The current issue and full text archive of this journal is available at
www.emeraldinsight.com/0263-2772.htm

Received November 2009
Accepted February 2010

The influence of plants on productivity

A critical assessment of research findings and test methods

Iris Bakker and Theo van der Voordt
Department of Real Estate and Housing and Center for People and Buildings, Faculty of Architecture, Delft University of Technology, Delft, The Netherlands

Abstract

Purpose – This paper aims to review available research into the impact of plants on people and labour productivity in order to test a number of hypotheses and the reliability and validity of "evidence based" statements.

Design/methodology/approach – An extended literature review was conducted of research concerning the potential impacts of plants on people and labour productivity. In order to be able to compare the findings of different researchers, an analysis was made of similarities and dissimilarities with regard to the research context, starting-points and test methods.

Findings – The paper identifies a lack of precise descriptions of the research design and poor comparability between different research with regard to the characteristics of the plant, test persons, test procedures, surrounding conditions and contents of the reports. Although it can be concluded that plants can have a positive impact on the productivity of human beings, it is remarkable that in research reports and research papers the properties of the plant itself are only mentioned by exception. The condition of the plant – whether it is healthy or not – is not described at all.

Research limitations/implications – Only 17 studies and underlying papers were investigated and no new research was conducted with the proposed improvements.

Practical implications – The findings can be used by managers to legitimate investments in plants and by researchers to improve (the comparability of) research into plants.

Originality/value – In addition to the review of the impact of plants on different types of productivity a vision is presented about the impact of the vitality of plants. Furthermore recommendations are given on how to cope with the methodological problem of poor comparability of research.

Keywords Plants, Productivity rate, Research methods, Work psychology, Workplace

Paper type Literature review

Introduction

In order to be able to design the optimal working environment where people can flourish in their work and organisations will be successful, it is important to know how the physical environment affects people and productivity. One of the variables is the

The authors want to express special thanks to Peter Vink/ TU Delft, John Klein Hesselink/TNO Bouw, and Bert van Duijn/Fytagoras BV, for their valuable suggestions and comments. This paper is part of an ongoing PhD research on maximising productivity in office environments, that is being supervised by prof Peter Vink of TNO/Quality of life, and dr. Theo van der Voordt of the Faculty of Architecture at the Delft University of Technology.

Facilities
Vol. 28 No. 9/10, 2010
pp. 416-439

0263-2772
DOI 10.1108/02632771011057170

presence of plants. In search for evidence-based knowledge about the impact of plants on labour productivity it turned out that the existing literature is not always clear on what the impact exactly is. It is needed to define this impact more exactly. Second, we observed a large variety of research methods and test conditions. As a consequence, the comparability of different research projects and the conclusions that came out of the research is limited. And third, the first scan of a number of studies and included references showed that in particular information about the plants themselves is often lacking. This is an omission, because probably nobody will be more productive by seeing a faded or dead plant. Apart from the appearance, the type of the plant may be an important issue too. It may be expected that people respond differently when seeing a cactus or a rose plant. These observations have led to three main questions for a more extensive literature review on the impact of plants on productivity:

(1) What is the influence of plants on productivity?

(2) Are different studies sufficiently comparable to draw sound conclusions?

(3) What is the impact of the appearance and vitality of the plant?

These questions have been rephrased into three hypotheses:

H1. Plants have a different impact on different types of productivity.

Productivity covers a diversity of activities such as routine work and creativity. Creativity tasks and complex knowledge work need inspiration and deepening. Through history many statements of famous philosophers, writers and artists such as Nietzsche or Liszt refer to the inspiring and deepening effect of nature. Our hypothesis is that in case of routine work plants might help to support wellbeing and as such keep people going on, whereas in case of creativity work a positive effect is expected in relation to inspiration and deepening:

H2. Research concerning the impact of plants on productivity is not well comparable.

Research is rather complex. Even when the focus is just on one "dependant" variable, plants, many "independent" variables can influence the results. It is expected that research so far does not use standardised research methods.

H3. Both the appearance, type and vitality of the plant have an impact on the productivity.

One of the wonders of nature is its infinite variation combined within certain patterns and structures. Each variety has its own characteristics. As a consequence one might expect different effects of different plants. In particular, the vitality of a plant is expected to be important. Probably a healthy plant has a more positive impact on people than a plant that is not vital. In addition it is important that a plant lives in an environment with healthy conditions that support the plant and conditions people need.

Research methods and conceptual model

Initially, 17 studies from renowned researchers and research institutes were collected (see the Appendix). These documents have been scanned on possible effects of plants

on people and labour productivity, relevant variables and references for further reading (see list of references). Without any exception all studies make a significant contribution to the field. Together an incredible amount of data has been collected on many different effects. Second, in order to enlarge the knowledge that came out of the documents – both technical and psychological – discussions with specialists of the knowledge institutes TNO and Fytagoras/TNO have taken place as well. Third, because of the many different phenomena that are being mentioned in the studies and additional references, the need came up to develop a conceptual model that visualises the different types of impact of plants on human beings (Figure 1). Two different mechanisms were traced:

(1) *Evolutionary influence*. Since our genesis we have been surrounded by green plants and trees. From this point of view it is generally assumed that seeing plants has, in general, a restful effect (Ulrich, 1984; Kaplan and Kaplan, 1989).

(2) *Healthy indoor climate*. Plants have an impact on the indoor climate; this indoor climate in turn affects people and their productivity (Wolverton, 1989; Wood *et al.*, 2004).

The evolution of human beings and a healthy indoor climate affect people in three ways: plants evoke a physical/physiological response, an affective response and/or a cognitive response. In the literature six components of the indoor climate are being mentioned in relation to the impact of plants: light, temperature, relative air humidity, air quality, sound and static electricity. Another point of attention is the characteristics

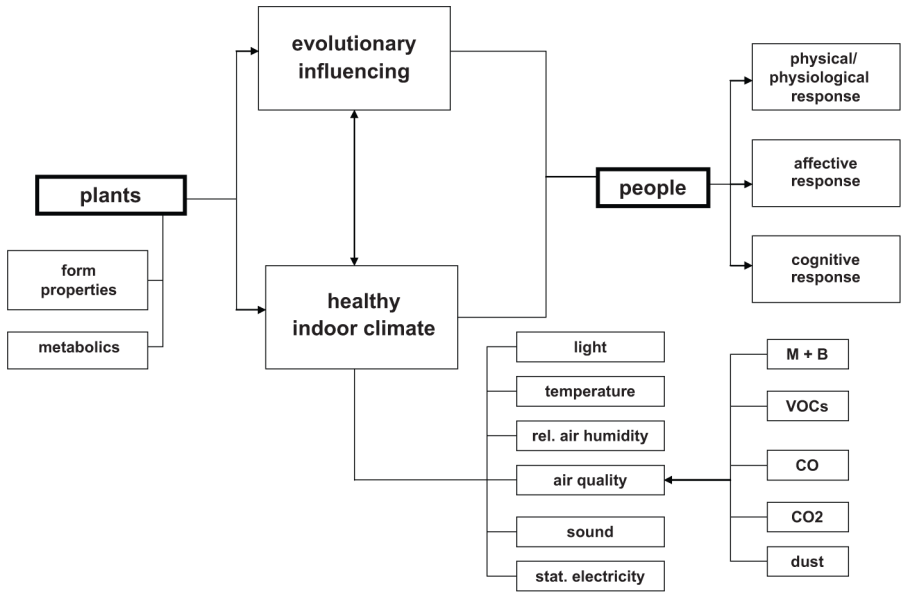

Figure 1.
Conceptual model of the impact of plants on people

Note: M+B = Molds and Bacteria; VOCs = Volatile Organic Compounds
Source: Iris Bakker, 2009

of plants themselves, including form properties and metabolics. The latter are hardly mentioned in the literature.

This conceptual model has been used as a guiding principle to analyse and discuss the collected data to examine the research findings and conclusions in the studies more closely. In a cyclic process of reading, reflecting, discussing, further reading, etc. a list of items has been traced with regard to the test conditions (Table I). This list includes six main aspects:

(1) characteristics of the plant;

(2) the test surroundings;

(3) the test persons;

(4) the test process;

(5) test strategies; and

(6) methods and variables.

Table II shows the variables that have been investigated in each research.

Research findings

Effects of plants on human beings: physical/ physiological, affective and cognitive response

The next responses are mentioned rather often:

- *Physical/physiological*. Primary physical responses are effects on blood pressure and heart beat and physiological decrease of complaints of headache; secondary responses are physiological phenomena like faster recovery (all documents excluding nos 9, 6, 10, 13, 14).
- *Affective*. Positive affective response on mood and affective behaviour like self-confidence, alertness or less aggression and positive feelings like pleasure (all documents, excluding nos 9, 13, 14, 16 and 17).
- *Cognitive*. Positive cognitive responses are better concentration capacity and higher response speed (all documents excluding Nos 9, 13 and 14). Ulrich (1984) and Lohr *et al.* (1996) showed significant statistical correlations between seeing plants and physical/physiological, affective and cognitive responses. These researchers use different methods like questionnaires, the Zipertest (Zuckerman Inventory or Personal Reactions), interviews and observation of behaviour. Unfortunately a clear explanation of the set-up of these methods is often missing.

In most research quantitative effects were also mentioned, be they quite underexposed. The following quantitative data are interesting:

- Wolf (2002) mentions in her research at shops an increase of sale concerning all products of 12 per cent when plants are present;
- Lohr *et al.* (1996) appoint an increase of the response speed of 12 per cent at simple recognition tests;
- Fjeld (1995) shows a decrease of symptomatic physical complaints of 23 per cent at 51 office employees;

Table I.
Overview of items to compare different research on plants

Plants	Test surroundings	Test subjects	Test process	Test strategies	Methods and variables
Spot	*Institute*	*Test subjects*	*Reduction Hawthorne-effect*	*Observation*	*Information*
Position in space	Outdoor area	Men	Attention	Observation by test subject	Observation
Height of view	Laboratory	Women	*Habituation process*	Observation researcher	By test subject
Indoor/outdoor	Education	Children	Attention	Technical supporting measurements	By researcher
View	Office	Patients		Data semantic questionnaire	Biophysical
Sort	Shop	Students	*Test surrounding*	Data standard interview	Questionnaires
	Hospital/care	Employees	Clear information at the beginning	Data interview/ survey	Standard
	Space type	Age	Intensive accompaniment	Data question conversation	Score model
Variety	One person space	Number	Acceptation management	Questionnaire	Quantitative
Intensity	Two persons space	Sort of work	*Test aspects*	Computer program	Qualitative
Dimension/number per square m	Multi persons space	Concentration	Placebo	*Biophysical observation*	Interview method
Number	Various	Creativity		Heartbeat	Guidance question conversation
Size	*Space characteristics*	Routine		System blood pressure	No guidance
Cleanliness order	Number of windows	*Commitment of test persons*		Muscle tension	Computer program
Maintenance situation	Size of windows	Relevance		Skin conductance	ZIPER test
Pot ground/hydroponics	Size of space	Seriousness of participation		Electrical brain activity	*Fee*
Pot size	*Relation to temperature*	To participate is own choice		*Number measurements*	Credit
Form pot	*Light level*	Involvement in final result			*Task*
Artificial plant	*Relation lighting*	Preference for plants		*Test duration*	Association task
Image plants	Fluorescent broad spectrum			Hours	Key typing task VDT
				Days	Computer task
Flower	Neon light			Weeks	Sorting task
Micro-organism	*Daylight*			Months	Concentration task
	Relative air humidity			Years	*Technology*
	Ventilation system			*Objectifying*	Air/ventilation systems
	Natural ventilation				

(*continued*)

Table I.

Plants	Test surroundings	Test subjects	Test process	Test strategies	Methods and variables
	Mechanical ventilation			Knowledge structure questionnaire	Light systems
	Air treatment				Measurement air quality
	Airco				*Concept*
	Quantity ventilation			*Effects*	Position plants
	Design ventilation quantity			Affective feeling	Number plants
	Real ventilation quantity			Affective mood	
	Sound			Affective behaviour	
	Static electricity			Physical primary	
	Colour space			Physical secondary	
	Fragrance			Physiological effects	
	Interior elements			Cognitive	
	Smoke			Cognitive concentration	
	Specification and VOCs			Cognitive memory	
	Parts and value parts of dust			Cognitive reaction time	
	CO2 and value CO2			Cognitive errors	
	CO and value CO			Cognitive discipline	
	Moulds			Adiposis	
	Pathological micro-org.			*Other mentioned effects*	
	Time			Productivity/performance	
	Link to seasons			Sound	
	Link day/night			Ecologically/reduction energy	
	One cell organism			Staff keeping and recruitment	
	Weather			On working environment	
				On plants	
				Start conditions	
				Single plant	
				Many plants	

Table II.
Aspects that were mentioned in 17 studies

Component	Aspect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sum
		Studies (numbers according to the Appendix)																	
Plants		×	×	×		×		×							×	×		×	8
Spot	Position in space		×	×		×		×											4
	Height of view	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	17
	Indoor/outdoor		×	×									×						3
	View		×	×		×	×	×			×		×	×	×		×	×	11
Sort				×		×	×	×			×			×	×		×	×	9
Variety				×		×		×			×			×	×				6
Intensity	Dimension/number per square m		×	×		×	×	×					×	×	×	×		×	10
Number				×		×		×			×	×						×	6
Size		×											×			×			3
Cleanliness order				×		×										×		×	4
Maintenance situation		×			×										×		×		4
Pot ground/hydroponics		×											×					×	2
Pot size					×								×		×				4
Form pot						×													2
Artificial plant													×						2
Image plants													×						2
Flower																			1
Micro-organism																			
Test surroundings		×						×					×			×			4
Type of environment	Outdoor area							×						×	×				3
	Laboratory		×																1
	Education		×			×	×											×	4
	Office															×			1
	Shop	×	×										×						3
	Hospital/care		×			×	×											×	4

(continued)

Table II.

Component	Aspect	Studies (numbers according to the Appendix) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sum
Space type	One person space																		0
	Two persons space							×											1
	Multi-persons space																		0
	Various		×				×	×			×	×							5
Space characteristics	Number of windows		×																1
	Size of windows		×			×	×	×			×			×	×			×	8
	Size of space					×		×		×				×				×	5
Temperature	Known		×			×		×											3
Light level	Known		×																1
Type of light	Florescent broad spectrum		×					×						×					3
	Neon light		×														×		2
	Unknown	×	×	×				×								×			5
Daylight	Known		×	×		×		×		×				×				×	7
Relative air humidity	Known					×												×	2
Ventilation system	Natural ventilation		×			×								×					2
	Mechanical ventilation					×													1
	Air treatment			×														×	2
	Airco													×	×			×	3
Quantity of ventilation	Designed ventilation quantity					×													1
	Real ventilation quantity			×		×							×						3
Sound	Known					×													1
Static electricity							×	×											2
Colour space	Known			×									×						2
Fragrance	Known						×	×			×	×							4
Interior elements				×		×							×	×					4
Smoke						×								×	×		×	×	5
Specification VOCs						×								×			×	×	4
Value VOCs			×			×								×					3
Parts of dust						×													1

(*continued*)

Table II.

Component	Aspect	Studies (numbers according to the Appendix) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sum
CO2						×								×				×	3
Value CO2			×			×								×				×	3
CO						×												×	3
Value CO			×			×												×	2
Moulds				×		×													2
Path micro-organism						×													2
Time	Which season(s)									×									1
	Day/night																		0
One cell organism						×													1
Test persons																			
Test persons	No distinction	×	×										×			×			4
	Men				×	×	×	×			×	×						×	6
	Women				×	×	×	×			×	×							6
	Children		×																1
	Patients	×											×						2
	Students					×	×	×			×	×							5
	Employees		×		×	×	×	×											6
	Age				×			×											2
	Number				×	×		×					×						4
Type of work	Concentration					×	×	×				×							4
	Creativity											×							1
	Routine					×	×					×							3
Commitment of test persons	Relevance						×				×	×							3
	Seriousness of participation																		0
	To participate is own choice				×		×	×			×	×						×	6
	Involvement in final result																		0
	Preference for plants							×											1

(*continued*)

Table II.

Component	Aspect	Studies (numbers according to the Appendix) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sum
Test process																			
Reduction Hawthorne effect	Attention		×																1
Habituation process	Attention		×			×	×					×						×	5
	Clear information at the beginning						×												1
Test surrounding	Intensive accompaniment						×									×			2
	Acceptance management																		0
Test aspects	Placebo																		0
Test strategies																			
Observation	Observation by test person				×			×					×					×	4
	Observation researcher							×					×						2
	Technical measurements																		0
	Data semantic questionnaire																		0
	Data standard interview																		0
	Data interview/survey												×			×			2
	Data question conservation															×			1
	Questionnaire		×		×	×	×				×		×						6
	Computer programme							×											1
Biophysical observation	Heartbeat		×					×					×						3
	System blood pressure		×					×					×						3
	Muscle tension												×						1
	Skin conductance												×						1
	Electrical brain activity												×						1
Number of measurements	Known							×						×				×	3
Test period	Ours		×				×				×	×							4
	Days					×								×			×		3
	Weeks																		0
	Months		×			×									×			×	3
	Years		×			×													2

(*continued*)

Table II.

Component	Aspect	Studies (numbers according to the Appendix) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Sum
Objectivity	Knowledge structure questionnaire																		0
Effects	Affective feeling	×	×	×		×		×			×		×			×			8
	Affective mood	×	×	×		×		×					×			×			7
	Affective behaviour	×		×												×			3
	Physiologically primary	×	×	×		×		×					×				×		7
	Physiologically secondary	×	×	×		×		×					×						6
	Cognitive	×	×				×	×			×		×						6
Other mentioned effects	Productivity/performance							×								×	×		3
	Sound																		0
	Ecological/reduction of energy															×			1
	Staff retraining and recruitment												×						1
	Impact on working environment		×		×						×						×		4
	Impact on plants					×													1
	Other				×										×				2
Start conditions	Single plant																		0
	Many plants					×													1
Total mentioned aspects		19	38	23	13	54	24	41	1	4	18	14	32	20	13	18	11	28	371

- research by Fjeld among 48 employees of an X-ray division showed a 25 per cent decrease of health complaints by using plants; and
- in 2001-2002 Fjeld revealed an average 24 per cent reduction of physical complaints among different groups of 48 bank employees after the introduction of plants and light with a broad spectrum.

When the results are analysed more closely, a uniform effect on physical/physiological, affective and cognitive responses comes up. This confirms the statements of many famous people that emphasise the positive effects of nature on human beings. Greek philosophers used the so called "peri-pathetic method": walking through the academy garden to discuss their ideas (Csikszentmyhalyi, 1998). Based on studies such as those presented above, it can be concluded that a relation exists between seeing and experiencing plants and physical/physiological, affective and cognitive responses. This relation however is merely qualitatively described and to a lesser extent quantitatively defined. The exact effect of plants on human beings is still not clear. In accordance with the model, three explanatory options are possible. The effect can be evolutionary: during centuries of development of human beings, plants have always been an important part of nature and a strong foundation in our existence. A second effect is the improvement of the indoor climate. Many aspects of the indoor climate are strongly connected to the presence of plants. Third, metabolics may have an influence on people. Plants form metabolics, chemical compounds with amongst other things fragrances and colour properties. These substances may be expected to influence people, but this has not been proven by research so far. Little attention has been paid to the impact of intermediary variables such as research conditions and test persons. So although the positive effects of plants on human beings are widely accepted and supported by research, we have to interpret the research findings carefully.

Effects of plants on the indoor climate

Plants and indoor climate affect one another. To be able to interpret research findings on the impact of plants correctly, detailed information is needed about the indoor climate in the test situation. But due to differences in descriptions and lack of essential information concerning technical data that might affect the process and the impact of plants it is rather difficult to draw clear conclusions. Nevertheless some interesting results have been found with regard to the six components of indoor climate that are included in the conceptual model: light, temperature, relative air humidity, air quality, sound and static electricity.

Light. With regard to photosynthesis the blue and red part of the spectrum are necessary for healthy plants. In many buildings light with a broad spectrum is absent, so probably insufficient blue and red light will be available for the plant. This obstructs the growth and also the processes of photosynthesis and metabolism. It is striking that in the examined studies both light colours (spectrum) and light intensity are usually not mentioned at all, in spite of its importance for the health of the plant. By contrast the reflection of light on the leaves of the plants affects the variation on light colours in the physical surrounding.

Temperature. Stec *et al.* (2005) revealed that an outside awning of plants is more effective than a regular awning. Schempp (2002) mentions a difference of two up to

three degrees with regard to outside temperature by application of an outside awning with plants in combination with plants inside.

Relative air humidity. Research of Costa and James (1995) and Strickler (1994) showed that the relative air humidity of a space without air treatment increases with approximately 5 per cent when plants are used. It is necessary to use a quite large number of plants. Lohr *et al.* (1996) mentions an increase from zero to 15 per cent if space is not ventilated; in a ventilated room there is an increase of 3 to 5 per cent. Applying plants means that you have to take care for them. When for instance the value of relative air humidity is too low, the stomata at the base of leafs will close.

Air quality. In the air volatile organic compounds (VOCs) occur, such as small dust particles, moulds, bacteria, metabolics, CO and CO2. Air quality is expressed by the VOCs concentration which is quantified in parts per million (ppm) value. Based on the experiments of Wolverton (1989) it is known that a synergetic process between plant and micro organisms that attaches themselves to the rootstructure of the plant contributes to the reduction of the VOCs' value. van der Wal and Hoogeveen (1993) proves that unrealistic amounts of plants are needed to reach a sufficient reduction of the VOCs' value. Quite often the indoor climate in buildings is not optimal for plants and therefore also not optimal for the process of VOCs reduction. Plants also have a positive influence on the reduction of dust accumulation. Research of Lohr *et al.* (1996) showed that plants in optimal conditions can cause a dust reduction of 20 per cent. Plants are selected in buildings in such a way that they will not grow too rapidly, because rapid growth increases the exploitation costs too much. It may be concluded that a positive effect of plants is not the right argument to use of plants as a means to control or improve the indoor air quality. Ventilation is much more effective.

Sound. Research by Costa and James (1995) shows that the reverberation time of sounds with a high frequency is shortened when plants are used, and as such the space will be quieter. At low frequencies more inflection of the sound takes place. Dependent of the exact location and the spreading, sound absorption takes place.

Static electricity. Employees working at least four hours at screens undergo less inconvenience from static electricity when plants are in their workspace than other employees without plants in their rooms.

Overall we may conclude that in real working environments the influence of plants on the indoor climate is rather small. So this cannot be a convincing argument to apply plants in working environment.

The effects of plants on productivity

According to the studies that have been analysed, the question of whether plants have an impact on the functioning and productivity of people can be answered in a positive way (Table III). Most studies mention the positive qualities of plants. However, it is hardly possible to compare the studies in a systematic way because of the lack of clear definitions of productivity and performance and a lack of clear information about which activities were measured, what exactly has been measured, what the characteristics were of the test persons and in which way the measured results were achieved. Because of the large amount of variables it is impossible to establish clear conclusions.

In spite of the methodological shortcomings we can discern a common thread:

Research	Conclusions	Document number (Appendix)
Asami *et al.* (1995)	Indoor plants reduce fatigue of the eye when working with screens	10
Conklin (1974, 1978); Isen (1990, 1993)	Plants in offices lead to higher employee morale and higher effectiveness	7, 11
Knez (1995); Isen (1990, 1993)	If people are in a positive mood, their creativity raises	6, 11
Isen and Shalker (1982)	Positive phenomena stimulate the brain for recalling more information and they initiate more cognitive manipulation that causes a higher level of creativity	6
Larsen *et al.* (1998)	A larger number of plants improves the mood, but reduces concentration; the perceived productivity increases in connection to the number of plants	1, 6
Lohr *et al.* (1996)	Plants lead to 12 per cent increase in response speed and reduce the number of mistakes	5, 8
Mayer *et al.* (2006)	Plants strengthen the capacity to think about life problems	1
Mayer and Frantz (2004)	Plants evoke a positive feeling of alliance and increase problem solving capacity	1
Marchant (1980); Srivens (1982)	With plants increase of productivity 10-15 per cent	7
Ottoson and Grahn (2005)	Staying one hour in a green space improves concentration	1
Shibata and Suzuki (2002)	Plants have a larger impact on performance than on women; in spaces with a plant men perform better; conducting a sorting and association task men performed on a lower level than women in case of no plants in the room, but when a plant was placed in front of them, men performed better than women. The impact of plants was larger at the association task, then at the sorting task. Plants had a negative effect on women in sorting tasks	1, 5, 11
Shibata and Suzuki (2002)	The presence of plants increases the performance score of women; in general the presence of a plant increases the mood and the appreciation of the space	11
Shoemaker (1992)	Plants have no impact on work satisfaction	5
Stone (1998)	Plants have a negative impact on performance and task perception	11

Table III.
Effects of plants on labour productivity (by alphabetical order of the author)

- Plants put people in a better mood and improve confidence and openness of the mind to the surrounding world. Plants have also a positive social effect in relation to alliance and morality.
- If people are in a better mood, the perceived productivity increases, whereas the measured ("real") productivity score decreases.
- The amount of plants plays a role.
- The presence of a plant stimulates people in different ways.
- The effect of plants can be different depending on the activities.
- With regard to productivity of creative work, a clear positive relation is evident on the basis of the research above.

Reflections on the attention paid to five test items

As has been said before, to improve the comparability of research on plants, a test structure has been developed with five test characteristics that should be described very clearly: the plant; the test surroundings; the test persons; the test process; and the test itself. Furthermore standard items have been formulated per aspect. The collected studies have been examined on the attention paid to these five aspects and the components (Table II).

The plant itself

Looking at the plant itself, most reports and papers only pay attention to its type, variety and number and sometimes the spot. Heights and sizes of pots are mentioned as well. The characteristics of the plant itself are usually not described at all. Several types of plants are used, with different varieties (Table IV). Particularly the *Dracaena*, *Spathiphyllum* and the *Epipremnum* are often used Because of the different plants that are involved in the investigations, the conclusions from the studies are not comparable.

Test surrounding

Most studies mentioned whether the tests have taken place inside or outside. In all studies, the environment of the test is described, including offices, a laboratory, shops, care sector and education buildings. Most attention is paid to the size of the space and the relative air humidity. All other aspects of the test surroundings are mentioned only very briefly and to an insufficient degree. Colour specification is extremely limited, whereas this variable affects the light frequencies required for the photosynthesis of the plant.

Test persons

The test persons vary from children to students (graduates and undergraduates), clients and employees and include men and women in different sectors. Usually reports and papers do not give any information about the psychological and social psychological situation of test persons or personal characteristics (beside age and sex), personal conditions or mood specifications. So, no valid statements can be made about the impact of these issues. Sometimes attention is given to the willingness of people to participate in the experiment.

Table IV. Names of plants appointed in the research documents

Plant species	Lohr (7)	Strickler (5)	Burchett Tarran (5)	Klein Hesselink (5)	Wood (16)	Wolverton (3)	Larsen *et al.* (6)	Shabita and Suzuki (10 + 11)	van der Wal (13 + 14)
Aglaonema	×								×
Chamaedora	×								
Dracaena	×	×	×		×		×	×	
Epipremium	×		×		×				×
Homalomena	×								
Hoya	×								
Philodendron	×	×						×	
Sansevieria	×								
Scindapsus	×								
Syngonium	×								
Dizygotheca		×							
Ficus benjamina		×		×					×
Hedera		×							
Howea			×		×				
Spathiphyllum			×	×	×				×
Schefflera			×		×				
Orchidee						×			
Bromelia achtigen						×			
Augusta									
Phycorapis								×	
Strelizia								×	

Note: Numbers refer to the numbers of the documents in the Appendix

Test process

Processes are very complex; there are many factors playing a role and also influencing one another. No single study paid attention to psychological effects like the Hawthorne effect. In a number of cases attention was paid to habituation. However, the way that habituation has been defined and being measured is described insufficiently. It is possible that both the habituation of the test persons and the early effects of VOCs reduction of plants have affected the test results, but in which way is still not known.

Test methods and variables

Observations, measurements, impact and test duration are only comparable in a limited way. The observations vary from individual perceptions of the test persons to observations by research workers and standard questionnaires with scores and/or scales. Biophysical observation has taken place to a limited extent.

It may be concluded that because of the huge variety in test characteristics the comparability of the 17 analysed documents is limited. Testing phenomena like effects of plants on productivity is related to many variables, so it is a very complex process. As a consequence it is nearly impossible to draw sound and transparent conclusions. Many studies do not pay sufficient attention to important terms. Quite often terms have not been formulated consistently or accurately. At this moment, there is no standard research framework that can be used as a guideline to design research. A positive exception is study no. 5 of TNO (Klein Hesselink *et al.*, 2006). The appointment of 55 aspects is a relatively complete description. The analysis of Fjeld and Bonnevie (2002) scores also high with an appointment of 44 aspects. The more technical considerations of Wood *et al.* (2004) and van der Wal (1991) have high scores as well. They focus on a pure technical and well-defined input.

A closer look at the appearance and vitality of a plant

Table V shows an overview of relevant aspects with regard to appearance and vitality. Based on this scheme, all remarks about the appearance and vitality of plants have been collected and analysed. It is obvious that researchers do not pay sufficient attention to the appearance of plants or their health condition. Research with significant evidence of the impact of the appearance and health condition of a plant on human behaviour has not been found yet. It has been noted that plants with flowers give most entertainment. Costa and James (1995) discuss the size of the leaf and/or the length of the little hairs in connection with admission of specks of dust and chemical substances. Only the study of Van Dortmont and Bergs (1997) discusses plant properties based on conversations with garden experts.

The comparative analysis shows that hardly any attention is being paid to the properties of the plant itself, like the shape of the leaves, colours and structures of the vascular bundle. One can imagine that a cactus has another effect on people than a rose plant, and that an unhealthy or nearly dead plant makes people feel less pleasantly than a strong and healthy plant. These considerations are missing in nowadays research.

Table V. Characteristics of plants and its application in 17 studies

Plant characteristics No.	Aspect	Subaspect	17 studies (numbers refer to the Appendix) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	Chemical activity	Bioproces system																		
2		Admission chem. Compounds																		
3		Quantity of transpiration									×									1
4	Plants differentiation	Plant type				×	×		×						×	×				5
5		Plant sort		×			×	×	×			×		×				×	×	8
6		Plant variety					×	×	×			×						×		5
7	Sizes	Plant height			×		×		×			×	×						×	6
8		Plant width			×															1
9		Proportions			×															1
10	Form	Apple/pear form																		
11		Fullness/mass																		
12		Horizontally or straight																		
13	Structure	Structure plant			×															1
14		Structure branches																		
15		Structure leaf																		
16		Mesophyll																		
17	Leaf	Number/intensity				×		×				×			×	×			×	6
18		Size			×												×		×	3
19		Form																		
20		Surface/tactility characteristic					×													1
21		Colour mix			×															1
22		Colour expression			×															1
23		Structure			×															1
24		Position																		
25		Expression																		
26		Brilliance																		
27		Difference colour front/back																		
28		Leaf edge																		
29	Fragrance plant	Nature			×	×														2

(*continued*)

Table V.

Plant characteristics			17 studies (numbers refer to the Appendix)																	
No.	Aspect	Subaspect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
30	Flower	Mentioned				×								×						2
31		Expression																		
32		Form																		
33		Structure																		
34		Colour																		
35		Colour differentiation																		
36		Position																		
37		Fragrance																		
38		Number/intensity																		
39		Brilliance																		
40	Seeds and fructification	Number																		
41		Size																		
42		Form																		
43		Colour differentiation																		
44		Colour expression																		
45		Structure																		
46		Position																		
47	Dynamics	Dynamics																		
48	External factors	Pot form			×		×							×					×	5
49		Pot ground/hydroponics	×				×									×		×		4
50		Position		×					×											2
51		Integration environment																		
52		Care and carefulness	×				×							×			×		×	5
53		Solitarily/group																		
54	Performance	Fine or grove structure																		
55	Metabolics																			
56	Health	Degree of vitality			×															1
Total			2	2	11	4	8	3	5	0	0	4	1	4	2	3	2	3	6	60

Discussion and conclusions

H1. *Plants have a different impact on different types of productivity*

Although a consistent positive influence of plants on creativity came out from the studies mentioned, the influence of plants on overall productivity varies. In general plants have a positive impact on the physical/physiological and affective response of people. Through centuries people are aware of the impressive nature. Modern research supports the so-called "Biophilia Hypothesis" that refers to the biological basis for human values in nature (Kellert and Wilson, 1993). There is also a growing awareness of the importance of nature to children's development – intellectually, emotionally, socially, spiritually, and physically (Kellert, 2005; Moore and Cooper Marcus, 2008). Plants support people in their feelings of safety, because all plants have a clear structure. Concerning cognition, the effects of plants are different for various reasons. Many factors play a role. Another issue is the infinite diversity of people, their way of being, living, doing, feeling and thinking. All people are completely different concerning their Intelligence and Emotional, Spiritual and Physical Quotient. Their personal situations are also different. So one might question if it is really possible to measure the effects of plants on people.

H2. *Research concerning the impact of plants on productivity is not well comparable*

Because of the lack of essential information and indistinct and incomplete data, the comparability of the analysed studies is limited. Accuracy concerning the various aspects playing a role in research is necessary to establish clear conclusions. Because of the complexity of this type of research and the lack of accurate information about the many aspects playing a role there is doubt about the validity of the posited conclusions from present research.

H3. *Both the appearance, type and vitality of the plant have an impact on the productivity*

None of the analysed studies discussed the appearance of the plant on a scientific basis.

Only study 3 refers to the vitality of the plant, whereas, hypothetically it is assumed that the more healthy the plant, the more positive the impact on people. It is remarkable that researchers were looking for a physical environment that is healthy for human beings, without paying sincere attention to the plant itself. Plants are – like ourselves – living beings and are permanently changing their form, colours and fragrances. It is really important to treat plants with respect. Nowadays, they are cultivated in a world with emphasis on low costs and less time. So, it is really the question if the cheap pots and cheap potting soils are benefiting the plants themselves. Moreover, the spots where plants in buildings will be placed are often too windy, too dark without daylight, or lack the blue and red light of the spectrum. When plants are unhappy, they cannot make people feel happy. When more attention is paid to the plant itself and when the plant stays healthier, this stronger interaction between people and plant will generate positive effects in a more socialising way. An interesting example is a home for older people, where the older men and women were allowed tot take care of their own plants, which they had selected themselves. These elderly people felt better and had fewer complaints. Just by bringing user involvement in the organisation, both plants and users of a building will be happier.

Recommendations

It is highly recommended to make the approach of future research less unambiguous in order to improve its comparability with other research and to support sound conclusions. For that purpose a more elaborate standard research approach is needed. The tables and schemes that came out of this paper may be helpful here, in particular in recording of the properties of plants in a structured way. It is also important to use unambiguous definitions without overlaps and to pay more attention to the appearance and vitality of plants. This will help to create a more complete picture. However, people have to be humble. Nature is so infinite in her expressions that it is impossible to gather all variations of nature in a model made by human beings. Finally it is recommended to pay more attention to the health of the plants themselves. It is hypothesised that the happier the plant, the more positive effect the plant has on human beings. It is interesting to study this hypothesis more closely.

References

Asami, D.K. (1995), "Effects of ornamental foliage plants on visual fatigue caused by visual display terminal operation", *Journal of Shita*, Vol. 7, pp. 138-43.

Conklin, E. (1974), "Interior plantings bring nature indoors", *American Nurseryman*, Vol. 12-13, pp. 105-12.

Conklin, E. (1978), "Interior landscaping", *Journal of Aboriculture*, Vol. 4, pp. 73-9.

Costa, P. and James, R.W. (1995), "Constructive use of plants in office buildings", *Lecture Notes for the Catalogue of the Symposium Plants for People*.

Csikszentmyhalyi, M. (1998), *Creativiteit*, Amsterdam, Boom, Amsterdam.

Dortmont, J.F. and Bergs, J.A. (1997), *Planten en productiviteit* (*Plants and Productivity*), Bloemenbureau, Leiden.

Fjeld, T. (1995), "The effects of interior plants for offices", paper presented at the Symposium Plants for People.

Fjeld, T. and Bonnevie, C. (2002), "Het effect van planten en kunstmatig daglicht op het welbevinden en de gezondheid van kantoorpersoneel, schoolkinderen en gezondheidsmedewerkers" ("The effect of plants and artificial daylight on the well-being and the health of office workers, school children and health care personal"), paper presented at the International Symposium, Floriade.

Isen, A.M. (1990), "The influence of positive and negative affect on cognitive organisation: some implications for development", in Stein, N., Leventhal, B. and Trabasso, T. (Eds), *Psychological and Biological Approaches to Emotion*, Lawrence Erlbaum, Hillsdale, NJ, pp. 75-94.

Isen, A.M. (1993), "Positive affect on decision making", in Lewis, M. and Haviland, J.M. (Eds), *Handbook of Emotions*, Guilford, New York, NY, pp. 261-77.

Isen, A.M. and Shalker, T.E. (1982), "The effect of feeling state on evaluation of positive, neutral and negative stimuli", *Social Psychology Quarterly*, Vol. 45 No. 1, pp. 58-63.

Kaplan, R. and Kaplan, S. (1989), *The Experience of Nature: A Psychological Perspective*, Cambridge University Press, New York, NY.

Kellert, S.R. (2005), "Nature and childhood development", *Building for Life: Designing and Understanding the Human-Nature Connection*, Island Press, Washington, DC, pp. 63-89.

Kellert, S. and Wilson, E.O. (1993), "The biological basis for human values in nature", in Kellert, S. and Wilson, E.O. (Eds), *The Biophilia Hypothesis*, Island Press, Washington, DC.

Klein Hesselink, J. and Hopstaken, L. (1995), *Planten op het werk* (*Plants in the Working Environment*), NIA, Amsterdam.

Klein Hesselink, J., de Groot, E., Loomans, M. and Kremer, A. (2006), *Fysiologische en psychische en gezondheidseffecten van planten in de werksituatie op gezondheid en welbevinden van mensen* (*Physiological and Mental and Health Consequences of Plants in the Work Situation on Health and Well-being of People*), TNO rapport 21573/018.10311, TNO Kwaliteit van Leven, Hoofddorp.

Knez, I. (1995), "Effects of indoor lighting on mood and cognition", *Journal of Environmental Psychology*, Vol. 15 No. 1, pp. 39-51.

Larsen, L., Adams, J., Deal, B., Kweon, B. and Tyler, E. (1998), "Plants in the workplace: the effect of plants density on productivity, attitudes and perceptions", *Environment and Behaviour*, Vol. 30 No. 3, pp. 261-81.

Lohr, V.I., Pearson-Mims, C.H. and Goodwin, G.K. (1996), "Kamerplanten kunnen de arbeidsproductiviteit verbeteren en de hoeveelheid stress verminderen in een omgeving zonder ramen" ("Interior plants may improve productivity and reduce stress in a windowless environment"), *Journal of Environment Horticulture*, Vol. 14, pp. 97-100.

Loomans, M. and Klein Hesselink, J. (2005), "Het effect van planten op het werk" ("The influence of plants in the working environment"), *Facility Management Magazine*, No. 133, pp. 17-21.

Marchant, B. (1982), "A look at the industry – dimensions and prospects", *American Nurseryman*, Vol. 156 No. 10, pp. 30-49.

Mayer, F.S. and Frantz, C.M. (2004), "The connectedness to nature scale: a measure of individuals' feeling in community with nature", *Journal of Environmental Psychology*, Vol. 24, pp. 504-15.

Mayer, F.S., Frantz, C.M., Bruehlman-Senecal, E. and Dolliver, K. (2006), "Mayer F.S.& Frantz, C.M., Bruehlman-Senecal, E., Why is nature beneficial? The role of connectedness to nature", *Journal of Environmental Psychology*, No. 28, pp. 192-9.

Moore, R.C. and Cooper Marcus, C. (2008), "Healthy planet, healthy children: designing nature into the daily spaces of childhood", in Kellert, S., Heerwagen, J. and Mador, M. (Eds), *Biophic Design: Theory, Science and Practice*, John Wiley & Sons, Hoboken, NJ.

Ottoson, J. and Grahn, P. (2005), "A comparison of leisure time spent in a garden with leisure time spent indoors: on measures of restoration in residents of geriatric care", *Landscape Research*, Vol. 30 No. 1, pp. 23-55.

Schempp, D. (2002), "Green architecture, plants in buildings; key massage plants for people", paper presented at the International Symposium, Floriade.

Shibata, S. and Suzuki, N. (2001), "Effects of indoor foliage plants on subjects' recovery from mental fatigue", *North American Journal of Psychology*, Vol. 3 No. 3, p. 385.

Shibata, S. and Suzuki, N. (2002), "Effects of an indoor plant on creative task performance and mood", *Journal of Environmental Psychology*, Vol. 22 No. 3, pp. 265-72.

Shoemaker, C.A. (1992), "Relationships between plants, behaviour, and attitudes in an office environment", *HortTechnology*, Vol. 2 No. 2, pp. 205-6.

Srivens, S. (1980), *Interior Planting in Large Buildings*, The Architectural Press, London.

Stec, W.J., van Paassen, A.H.C. and Maziarz, A. (2005), "Modelling the double skin facade with plants", *Energy and Buildings*, Vol. 37 No. 5, pp. 419-27.

Stone, N.J. (1998), "Windows and environmental cues on performance and mood", *Environment and Behavior*, Vol. 30 No. 3, pp. 306-21.

Strickler, B. (1994), "Water evaporation of five common indoor plants under various climate conditions", *AIVC*, Vol. 1, pp. 151-62.

Ulrich, R.S. (1984), "View through a window may influence recovery from surgery", *Science*, No. 224, pp. 420-1.

Ulrich, R.S. (2002), *The Consequences on Health of Plants in and around Hospitals on Patients and Nursing Staff*, Center for Health Systems and Design, Texas A&M University College State, College Station, TX.

van den Berg, A. and Winsum Westra, M. (2006), "Ontwerpen met groen voor gezondheid" ("Designing with plants creating health"), *Reeks Belevingsonderzoek*, No. 14, Alterra rapport 1371.

van der Wal, J.F. (1991), *Oriënterend onderzoek naar de luchtzuiverende werking van potplanten in een mechanisch geventileerde proefruimte* (*Orientation Study Concerning the Air Cleansing Functioning of Pot Plants in a Mechanically Ventilated Test Space*), TNO rapport, TNO Bouw, B-91-0137, TNO, Delft.

van der Wal, J.F. and Hoogeveen, A. (1993), *Onderzoek naar de regeneratie van actieve kool door potplanten* (*Study Concerning the Regeneration of Active Cabbage by Pot Plants*), TNO rapport, TNO Bouw, B-92-1155, TNO, Delft.

Wolf, K.L. (2002), "Het effect van natuur in en rond winkelgebieden; creatie van een consument gerichte leefomgeving", ("The impact of nature in and around shop areas; creation of an environment specifically suited to a consumer"), paper presented at the People/Plant Symposium, Amsterdam.

Wolverton, B.C. (1989), *Interior Landscape Plants for Indoor Air Pollution Abatement*, NASA, John C, Space Center.

Wood, R., Orwell, R. and Tarran, J. (2004), *Planten om de luchtkwaliteit van een kantoor te verbeteren* (*Plants to Improve Office Air Quality*), Flower Council of Holland, Sydney, Final report of Office "On-Location" Study.

Wood, R.A., Burchet, M.D., Tarran, J. and Torpy, F. (2002), "Het vermogen van planten/aarde om schadelijke stoffen uit vervuilde lucht binnenskamers te verwijderen" ("The capacity of plants/ground to remove indoor detrimental substances out of polluted air"), *Journal of Environment, Horticulture and Biotechnology*, Vol. 77 No. 1, pp. 120-9.

Further reading

Csikszentmihalyi, M. (1996), *Creativity: Flow and the Psychology of Discovery and Invention*, Harper Perennial, New York, NY.

Lohr, V.I. (2000), "Physical discomfort may be reduced in the presence of interior plants", *HortTechnology*, Vol. 10 No. 1, pp. 53-8.

Appendix. List of the 17 examined research reports

(1) van den Berg and Winsum Westra (2006);

(2) Fjeld and Bonnevie (2002);

(3) Dortmont and Bergs (1997);
(4) Klein Hesselink and Hopstaken (1995);
(5) Klein Hesselink *et al.* (2006);
(6) Larsen *et al.* (1998);
(7) Lohr *et al.* (1996);
(8) Loomans and Klein Hesselink (2005);
(9) Schempp (2002);
(10) Shibata and Suzuki (2001);
(11) Shibata and Suzuki (2002);
(12) Ulrich (2002);
(13) van der Wal (1991);
(14) van der Wal and Hoogeveen (1993);
(15) Wolf (2002);
(16) Wood *et al.* (2002); and
(17) Wood *et al.* (2004).

Corresponding author
Iris Bakker can be contacted at: iris.bakker@levenswerken.eu