

(Nejati et al. 2016)	Well-being [Energy & Aesthetic]	Outdoor access through a balcony has the higher restorative capacity.	Indoor	Large (views)	958 nurses from the Academy of Medical-Surgical Nurses (AMSN), (993 responded but 35 surveys eliminated from analysis) 94% female	Simulation: Nurses evaluated the restorative level of staff break room with (1) outdoor access through a balcony, (2) outdoor view through a window, (3) a nature artwork, (4) an indoor plant, (5) control - nothing. Two staff rooms used for image simulation: a meeting room, and a break room	An online survey (~20min). Qualtrics Online Survey Software: Demographic, Work environment, break patterns, break quality, future break areas, feedback	Simulation showcased a medium sized leafy plant, a view to a city landscape with at least one tree next to window/balcony.	Restorative qualities: restfulness, refreshment in a 1-10 scale. Individual aesthetic preference,	With increasing levels of restorative effect we have; a room with no window, plants or decoration (1.45); a plant; nature artwork; window view; balcony (7.81). -based on the meeting room. Almost no difference reported between a plant and nature work (1 point). The break room had higher ratings for every condition (by approximately one point).
(Korpela et al. 2014)	Well-being [Happiness]	Longer periods of time spent in nature yields a higher benefit.	outdoor	Large	3060 surveys age 15-74	Exploring the correlation between the average time spent in nature, (1) Blue places -Lake, (2) green – forests, (3) white – snow	Varied length of stay. Survey period between 2009-2010.		Self-reported well-being, participation in nature recreation, Restoration Outcome Scale, Social company, Duration of the visit.	the longer time in nature-based recreation associated with restorative experiences the better emotional well-being perceived four weeks backwards
(Nielsen & Hansen 2007)	Well-being [Health - Obesity & Stress]	Short distances from quality green areas (including garden) are conducive to lower obesity.	outdoor	large	1200 18-80 in Denmark	A survey on access and use of green areas. It was completed by participants followed including a 'health' section gathering height and weight. This data used to calculate the obesity index BMI.	n/a	green space	Activity type in public green areas, self-reported preferences (aesthetic), distance from work, frequency of visits, obesity (BMI), stress	Access to a garden or short distances to green areas from the dwelling is associated with less stress and a lower likelihood of obesity. The number of visits cannot explain the effects of green areas on the health indicators. It is suggested that the significance of distance to green areas is mainly derived from its correlation with the character of the neighbourhood and its conduciveness to outdoor activities and ''healthy'' modes of travel. There is a geography of overweight (BMI427.5) and experienced stress in relation to distance to publicly accessible green areas—as well as access to a private garden or a shared green area at the dwelling.
Fjeld 2000 In In (Fjeld 2002)	Well-being [Health]	Plants improve health (reduce sick leave)	Indoor	Small	48 employees of a hospital radiology department; a large (80m2) windowless room with no natural light.	(1) Plants distributed through the room and light sources changed to full spectrum fluorescent light with higher lux; (2) no- intervention control	3 months during work days sampling control (Sep. – Oct 1997) followed by 3 moths of treatment (Nov - Feb 1997).	23 containers with one or more indoor foliage plants.	Health symptoms on test day (12 different symptoms in total). Info collected through Questionnaire	25.6% reduction in mean symptom score for the group; amount of symptom reduction a function of exposure time, 34% decrease in complaints amongst those who spend most of their day in the room 21% and 17% decrease in complaints in those spending 50% or 40% of their time in the room. Department head reported 15% decrease in sick leaves

(Park & Mattson 2008)	Well-being [Health]		Indoor	Small	90 patients recovering from an appendectomy (52 males and 38 females) In a hospital in Korea. Good health before diagnosis and surgical treatment.	Patients randomly assigned to a room (1) without plants; (2) with 12 potted plants of eight species of foliage and flowering plants	During hospital stay, Study conducted for 6 months (July-Jan - 2005/06)	Arrowhead vine (Syngonium podophyllum), cretan brake fern (Pteris cretica), variegated vinca (Vica minor), yellow star jasmine (Trachelospermum asiaticum), peace lily (Spathiphyllum), golden pothos (Epipremnum aureum), kentia palm (Howea forsteriana). Potted with sterile, soilles potting mix	Lenth of stay, pain medication, vital signs, self-reported pain intensity, distress, anxiety and fatigue (PPAF). State trait anxiety inventory from (STAI-Y1), environmental assessment scale (EAS), and room satisfaction.	With plants: fewer analgesic intakes, lower blood pressure, lower heart rate, pain ratings, less anxiety and fatigue. The stronger effect was for anxiety for both tests which was significantly lower in three days. Systolic blood pressure and heart rate were significantly lower both during the surgery and during the first day after the surgery. The increase in positive feelings, room satisfaction (94% stated plants as the most favoraboule thing of their room). The length of stay was not significantly different (4.64 vs 4.88 days).
(Raanaas et al. 2011)	Well-being [Health]		Indoor	Small	282 Patients of a rehabilitation centre. Two groups (1) heart surgery patients (2) pulmonary disease (i.e.asthma, chronic obstruction)	Quasi-experiment. (1) control group - 2007. (2) treatment group in 2008. 8 lung in 10 heart groups each year. Questionnaires filled every fortnight beginning 2 weeks before the program.	A 4-week program conducted from Jan-Nov in two consecutive years (2007, 2008). Each program with ~20 patients	28 pots added to common areas of the rehabilitation centre. In self-watering pots and cared for by horticulturist in the research team. Size generally 40 cm height	Self-reported measures of health, well-being and emotions	For analysis 80 heart and 64 lung patients successfully completed all questionnaires. Women expressed significantly higher satisfaction with plant treatment than men. Lung patients in plant group reported larger improvement during the program. Emotional state slightly higher in plant treatment. Physical and mental well-being reported relatively low at beginning and increases through a period in both instances. No significant differences in these study> authors explanation are that participants were mobile and exposed to a variety of treatments and activities.
(Mao et al. 2017)	Well-being [health]	Forest bathing can aid recovery from cardiovascular diseases	outdoor	Large	34 elderly patients (65-80 years old) with chronic heart failure (CHF); Hangzhou City. Good health aside from the CHF	Participants recovery process was modified to include a four day trip to (1) forest - 23 participants (2) urban control area - 10 participants. Monitored measures were taken before (baseline levels) and after the trip. Food, physical activity were controlled. Intake of alcohol, smoking or coffee was not permitted.	four days	Participants sent to Huangtan Forest Park about 160km away from the city	Mood (POMS); PM; brain natriuretic peptide, BPN; Cardiovascular disease associated factors (endothelin-1, ET-1; renin-angiotensin system, RAS; angiotensinogen, AGT; angiotensin II, ANGII; and ANGII receptor type 1 or 2 AT1 or AT2)	Patients exposed to forest showed significant reduction of brain natriuretic peptide in comparison to the city group and their own baseline. Cardiovascular disease associated factors were also significantly lower in the forest patients. Some of these effects are attributed to higher air quality of the forest (lower PM levels)
Fjield 2000 (b) In (Fjeld 2002)	Well-being [Health] & Air Quality [VOC]	Classrooms with plants have lower VOC and lower health complaints. Indoor plants don't increase fungi spores.	Indoor	Small	120 junior high school students distributed in 6 classrooms; 3 intervention and 3 ordinary classrooms	(1) 3 classrooms with plant and full spectrum fluorescent light with higher lux – 600-800 lux. (2) 3 ordinary	1 year (April 1998-1999)	5 plants in containers from 10 to 20 cm in size,	Health symptoms during the past week Room assessment Self-reported measures of air quality	Symptoms (health complaints) reduced by 9% while control group reported an increase in symptoms of 12% - total change of 21% lower mean score for health symptoms in classrooms with plants (significant lower coughing, fatigue and eye irritation). 35% lower VOC. No difference in fungi spores. Plants don't increase fungi spores. more positive evaluation of the classrooms with plants (more beautiful, brighter and more comfortable)
Park & Mattson, 2009 in (Bringslimark et al. 2009)	Well-being [Hopsital length of stay]	12 Plants in hospital lead to a lower length of stay for thyroidectomy patients.	Indoor	Small	80 female thyroidectomy patients; identical single and 6-patient rooms	Randomised experiment with repeated measures (1) 12 potted foliage and flowering plants in view from the bed, (2) no-plant control	Multiple days of postoperative recovery	spider plant (Chlorophytum comosum), and golden pothos (Epipremnum aureum),	Length of stay in hospital from the day of surgery; use of pain medication; BP, HR, respiratory rate, body temperature; self-reports of pain intensity, pain distress, fatigue, and state anxiety; room assessments	With plants, lower systolic BP and HR day of surgery and the 1st day after surgery; fewer anxiety days 1–3 of recovery; less frequent analgesic intake, less pain intensity, distress, and fatigue 3 days after surgery; rooms rated more positively. No effects of plants for the length of hospitalisation, diastolic BP, body temperature, or respiratory rate during recovery

Shoemaker et al., 1992 in (Bringslimark et al. 2009)	Well-being [Job Satisfaction]		Indoor	Small	Workers in private and open offices (number not clear, but 157 or more); only 14 completed all 3 surveys	Quasi-experiment with three measurement points. Removal of personal plants, followed by 3 months by (1) plant scaping (1–3 desk or floor-sized plants for private offices; planters and desk- or floor-sized plants for open areas), or (2) installation of artwork and then plant scaping 6.5 months later	Workdays over (1) 6.5þ 3 months or (2) 3 months		Job satisfaction, assessment of workspace, attitudes toward plants and artwork	No significant effects of plants between conditions, across measurement points or at any one measurement point, but a positive attitude toward plants
(Dravigne et al. 2008)	Well-being [Life Satisfaction]	Indoor plants improve job satisfaction and life quality.	Indoor	Small	450 employees in Texas, USA. (full-time workers)	Voluntarily responding Web-based job satisfaction survey. The survey was emailed once they agreed to participate and the study was promoted through newsletters. The participants self-selected.	N/A	No description provided	self-perceived life quality, Job satisfaction; presence, the absence of plants (or nature views), demographic info.	No statistical differences when considering age, ethnicity, salary, education levels, and position among employees who worked in offices with or without plants or window views. Males reported higher job satisfaction in the plant. The satisfaction scale (happy, content): No-window/No-plant 58%, window 60%, Plants 69%, plants/window, 82%. -- At least 10% increase in job satisfaction when indoor plants are available. Results apply to perceived life quality with only 1-3% difference for each category,
(Jones 2017)	Well-being [Life Satisfaction]	Observing dead/sick plants has negative effects on well-being.	outdoor	Large	189 counties in 15 US states (where the beetle was detected between (2005-2011).	Extracting data on life satisfaction from a countrywide annual survey in operation since 1989. - Behavioural Risk Factor Surveillance System, 'How satisfied are you with your life?' comparison, (1) before beetle, (2) during beetle	A survey conducted over the phone by an independent group. Time not specified. It is annual survey randomly to selected individuals	An invasive beetle (emerald ash borer) Native to Asia. At sufficient density, the tree (ash tree) is unable to continue functioning and dies.	Life satisfaction (happiness index), years since beetle detection, Other variables: demographics, income, age, health, etc.	People living in counties where the beetle has been detected report lower life- satisfaction. (0.127 less satisfied in a 4-point scale), Effect is lagged 5 years (consistent with tree mortality rates and reduction of environmental quality). The change could be attributed to delay of time it takes for people to subjectively perceive the change or because of modified behaviours. Effect is equivalent to a 2.3% economic contraction as reported by De Nerve et al. 2014
(Morton et al. 2017)	Well-being [Memory]	Restoration effect responds to preferences (linked to identity)	Indoor	Large (views)	Three studies in south west England: (1) 140 psychology students (116 female) (2) 109 psychology students (85 female) (3) 122 British psychology students (93 female)	Simulation: view slides of urban or nature sights within the obscure room. (1) Participants assigned an 'urban/ rural identity through the intro. (2) Participants completed memory task (stream of numbers in a computer program) before and after identity manipulation (3) Identity manipulation focused on national and personal identity. They were shown urban pictures as well as typical British and Australian nature. For every experiment participants asked to reflect on what it means to be an 'urbanite', 'ruralite', 'British', or 'personal' identity.	(1) tested on four separate occasions. 1 min per image. ~20 min to complete survey (2) memory test	(1) Nature pictures included forests and lakes. Urban pictures included city skylines, traffic, shopping malls.	(1) aspirations (intrinsic vs. extrinsic aspirations) (2) short-term memory	(1) Identity-based manipulation shifts the way people think about themselves, (1) Exposure to images corresponding to the identity increase intrinsic aspirations (you will make the world better) – important but not significant relationship, (2) short-term memory is better after exposure to images consistent with the salient identity (urban or rural). (3) Intrinsic aspirations increase when exposed to images relevant to their identity. A variety of environments (natural and urban) can have restorative potential depending on the preferences of the individual

(Shibata & Suzuki 2004)	Well-being [Mood & Creativity]	Plants have no effect on mood. Magazines have a negative effect on mood.	Indoor	Small	90 students (35 males and 55 females);	Inside a laboratory room with a curtained window, students perform a word association task in either (1) a room with a plant approximately 2.5m in front of the desk (2) a magazine stand in the same position of the plant or (3) control room. 30 students per treatment	Approx. 15 min. 5 min wait within the room, mood survey, association task (10 min), mood evaluation, room eval, task eval.	Plant was a 1.5m Massangeana Dracena	Word association task, mood (happy, tired, calm, confident, tense, concentrated, at-ease, energised, distracted), assessment of feelings about the task, their own performance, the room, and effects of the room on their performance	Women performed word association better than men across every treatment. Best performance in a room with the plant, followed by control room and lastly by magazine room. Significant differences only between plant and magazine. Mood: participants in control room felt less confident and energised; plants rated calmer and tranquil; magazines distracting.
(Lohr & Pearson-mims 2000)	Well-being [Pain Tolerance]	Room with plants perceived as cheerful. Pain tolerance higher than no plants or attractive decorations	Indoor	Small	198 adults. (mostly university students). Paid $10.00 for their participation	Within a room (3.5X6X2.4m) with white walls, subjects placed their hand in icy water under one of three treatments: (1) no-plant control, (2) decorated with colourful art and lamp (3) 4 plants. Temperature and light kept constant. Hand temperatures calibrated with 2 min immersed in 37C water, Subjects were free to remove their hands from cold water when they 'felt uncomfortable'.	10 min desensitising subject from outside stress (and completing surveys), 2 min warm water (37C), 5 minutes on icy water, 5-10 min completing post-surveys	4 different plants, species not specified. From article images: 1 succulent cascading down from the bookshelf, 2 small plants on the desk and one tall plant beside the desk.	demographic, self-evaluated ability to handle pain, room assessment (following Semantic Differential Scale), physiological response (skin temperature, blood pressure), ZIPPERS, time	Room with plants present rated as cheerful, calming and attractive. Rated higher than decorated room but not significantly different. No differences for the physiological measures on any of the three treatments. Plant rooms reported more positive emotions (carefree, friendly) (authors report variations with previous studies with Lohr (1996) and Shoemaker (1992) didn't find the variation). People in all rooms felt happy before experiment but only plant room remained happy after icy water exercise. People in Plant room were twice more likely to complete the icy water exercise.
Park et al., 2004 in (Bringslimark et al. 2009)	Well-being [Pain Tolerance]	Flowering plants lead to lower pain distress. (simulation)	Indoor	Small	90 female students; simulated hospital patient room set up in windowless biomonitoring laboratory	Randomised experiment with repeated measures (1) 10 foliage plants, (2) 3 foliage plants and 7 flowering plants, (3) no-plant control	Approx. 10 min		Pain tolerance, self-ratings of pain intensity and pain distress, EEG, EDA, ST	With foliage plants alone, longer pain tolerance, lower self-ratings of pain intensity, lower EDA compared to no-plant control; with both foliage and flowering plants, longer pain tolerance, lower self-ratings of pain intensity and pain distress than both foliage plants alone and no-plant control
(Smith et al. 2011)	Well-being [Productivity - sick leave & Aesthetic]		Indoor	Medium	151 office workers who responded both surveys and work in one of 2 open plan offices of similar size and orientation	A participant responded a survey before and after treatment: (1) office with plants (2) no plant control. Office with plants first decorated with two 1.8 Ficus, 1 Dracena, two Philodendrons, two Schindapus and 6 screen planters mixing Dracena and Calathea. Halfway through the study period, decoration changed to plants under 1m tall (similar species); additionally 39 'desk bowls' were distributed.	6 months, from February-July 2008. A change in installation occurred after 3.5 months.	the First seven plants were tall plants (1.6m) with the ficus reaching 1.8m. The screen planters had lower plants (80 cm). For second part no plant was higher than 1.05 m tall. Watering and dusting every 3 weeks.	Viability, Aesthetics, User experience of place (self-reported comfort, productivity, stress, mood, noise, creativity, motivation, plant preference, etc), short term sickness statistics	Offices with plants are more comfortable and aesthetically pleasing. The addition of plants reduced stress and health concerns. An indication that the level of plants provided for plant treatment group is close to optimum (19 large plants or 19 medium and 39 small plants). Plants in plant treatment had significantly less sick leave than the same period for the previous year while the control group increased their sick leave. The difference saving equates to approximately £45,000 accounting for the cost of plants the net gain would be £38,700. There are many other factors that can influence the results including management, light, temperature, furniture, ventilation, etc.
(Larsen & Adams 1998)	Well-being [Productivity & Social Cohesion]	more plants more perception o well-being and productivity and attractiveness of the office	Indoor	Small	81 people	no plants, some plants (10 per 130 feet office 7% volume)), lots of plants (22 and 19% of volume), give a task and give a questionnaire. A convenience sample, advert for testing font preference and paid small reimbursement.	series of timed activities 6min, 60-second x 3 and questionnaire not timed.	see methodology	productivity and attractiveness, comfort, etc.	The number of plants decreased productivity but people felt better: more comfortable as the office was more attractive. Mood evaluation showed improvement when plants are dense

(Wei et al. 2014)	Well-being [Prosocial Behaviour & Aesthetic]	More well-being = more empathy, agreeable, positive feeling.	outdoor	large	(1) 846 adult volunteers self-selected to take one or more surveys from 15-20 survey list. (2) 180 individuals (3) 112 participants (27% women). (4) 45 students	4 studies: (1) surveys relating perceptiveness, connection with nature. (2) exposed to natural images (rated by beauty) + dictator task to measure generosity (3) a different set of images and the Trust Game. (4) participants exposed to houseplants folding pamphlets for charity	The images for experiment 2 and 3 were turned into 1 min videos. Followed by surveys.	Beautiful images usually mountain landscape and water bodies. Non-beautiful more uniform vegetation. Plants used for experiment four not specified.	Perceive natural beauty, connectedness with nature Agreeableness, perspective taking, empathy, generosity, trusting, helping behaviour	The participants with self-reported higher tendency to perceive natural beauty were more agreeable, perspective taking and empathic. Beautiful plants lead to more helpful behaviour (more pamphlets folded) – Reviewers note: is it maybe measuring productivity instead of helpful behaviour?
(Aitken & Palmer 1989)	Well-being [Prosocial behaviour]	Plant decoration improves perceptions of the business visitors/clients	Indoor	Small	170 students of basic communication.	190 statements extracted from student essays on the use of plants in communication. The statements represent comments about feelings and opinions generated by the plants.	N/A	N/A	feelings, attitudes, constructed meanings attached to plants	Most students attributed meanings to plants. In general, the use of plants conveys an image of professionalism, caring and improves social connection (more personal, improves the perception of staff). Some differences responding to gender 54% of females believe it makes the office more personal (vs 30% of males).
(Zang et al. 2017)	Well-being [Prosocial Behaviour]	More well-being = more empathy, prosocial behaviour)	both		Participants were 846 adult volunteers residing in the US. Participants self-selected …	Three studies: 1) nature perception and agreeableness; 2) participants rate images in a video based on their beauty (1-7 scale beauty index); participants also asked to indicate proportion, symmetry and complexity perceived in the images. 3) different images from previous study and observations of prosocial behaviour through the Trust Game (Berg, Dickhaut, & McCabe, 1995). 4) participants exposed to house plants while completing a questionnaire of positive emotions. The experimenter then left the room and returned with origami papers to administer the measure of helping behaviour.'you can leave or want to help?	varied	images nature and house plants - 8 chosen but not which stated	Study 1: Agreeableness (44-item Big Five Inventory); Interpersonal Reactivity Index (ability to understand others), beauty nature = better prosocial behaviour, The Engagement with Natural Beauty subscale (Diessner et al., 2008) is a 4-item measure that assesses the individual's self-reported tendency to perceive natural beauty	exposure to more beautiful nature, relative to less beautiful nature, increases prosocial behavior. Study 1 yielded correlational evidence indicating that participants prone to perceiving natural beauty reported greater prosocial tendencies, as measured by agreeableness, perspective taking, and empathy. In Studies 2 and 3, exposure to more beautiful images of nature (versus less beautiful images of nature) led participants to be more generous and trusting. In Study 4, exposure to more beautiful (versus less beautiful) plants in the laboratory room led participants to exhibit increased helping behaviour.

(Maas et al. 2009)	Well-being [Reduced loneliness]	living near green space less lonely	outdoor	large	10,089	data from the national Dutch survey and a survey/interview carried out interviews were done across population range including 12-17yr olds and compared to land use database - analysed - Perceived general health, Number of health complaints (maximum 43)experienced in the last 14days, and, Self-rated propensity to psychiatric morbidity	n/a	green space	Well-being data	This study explored whether social contacts are an underlying mechanism behind the relationship between greenspace and health. We measured social contacts and health in 10,089 residents of the Netherlands and calculated the percentage of green within 1 and a 3 km radius around the postal code coordinates for each individual's address. After adjustment for socioeconomic and demographic characteristics, less green space in people's living environment coincided with feelings of loneliness and with perceived shortage of social support. Loneliness and perceived shortage of social support partly mediated the relation between green space and health. Overall, people with more green space in their living environment feel healthier, have experienced a lower number of health complaints in the last 14 days and have a lower self-rated propensity for psychiatric morbidity (Table2, models1and2).The relation between green space and the different health indicators was stronger and more consistent for the percentage of green space in a 1km radius around people's home.
Chang & Chen, 2005 in (Bringslimark et al. 2009)	Well-being [Relaxation]		Indoor	Large (views)	38 students in laboratory setting observing room simulation	Phots offered as a simulation of six different conditions: (1) no view, no plant (2) no view, yes plant, (3) view of the city, no plant, (3) city view, plant (5) nature view, no plant, (6) nature view, yes plant. Participants seated 3m away from the screen. Physiological response of the participant measured by a biofeedback device. Participants asked to use adjectives to describe the office and complete a state-anxiety inventory. A nature scenery showed at the beginning of each exercise as a baseline.	24 seconds of nature scenery (sand dunes), 5-second blank blue slide, treatment image with no limit of time to provide adjectives, 15 seconds view, no time limit to complete Anxiety inventory. Repeat for every condition.	Plant treatments show three indoor leafy plants (Cuphea signal, Aglanonema spp., Euphorbia pulcherrima). The natural view is a tree (Ficus religiosa)	Electromyography, electroencephalography, blood volume pulse, state-anxiety.	The combination of nature view and a plant engendered the lowest mean level of alpha activity as measured on the right the side of the head; lower anxiety with plants present, especially if combined with nature view. Lowered tension levels, using EEG, EMG, blood pressure readings. View better than no view. Nature view better than city view. View and plants better than the only view.
(Chen et al. 2009)	Well-being [Relaxation]	this was a study of method. But also showed people appreciated different sense aspects	outdoor	Large	178 visitors to the gardens	On-the-spot survey aided with visual photo stimuli for evaluation. The photos were taken and presented to respondents for landscape aesthetic assessment. Two part survey (1) from June to July to select photos that were later used in the main photo panels (quantitative opinion survey). (2) questionnaire survey ranking of photos by respondents was done from mid-August to mid-October.	walking in the park + question time.	photos of landscapes	the method of photo panel preparation to minimise photo quality and montage impact on results	their method removed photo bias, for this research most of 178 respondents went for stress relief

(Ikei et al. 2014)	Well-being [relaxation]		Indoor	Small	31 male office workers, Tokyo. Mean age of 37 years old.	(1) flower treatment: a flower vase with 30 pink roses placed on the desk in front of the worker (~40cm distance). (2) control condition. The room had constant temperature (~24C) and constant humidity (31.6%)	4 min.	unscented pink roses in a cylindrical glass vase	heart rate variability, pulse rate, subjective responses through a 13-point rating scale including POMS (profile of mood states).	Rose condition showed a 21% increase in parasympathetic nervous activity (high frequency of high rate variability). Self-reported measures indicate the office workers exposed to flowers are more comfortable and relaxed. They were also twice as likely to feel vigour (energetic)
(Korpela et al. 2017)	Well-being [Restorative - energy & Happiness]	Nature yields creativity and happiness. Active engagement (outdoor exercise) is more effective than passive.	Both	All	841 employees of 11 organisations within 150 m from urban parks and woodlands	Surveys questioning the characteristics of the working environment, the views, their level of activity and self-reported well-being.	Electronic questionnaire		Exposure to nature (real or artificial plants in workspace), nature views, frequency of looking, physical activity, happiness, vitality, creativity, job autonomy, social support, workload, break time, gender, age	Mixed results. Authors acknowledge 'gaps' in experiment design but highlight that in real-life scenarios "only a small portion of the variance in employee well-being might be explained by perceived nature exposure after controlling for the stability of well-being and job characteristics" Active engagement (swimming, running, cycling) in nature yield more vitality than passive (views). More time spent in garden yields higher happiness. Self-reported creativity at work predicted more frequent self-reported use of one's yard/garden. Creative people may be inclined to select green homes.
(Fjeld et al. 1998)	Well-being [Restorative - energy]	Plant presence increases energy (reduced fatigue)	Indoor	Small	51 people working in private office (10m2) and with a large window. Participants had history of 'building sickness' symptoms	(1) Treatment group: in window sill - 13 small foliage plants In the back corner - 1 large plant (175cm) with 4 smaller plants at the base. 3 months, (2) control group	A study conducted Feb 1995-Feb 1996. Fortnightly surveys completed over two periods: spring 1995 and spring 1996.	Aglaonema commutatum, Dracena deremensis, Philodendron scandens, Dracena fragans, Epipremnum aureum,	Self-reported through a questionnaire (completed each fortnight), Health symptoms during test days: fatigue, dry throat, cough.	Offices with plants had: 21% lower symptom score: (from 7.1 to 5.6 in period with plants) 23% decrease in neurophysiological symptoms in office plants - greatest reduction in fatigue 24% decrease in mucous membrane systems – greatest reduction for dry throat and cough
(Qin et al. 2013)	Well-being [Satisfaction]	colour, special and rare elicited satisfaction	outdoor	large	249 and 64 visitors	of urban green spaces on a human was evaluated with subjective questionnaires as well as physiological measurements. 249 questionnaires on subjective satisfaction evaluation were collected; in addition to 64 visitors took the measurement of physiological parameters like Electroencephalogram(EEG) and Electrocardiogram(ECG)	being in the park	different landscapes	questionnaire and EEG	interesting: "colour", "special" or "rare" resulted in more satisfaction. Questionnaire results show that colour is one of the most important factors which affect the overall satisfaction of people with their vegetation environment. Age difference analysis how children and elder people presented higher satisfaction with vegetation environment than adults. Significant negative correlation between the ratio of low-frequency to high-frequency(LF/HF) values in heart rate variability (HRV) analysis is and satisfaction values indicated HRV may be an effective parameter for green spaces influence evaluation.
(Gilchrist et al. 2015)	Well-being [Satisfaction]	Longer visits are more effective than short yet frequent visits. Flowers, woodland and mown grass more satisfying views.	outdoor	Large	366 employees in 'knowledge' generation. Research, technical, management, administration.	Employees filled out a survey outlining: the view from the window divided by vegetation and building typology. Rated their satisfaction with the view, frequency and length of visits to the park.	The study lasted 10 weeks. Part of their every-day work life. Views and breaks spent in nature.	Five peri-urban parks. Varied from lawn, meadow, woodland, bushes and flowering plants, water features, distant fields	Subjective measures, Short-version Warwick-Edinburg Mental Well-being Scale + views of the green space at their workplace.	Use and views of green space for stress management. Longer time spent in green space predict higher well-being score. The frequency of visits and naturalness of the space do not predict well-being score. Views of woodland, mown grass, and flowering plants were significantly and positively related to well-being.

(Taylor et al. 2002)	Well-being [Self Discipline]	Natural surroundings increase self-discipline.	outdoor	Large	169 inner-city teenagers in 12 identical high-rise buildings (public housing) Mean age: 9.6	Relationship with near-home nature and three forms of self-discipline:	View from home. Interviews lasted 45 min.	Pockets of trees and grass in between some buildings.	Parents ratings of near-home-nature (view from the window). Three forms of self-discipline: concentrating, inhibiting initial impulses, delaying gratification.	More natural views increased self-discipline. 20% higher discipline in girls with natural views No relationship for boys.
Talbott et al., 1976 in (Bringslimark et al. 2009)	Well-being [Social Cohesion]		Indoor	Small	15 people with Severe psychopathology, able to eat in a hospital dining room	(1) No-plant control = 4-week observation in a dining room. Followed by (2) 4-week observation in a dining room with flowers	1 hour during lunch break over 4 weeks	Flower vase with yellow chrysanthemums on each dining table	Vocalisation, social gazing, seating location, time in the room, amount of food consumed	Significant but transient the increase in vocalisation; a significant increase in mean time spent in dining room and food consumed
Coleman & Mattson, 1995 in (Bringslimark et al. 2009)	Well-being [stress]		Indoor	Small	26 (of 30) students completed all 12 sessions, run in 3 compartments in a classroom	(baseline and then 3 treatment sessions); (1) One 25 cm foliage plant in front of the subject on a stool, (2) a life-sized photo of the same plant in front of the subject on the stool, (3) the stool alone, without plant or photo, (4) no-plant or stool baseline	20-min sessions twice a week for 6 weeks		ST	No significant effects
Liu et al., 2003 in (Bringslimark et al. 2009)	Well-being [Stress]		Indoor	Small	66 students; windowless biomonitoring laboratory	Four-period crossover design: randomization of treatments to time slots (1) One 45 cm wide and high flower arrangement, (2) lavender fragrance diffused in the room, (3) both flower arrangement and fragrance, (4) no-plant or fragrance control	4 weeks 30-min in each condition; one session per week		EEG (alpha and beta), EDA, ST, ZIPPERS	Among women, comparisons of the control to the visual and olfactory exposures alone and in combination suggest lower levels of activation and negative affect with treatments, for particular minutes or subperiods of the exposure both before and after a mental task, but not consistently over the different physiological indices. Among men, the cut flower arrangement reduced fear, and the lavender fragrance alone increased EDA for some minutes of exposure
(Dijkstra et al. 2008)	Well-being [Stress]	The more attractive the room, the less stressful. Plants make a room attractive	Indoor	Small	77 Students asked to visualise a specific scenario and looking to single photo of a hospital room	A simulation study (1) hospital room with plants and (2) without plants. Scenario: Participants had been hospitalised with symptoms of legionella infection (a headache, muscle pain).	15 to 20 min while completing the perceived stress survey and	Treatment group were provided with an image. The simulation included 5 plants: 2 large and leafy, 2 medium sized and one small	Perceived stressed (based on Stress Arousal Checklist). Perceived attractiveness of the hospital room	Rooms with plants were significantly deemed as more attractive and test-subjects perceived less stress (1.92 stress level vs. 2.30 stress level). This effect would be attributed to any plant. Attractiveness level of a room correlated to reduced stressed levels.
(Bratman et al. 2015)	Well-being [Stress]	Walk in nature more restorative than walk in city	outdoor	Large	45 participants (23 nature, 22 urban)	A walk in (1) natural environment, (2) urban environment. With psychological assessments before and after. They took pictures through their walk.	50-min walk through urban green space or urban streets. 75 min for tests	The paved path through a grassland with scattered shrubs and oak trees. Urban walk in 4-lane street.	Anxiety (STAI – State-trait anxiety inventory), Rumination Reflection Questionnaire (RRQ), PANAS (Positive and Negative Affect Schedule), ANT, memory, attention network test, OSPAN (operation span task),	The decrease in anxiety, rumination, and negative affect (supporting stress reduction theory). Increased verbal working memory measured OSPAN test (supporting attention restoration theory) – The test can predict advanced reasoning, problem-solving, reading comprehension. No change in visuospatial working memory.