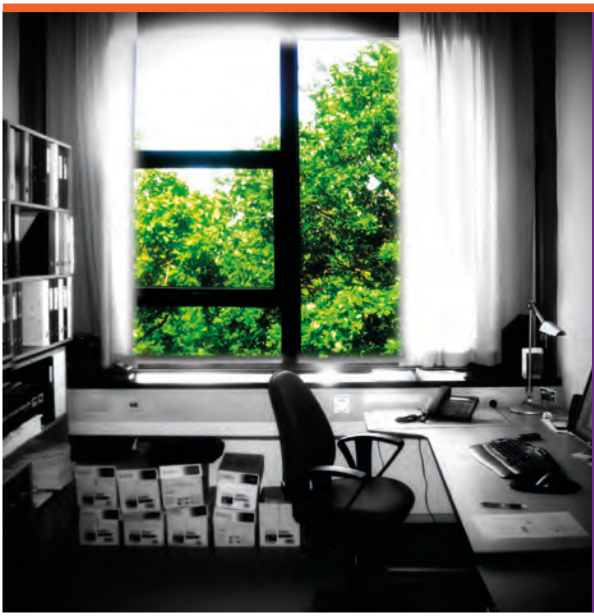
Human comfort and self-estimated performance in relation to indoor environmental parameters and building features



Monika Frontczak

PhD Thesis

Department of Civil Engineering

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Preface

The present Ph.D. thesis summarizes the author's research work performed at the International Centre for Indoor Environment and Energy, Department of Civil Engineering at the Technical University of Denmark in the period between September 2008 and November 2011 under the supervision of Associate Professor Paweł Wargocki.

I would like to express my sincere gratitude to my supervisor Paweł Wargocki for his guidance throughout my Ph.D. study. I much appreciate all the inspiring discussions of my work, his valuable advice, his involvement and help.

My sincere thanks to all co-authors of my papers: Paweł Wargocki, Rune Korsholm Andersen, Stefano Schiavon, Edward Arens, Hui Zhang and John Goins. I am grateful for their valuable feedback on my research work and their suggestions on how to improve the papers. Many thanks to Rune Korsholm Andersen for his help with preparation and distribution of the questionnaire survey, and his translation of the abstract into Danish. Special thanks to Stefano Schiavon for his help with the statistical analyses and R software, and his prompt responses to all my questions.

Warm thanks to my colleagues at the International Centre for Indoor Environment and Energy for turning ICIEE into more than 'just a workplace'. I enjoyed working among you. And many thanks to my colleagues at the Center for the Built Environment at the University of California Berkeley for their warm welcome and their hospitality during my 6-month stay in the USA.

Thanks to all project partners (Karsten Andersen and Peter Foldbjerg from Velux, Jannick Karsten Roth and Thomas Berend Nielsen from WindowMaster, Jesper Pedersen, Jacob Buur, Jared Donovan and Svenja Jaffari from the University of Southern Denmark, Susanne Hoejholt from Saint-Gobain Isover and Lis Jacobsen from Nilan) for their comments on the content of the questionnaire survey and on the preliminary results of my study.

Special thanks to my parents and my brother: for their never-ending support.

And last but not least, thanks to my beloved Wilhelm for bringing so much happiness into my life and for his excellent computer support.

The Ph.D. study was performed as a part of the project "Indoor climate and quality of life" granted by the Danish Enterprise and Construction Authority (EBST) in the programme for user-driven innovation in the period 2008-2011, grant no. 07/08368. The stay at the Center for the Built Environment at the University of California Berkeley was facilitated and financially supported by the partnership agreement between the Danish Agency for Science, Technology and Innovation (DASTI) and the Center for Information Technology Research in the Interest of Society (CITRIS) at the University of California Berkeley.

Kongens Lyngby, November 2011

Monika Frontczak

Abstract

The main objective of the Ph.D. study was to examine occupants' perception of comfort and self-estimated job performance in non-industrial buildings (homes and offices), in particular how building occupants understand comfort and which parameters, not necessarily related to indoor environments, influence the perception of comfort.

To meet the objective, the following actions were taken: (1) a literature survey exploring which indoor environmental parameters (thermal, acoustic, visual environment and air quality) predominantly determine overall comfort and whether other factors unrelated to the indoor environment influence the perception of comfort; the literature survey summarized 42 peer-reviewed and conference articles and 1 book covering the period from 1970 to 2009; (2) preparation, distribution and analysis of a questionnaire survey sent to 2499 addresses representing the most common types of residential buildings in Denmark and filled out by 645 persons (response rate of 26%); and (3) analysis of the post-occupancy satisfaction survey conducted by the Center for the Built Environment (CBE) at the University of California Berkeley in 351 mainly U.S. office buildings and filled out by 52,980 building occupants.

The results of the literature survey showed that thermal, acoustic and visual environments and air quality all influenced evaluation of the overall indoor environment and that thermal comfort was ranked in the majority of cases to be of slightly greater importance for overall comfort than acoustic and visual comfort and satisfaction with air quality. The data from the Danish residential buildings showed actually slightly different results, indicating that when the acceptability of thermal, acoustic, visual conditions and air quality are of a similar magnitude, corresponding to low levels of dissatisfaction, then the acceptability of the overall indoor environment can be approximated by averaging acceptability of these individual parameters.

The literature survey suggested also that there are other factors unrelated to indoor environment such as personal characteristics of building occupants, building-related factors (type of building and control over the indoor environment) and the outdoor climate (including seasonal changes), that can influence the perception of comfort. Providing people with the possibility to control the indoor environment had a beneficial effect on the perception of comfort, indicating that control over the indoor environment should be delegated to building occupants. When the systems for controlling thermal environment are designed, the building type (naturally ventilated or air-conditioned) and local climate conditions should be taken into account. This has been further confirmed by the results from the Danish residential buildings showing that not only indoor environmental parameters contributed to occupants' comfort but also a peaceful atmosphere, contact with nature and the view through a window.

In office buildings, overall satisfaction with personal workspace was influenced by satisfaction with not only indoor environmental parameters but also satisfaction with workspace and building features. The highest increase in overall satisfaction with personal workspace would be achieved when increasing satisfaction with the amount of space for work and storage, noise level and visual privacy. However, if job performance is considered, then satisfaction with the main indoor environmental parameters should be addressed first as they affected self-estimated job performance to the highest extent. The present study showed that overall satisfaction with personal workspace affected significantly the self-estimated job performance. Increasing overall satisfaction with the personal workspace by about 15% would correspond to an increase of self-estimated job performance by 3.7%. Among indoor environmental parameters and building features, satisfaction with temperature was the most important parameter for self-estimated job performance, followed by satisfaction with noise level and air quality. It is obvious that there is a discrepancy between ranking of indoor environmental parameters and building features regarding their importance for overall workspace satisfaction and self-estimated job performance. Thus, the investments in improving conditions in indoor environments should be made according to whether improvement of satisfaction or self-estimated job performance is the aim.

The study in Danish residential buildings indicated that manual control of the indoor environment was highly preferred, and only in the case of temperature did respondents accept both manual and automatic control. The majority of respondents who reported having at least one problem related to the indoor environment, did not try to find information on how to solve the problem. This may suggest that there is a need for increasing people's awareness regarding the consequences of a poor indoor environment on their health and for improving people's knowledge on how to ensure a good indoor climate.

The present results, although comprehensive, need further validation.

Resumé

Hovedformålet med Ph.d. projektet var at undersøge beboernes opfattelse af komfort og selvanslåede arbejdspræstation i ikke-industrielle bygninger (boliger og kontorer), især hvordan bygningens brugere forstår komfort og hvilke parametre, ikke nødvendigvis relateret til indeklimaet, har indflydelse på opfattelsen af komfort.

For at opfylde målsætningen blev følgende tiltag fulgt: (1) en litteraturoversigt som udforsker hvilke indeklimaparametre (termisk, akustisk, visuelt miljø og luftkvalitet) der overvejende fastsætter den samlede komfort og hvorvidt andre faktorer, der ikke er relateret til indeklimaet, påvirker opfattelsen af komfort; litteraturoversigten sammenfatter 42 tidsskrift (peer-reviewed) og konference artikler og 1 bog, der dækker perioden fra 1970 til 2009. (2) forberedelse, distribution og analyse af en spørgeskemaundersøgelse sendt til 2499 adresser, der repræsenterer de mest almindelige typer af boliger i Danmark og udfyldt af 645 personer (responsrate på 26%) og (3) analyse af 'post-occupancy' tilfredshedsundersøgelse foretaget af Center for the Built Environment (CBE) ved University of California Berkeley i 351 hovedsageligt amerikanske kontorbygninger og udfyldt af 52.980 brugere af bygningerne.

Resultaterne af litteraturundersøgelsen viste at det termiske, akustiske og visuelle indeklima og luftkvalitet alle påvirker vurderingen af det samlede indeklima. I størstedelen af tilfældene havde den termiske komfort lidt større betydning for den overordnede komfort end akustisk og visuel komfort og tilfredshed med luftkvaliteten. Men dataene fra de danske beboelsesejendomme viste lidt forskellige resultater, der indikerer at når acceptable termiske, akustiske, visuelle forhold og luftkvalitet er af samme størrelsesorden, der svarer til et lavt niveau af utilfredshed, så kan accepten af det samlede indeklima approksimeres ved at tage gennemsnittet af accepten af disse individuelle parametre.

Litteraturoversigten antydede at der er andre faktorer, der ikke er relaterede til indeklimaet, såsom personlige karakteristika af bygningens brugere, bygningsrelaterede faktorer (type af bygning og kontrol over indeklimaet) og vejret (herunder sæsonmæssige ændringer), som kan påvirke opfattelsen af komfort. At give mennesker mulighed for at styre indeklimaet har gavnlig effekt på opfattelsen af komfort, hvilket indikerer, at kontrollen over indeklimaet skal uddelegeres til bygningens brugere. Når systemer til kontrol af termisk indeklima skal designes, skal bygningen type (naturlig ventilation eller air-condition) og lokale klimaforhold tages

i betragtning. Dette er blevet yderligere bekræftet af resultaterne fra de danske boliger, der viser, at ikke kun indeklimaparametre bidrager til beboernes komfort, men også en fredelig atmosfære, kontakt med naturen og udsigten gennem et vindue.

I kontorbygninger blev den generelle tilfredshed med det personlige arbejdsområde præget af tilfredshed med ikke kun indeklimamæssige parametre, men også af tilfredshed med arbejdspladsen og bygningens funktioner. Den højeste stigning i den samlede tilfredshed med den personlige arbejdsplads kunne opnås ved at øge tilfredsheden med mængden af plads til arbejde og opbevaring, støjniveau og visuelt privatliv. Men hvis man betragter arbejdspræstationen bør tilfredshed med de vigtigste indeklimaparametre behandles først, da de i den højeste grad påvirkede den selvanslåede arbejdspræstation. Denne undersøgelse viste at den samlede tilfredshed med den personlige arbejdsplads havde en signifikant påvirkning af den selvanslåede arbejdspræstation. At øge den samlede tilfredshed med den personlige arbejdsplads med omkring 15 % ville svare til en forøgelse af den selvanslåede arbejdspræstation med 3,7 %. Blandt indeklimaparametre og bygningens funktioner var tilfredshed med temperaturen den vigtigste parameter for selvanslåede arbejdspræstation, efterfulgt af tilfredshed med støjniveauet og luftkvaliteten. Det er indlysende, at der er en uoverensstemmelse mellem rangordning af indeklimaparametre og bygningens karakteristika i forbindelse med deres betydning for den overordnede tilfredshed med arbejdspladsen og den selvanslåede arbejdspræstation. Derfor bør investeringer i at forbedre forholdene i indeklimaet gøres afhængig af, om det er forbedring af tilfredshed eller selvanslåede arbejdspræstation der er målet.

Undersøgelsen i danske boliger viste, at manuel styring af indeklimaet i høj grad blev foretrukket og kun i tilfælde af temperatur accepterede respondenterne både manuel og automatisk styring. Flertallet af respondenterne der rapporterede at have mindst et problem relateret til indeklimaet, havde ikke forsøgt at finde oplysninger om, hvordan man løser problemet. Dette kan antyde, at der er behov for at øge folks bevidsthed om konsekvenserne af dårligt indeklima på deres helbred og for at forbedre folks viden om, hvordan man sikrer et godt indeklima.

De foreliggende resultater har, selv om de er omfattende, brug for yderligere validering.

Table of Contents

List of papers

The Ph.D. thesis is based on the following publications:

Paper I: Frontczak, M. and Wargocki, P. (2011) Literature survey on how different factors influence human comfort in indoor environments, Build Environ, 46(4), 922-937.

Paper II: Frontczak, M., Andersen R.V. and Wargocki, P. (2012) Questionnaire survey examining factors influencing comfort with indoor environmental quality in Danish housing, Build Environ, 50, 56-64.

Paper III: Frontczak, M., Schiavon, S., Goins, J., Arens, E., Zhang, H. and Wargocki, P. (2012) Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design, Indoor Air, 22(2), 119-131.

Paper IV: Frontczak, M., Wargocki, P., Schiavon, S., Goins, J., Arens, E. and Zhang, H. Relationships between self-estimated performance and satisfaction aspects of indoor environmental quality and building design (manuscript).

Paper V: Wargocki, P., Frontczak, M., Schiavon, S., Goins, J., Arens, E. and Zhang, H. (2012) Satisfaction and self-estimated performance in relation to indoor environmental parameters and building features, Proceedings of the 10th International Conference Healthy Buildings, Brisbane, Australia.

Chapter 1

Introduction

In the developed parts of the world people spend almost 90% of their time indoors (Klepeis et al., 2001; Leech et al., 1997). Indoor conditions have therefore far-reaching implications for their health, general well-being and performance. Many studies have explored how building users perceive the indoor environment and what conditions are considered by building occupants to be comfortable. In indoor environments, a number of physical and chemical parameters have been identified that influence the comfort of building occupants. Standards dealing with indoor environmental quality have been developed to define the acceptable ranges of these parameters. Even though the requirements of these standards are met, not all building occupants are satisfied with the indoor environment. The same indoor environmental conditions may lead to different subjective responses. One obvious reason is that people differ and therefore not all are satisfied by the same conditions. Another reason could be that not only physical conditions (temperature, sound level, illuminance level, CO_2 level, etc.) influence satisfaction with the indoor environment. There may also be other factors, unrelated to indoor environmental quality, such as personal characteristics of building occupants (gender, age, country of origin etc.), building-related factors (room interior, type of building and control over the indoor environment) and the outdoor climate (including seasonal changes) that influence whether the indoor environment is considered to be comfortable or not. Finally, the standards define conditions for single indoor environmental parameters, while humans integrate their impact in their responses. How to combine the impact of single conditions is unclear.

Many studies examining the issue of comfort of building occupants in indoor environments were focused mostly on the effects of single environmental conditions on humans, e.g. the visual environment (Galasiu and Veitch, 2006), the acoustic environment (Navai and Veitch, 2003), the thermal environment (Fanger, 1970) or air quality (Wargocki et al., 2002). Some studies investigated which factors not related to the indoor environment such as perceived control, adaptation, expectations and outdoor climate influence evaluation of e.g. the visual environment (Veitch, 2001) or the thermal environment (Brager and de Dear, 1998; Nicol and Humphreys, 2002). Very few studies looked at the impact of factors unrelated to the indoor environment on overall satisfaction with the indoor environment. However, occupants in buildings are exposed to all indoor environmental parameters simultaneously and their evaluation of the indoor environment is most likely influenced by the combined effect of different environmental parameters. Besides studying the combined effect of satisfaction with single environmental parameters on overall comfort, it is also important to examine the perception of comfort from a broader perspective and include the impact of parameters unrelated to indoor environment when investigating comfort.

In office buildings it was shown that occupants' satisfaction was affected not only by indoor environmental parameters (thermal, visual, acoustic environment and air quality) but also by workspace and building features, such as the view, control over the indoor environment, amount of privacy as well as layout, size, cleanliness, aesthetics and furniture of office (Bluyssen et al., 2011; Choi et al., 2009; Marans and Yan, 1989; Schakib-Ekbatan et al., 2010; Veitch et al., 2007). Occupants' satisfaction was also shown to be positively correlated with the self-estimated productivity of office workers (Leaman et al., 2007; Thomas, 2010). Occupants uncomfortable with the overall environment reported much lower self-estimated productivity than those who felt comfortable with the overall environment (Leaman and Bordass, 2001). Occupants' satisfaction with workspace was also positively associated with job satisfaction (Donald and Siu, 2001; Oldham and Rotchford, 1983; Veitch et al., 2007; Wells, 2000), which in turn had an impact on job performance (Judge et al., 2001). Job satisfaction was also related to frequency and duration of absenteeism (Hardy et al., 2003; Sagie, 1998) as well as intention to quit work (Hellman, 1997; Sagie, 1998; Shaw, 1999; Van Dick et al., 2004), issues which may have financial consequences for employers. Therefore, there is much to gain from maximizing occupants' satisfaction and more information should be collected on this matter.

The present study was part of a larger research programme on user-driven innovation aiming to develop concepts of control solutions for indoor environments that maximize comfort and performance of building occupants and enhance their quality of life. Thus the present study was designed to collect information on how future solutions for controlling the indoor environment should be developed so that they ensure the comfort of building occupants and at the same time are acceptable and desirable for building occupants themselves. To reach this goal it was investigated what constitutes comfort for building occupants, considering both indoor environmental parameters and factors unrelated to the indoor environment.

Chapter 2
Objectives

The main objective of the Ph.D. study was to examine occupants' perception of comfort and self-estimated job performance in non-industrial buildings (homes and offices), in particular how building occupants understand comfort and which parameters, not necessarily related to indoor environments, influence the perception of comfort.

Specific objectives of the Ph.D. study were the following:

- to examine what constitutes human comfort in non-industrial buildings (homes and offices) with particular focus on which environmental conditions (thermal, visual, acoustic environment and air quality) were ranked by building occupants as being the most important determinants of comfort (Papers I and II);
- to investigate which factors unrelated to the indoor environment contribute to the perception of human comfort (Papers I, II, III and V);
- to investigate which subjectively evaluated indoor environmental quality parameters and building features mostly affect self-estimated job performance in office buildings (Papers IV and V);
- to examine the link between occupants' satisfaction with their personal workspace and self-estimated job performance (Papers IV and V);
- to study whether type of office and distance from a window affects occupants' satisfaction and self-estimated performance levels in office buildings (Papers III and IV);
- to examine building occupants' behaviour related to securing a good indoor climate, in particular: (a) preferred ways of achieving comfort; (b) behaviour when people face indoor environmental problems and source of the information about how to deal with such problems and (c) self-estimated knowledge about using systems for controlling the indoor environment (Paper II).

Chapter 3

Methods

To meet the objectives of the Ph.D. study the following actions were taken: (1) performing a literature survey (Paper I); (2) preparation, distribution and analysis of a questionnaire survey conducted in residential buildings in Denmark (Paper II); and (3) analysis of the post-occupancy satisfaction survey conducted by the Center for the Built Environment (CBE) at the University of California Berkeley in office buildings (Papers III, IV and V). The methodology is described in detail in the following.

3.1 Literature survey (Paper I)

A literature search was undertaken for articles relevant to at least one of the aims of the paper: (1) articles presenting how thermal, acoustic and visual comfort, as well as satisfaction with air quality, are ranked by building occupants in connection with overall comfort and (2) articles discussing whether factors unrelated to the indoor environment, such as personal characteristics of building occupants (gender, age, country of origin etc.), building-related factors (room interior, type of building and control over the indoor environment) and the outdoor climate (including seasonal changes) play a role in the perception of comfort. Comfort concerned satisfaction with only the indoor environment and did not include satisfaction with other aspects of the building such as furniture, colours, etc. The literature search was limited to studies that were performed in non-industrial buildings (homes, offices and schools) or in the climate chambers in which environmental conditions resembled non-industrial buildings. Relevant articles were searched electronically in the databases of Science Direct, Compendex and Web of Science, and manually in the proceedings of Indoor Air and Healthy Buildings conferences. The literature survey summarizes 42 articles covering the period from 1977 to 2009. Additionally, a book of Fanger (1970) was included as it comprehensively describes the aspects related to the effects of the thermal environment on man.

3.2 Questionnaire survey in Danish residential buildings (Paper II)

A questionnaire survey was prepared, distributed among Danish citizens and analyzed. The questions included in the questionnaire were selected in accordance with the objectives of the project, i.e. to gain inspiration for concepts of future solutions for controlling the indoor environment, which will ensure comfort to building occupants and at the same time be solutions which are desired by them. The contents of the questionnaire were selected based on the results of earlier stages of the project: the literature survey (Paper I) and field studies among 5 families (Jaffari and Matthews, 2009; Jaffari, 2010). During the field studies the families were visited at their home, workplace and kindergarten (children). They were interviewed concerning their perception and knowledge about the indoor environment, their behaviour in relation to it and the way of dealing with indoor environmental problems if any.

Invitations to participate in the survey were sent by regular mail to 2499 addresses in Denmark. The addresses were obtained from a national building and housing database (BBR) and they represented different types of the most common residential buildings in Denmark. 2 reminders were sent to non-respondents 6 and 12 days after the invitation letter. In total, 47 letters were returned due to wrong addresses, resulting in a final sample size of 2452 addresses. 645 persons filled out the survey resulting in a response rate of 26%.

The questionnaire survey collected the following information: (1) background information including: socio-demographic data regarding age and gender of the respondent and co-habitants, education and type of work of the respondent, total income of the family; evaluation of the indoor environment (on continuous scales exemplified in Figure 3.1 and recommended by Standard EN15251 (2007), annex H) and perceived importance of single environmental parameters for achieving a good indoor climate; location where respondents feel comfortable and what factors contribute to comfort at this location; and (2) information addressing the following issues in home and office environment: behaviour in relation to window opening, adjusting heating and turning the lights on; preference for ways of controlling the indoor environment (Figure 3.2); self-estimated level of knowledge about how to use heating and ventilation systems optimally and extent of benefiting from receiving advice on how the homes should be ventilated, cleaned and heated (Figure 3.3); indoor environmental quality problems that respondents had and the methods used to solve them as well as how knowledge about the solution of problems was found (Figure 3.4). In the study the results of background questions and questions addressing home environment are reported. The questionnaire survey (in Danish) is presented in Appendix A.

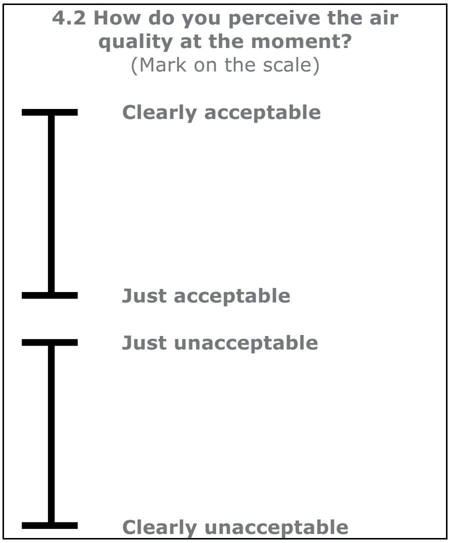

Figure 3.1 *Continuous scale used for evaluation of perception of the thermal environment, air quality, sound quality and light quality.*

16.2 How would you like to control the following in your home? (Put one cross for each line)

	Manually	Automatically	Combination of manual and automatic control	I do not know
Artificial light	☐	☐	☐	☐
Window opening	☐	☐	☐	☐
Solar shading	☐	☐	☐	☐
Temperature	☐	☐	☐	☐

Figure 3.2 *Question collecting information about preferred ways of controlling the indoor environment at homes.*

19.3 Do you think you would profit from being given advice about your behaviour in relation to ventilating, cleaning and heating?

- ☐ Yes, I would profit a lot
- ☐ Yes, I would profit a bit
- ☐ No, I would not profit so much
- ☐ No, I would not profit at all
- ☐ I do not know

Figure 3.3 *Question collecting information about the extent to which people would profit from being given advice about their behaviour in relation to ventilating, cleaning and heating.*

21.4 Have you tried to find information about how to solve the indoor environmental problems you have?

- ☐ No
  - ☐ I know what to do and I do not need more information
  - ☐ I do not know where to look for information
  - ☐ The problem is not serious enough to take action
  - ☐ It is not my responsibility
  - Other: __________
- ☐ Yes
  - ☐ I asked my friends
  - ☐ I asked my family
  - ☐ I consulted an expert (not relatives) / a company specializing in the field
  - ☐ I searched on the internet
  - ☐ I asked my doctor
  - ☐ I contacted the authorities
  - Other: __________
- ☐ I do not know

Figure 3.4 *Question collecting information about whether people looked for information on how to solve indoor environmental problem they had.*

Using the data collected in the questionnaire survey, the relationship between acceptability of overall indoor environment and acceptability of single environmental parameters (thermal, visual and acoustic environment and air quality) was examined; Spearman rank correlation was used (Siegel, 1956). This method was chosen because the data were not normally distributed and no linear model could be applied. The results were considered statistically significant when $p<0.05$.

3.3 CBE occupant satisfaction survey in office buildings (Papers III, IV, V)

Over a 10-year period the Center for the Built Environment (CBE) at the University of California Berkeley has conducted post-occupancy evaluation surveys in more than 600 buildings including offices, hospitals, schools and universities, research centres, assembly halls, commercial, governmental, residential, industrial and public buildings (e.g. libraries) and prisons. The subset of data collected by CBE in recent years was analyzed in the present study. This subset comprised only office buildings and people working in offices (single or shared offices, cubicles or open-space offices), resulting in a dataset containing responses from 52,980 building occupants from 397 surveys performed in 351 different buildings.

The CBE occupant satisfaction survey is a web-based tool collecting information about occupants' satisfaction and self-estimated performance in the following categories: office layout, office furnishings, thermal comfort, air quality, lighting, acoustic quality, cleanliness and maintenance as well as overall satisfaction with workspace and building and overall job performance (Zagreus et al., 2004). In each of above-mentioned categories there are between 1 and 3 questions pertaining to satisfaction and 1 question pertaining to self-estimated performance. The list of parameters evaluated in CBE occupant satisfaction survey is presented in Table 3.1 and the survey is shown in Appendix B.

Table 3.1 *List of parameters assessed by the CBE occupant satisfaction survey.*

Questionnaire item (satisfaction)	Questionnaire item (performance)
Amount of space available for individual work and storage	Office layout
Level of visual privacy	Office furnishings
Ease of interaction with co-workers	Thermal comfort
Comfort of office furnishings (chair, desk, computer, equipment, etc.)	Air quality
Ability to adjust furniture to meet your needs	Lighting quality
Colours and textures of flooring, furniture and surface finishes	Acoustic quality
Temperature in your workspace	Cleanliness and maintenance of the building
Air quality in your workspace (i.e. stuffy/stale air, air cleanliness, odours)	Job performance
Amount of light in your workspace	
Visual comfort of the lighting (e.g., glare, reflections, contrast)	
Noise level in your workspace	
Sound privacy in your workspace (ability to have conversations without neighbours overhearing and vice versa)	
General cleanliness of the overall building	
Cleaning service provided to your workspace	
General maintenance of the building	
Your personal workspace	
Building overall	

Questions about satisfaction have the following structure: "How satisfied are you with (e.g. temperature in your workspace, etc.)?" and the example of a question is given in Figure 3.5. The answers are subsequently coded as follows: "very satisfied" =+3, "very dissatisfied" = -3, and a neutral midpoint is coded as 0. Questions about performance are as follows: "Overall, does (e.g. thermal comfort, etc.) enhance or interfere with your ability to get your job done?" as exemplified in Figure 3.6. The scale is coded as follows: "enhances" =+3, "interferes" =-3, while a neutral midpoint is coded as 0. The summarizing performance question collecting information about the combined impact of all parameters on performance is as follows: "Please estimate how your job performance is increased or decreased by the environmental conditions in this building (e.g. thermal, lighting, acoustics, cleanliness)" as shown in Figure 3.7. An estimate is given on a 7-point scale ranging from 'increased' to 'decreased' with each point defined as 20%, 10%, 5%, 0%, -5%, -10% and -20%.

Figure 3.5 *Sample of questions and scales used in CBE occupant satisfaction survey to collect information on the satisfaction with different environmental parameters and building features as well as overall workspace and building satisfaction.*

Figure 3.6 *Sample of questions and scales used in CBE occupant satisfaction survey to collect information on whether different indoor environmental parameters and building features enhance or interfere with the ability to do a job.*

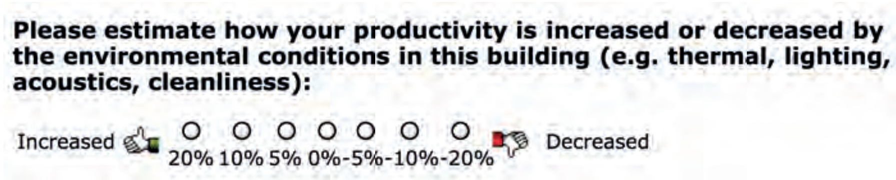

Figure 3.7 *Question and scale used in CBE occupant satisfaction survey to estimate how much job performance is increased or decreased by all environmental conditions in the building.*

As a part of the CBE occupant satisfaction survey respondents provide also information about their gender, age group, type of work performed, office type, proximity of workstation to windows and external walls as well as duration of working in the present building and at the present workspace. A building facility manager is also asked to fill out a building information form providing descriptive information about the building and its systems such as the building's age, location and size, number of floors, number of occupants, type of HVAC system, solar shading and controls, buildings' LEED rating, energy use and cost of building construction, etc.

The relationship between overall satisfaction with personal workspace and satisfaction with indoor environmental parameters and building features was examined using the data collected through the CBE occupant satisfaction survey; proportional odds ordinal logistic regression was used (Papers III and V). This method was chosen because response variable (satisfaction with personal workspace) is an ordinal variable: it takes only values that have a natural ordering (-3, -2, -1, 0, 1, 2, 3) but are not continuous (Baayen, 2008). The relationship between (1) self-estimated job performance and overall satisfaction with personal workspace and (2) self-estimated job performance and satisfaction with indoor environmental parameters and building features was also investigated; linear regression was applied (Papers IV and V). Linear regression was used as it provides a quantitative measure of the effect of satisfaction on the self-estimated job performance. It was also analyzed whether an office type (single or shared office, cubicles with high or low partitions) and distance of workstation from a window (within 4.6 m or further) has an effect on satisfaction levels. The Wilcoxon rank sum test (known also as Mann-Whitney test) was used as the satisfaction is measured on an ordinal scale (Siegel, 1956). The results were considered statistically significant when $p<0.05$.

Chapter 4

Results

4.1 Parameters influencing comfort

The results of the literature survey (Paper I) showed that thermal, acoustic and visual comfort and satisfaction with air quality all influenced evaluation of the overall indoor environment. Figure 4.1 summarizes the ranking of indoor environmental parameters regarding their importance for overall comfort; the majority of surveyed studies showed that thermal comfort was ranked to be of slightly greater importance for achieving overall comfort than acoustic and visual comfort and satisfaction with air quality. The data from the Danish residential buildings (Paper II) showed, on the other hand, that the assessment of all 4 main environmental parameters was equally important for the assessments of the overall indoor environment and contributed equally much to the overall acceptability. This was because the assessments of acceptability of the overall environment and acceptability of thermal, visual and acoustic environments and air quality were correlated and that correlation coefficients were of the similar magnitude (Table 4.1). This observation is only valid if the acceptability of the individual environmental parameters is of a similar magnitude corresponding to less than 30% of dissatisfied as those were the data obtained in Danish residential buildings. Equal contribution of individual parameters to overall comfort was further indicated by respondents in the Danish residential buildings (Paper II) when they were asked to compare pairwise which indoor environmental parameters were more important for a good indoor climate.

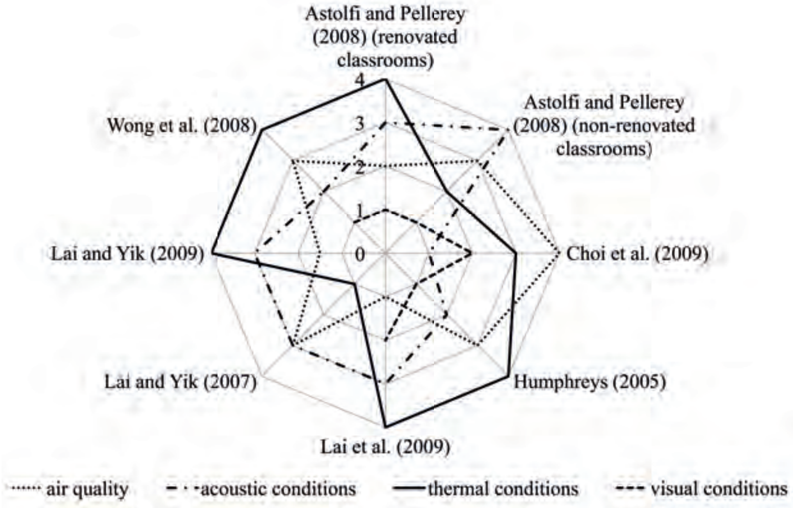

Figure 4.1 *Ranking of the importance of different environmental conditions for overall comfort; the higher number indicates higher ranking (importance).*

Table 4.1 *Spearman rank correlation coefficients between acceptability of the overall indoor environment and acceptability of the thermal, visual and acoustic environment and air quality.*

Parameter	Coefficient*
Air quality	0.64
Visual	0.52
Acoustic	0.52
Thermal	0.48

* $p<0.001$ (2-tailed test)

4.2 Factors unrelated to the indoor environment influencing comfort

The results of a literature survey (Paper I) indicated that there are other factors unrelated to the indoor environment such as personal characteristics of building occupants, building-related factors (type of building and control over the indoor environment) and the outdoor climate (including seasonal changes), which can influence the perception of comfort. There were some inconsistencies among the surveyed studies. Nevertheless, age, body build, fitness, health, self-estimated environmental sensitivity, menstruation cycle, pattern of smoking and coffee drinking, job stress and hours worked per week were shown in the majority of cases to have no influence on whether the indoor environment was assessed to be comfortable or not. The majority of surveyed studies showed that country of origin, level of education, type of job, psychosocial atmosphere at work and time pressure did influence assessment of the indoor environment. Gender, job satisfaction and relationship with superiors and colleagues in some studies were shown to have an influence and in some studies to have no effect on whether the indoor environment was assessed to be comfortable or not. Considering the building-related factors, type of building had an impact on perception of thermal comfort. Occupants in naturally ventilated buildings accepted higher indoor temperatures in summer and lower indoor temperatures in winter, and they also accepted wider temperature ranges compared with occupants in air-conditioned buildings. Providing people with the possibility to control the indoor environment improved thermal and visual comfort and satisfaction with air quality as well as overall satisfaction with the indoor environment. Outdoor climate and season had also an impact on the perception of thermal comfort. Neutral temperatures increased with increasing outdoor temperatures and differed between seasons.

The results of the literature survey (Paper I) showing that not only indoor environmental parameters influenced occupant satisfaction were further confirmed by the findings from the questionnaire survey conducted in Danish residential buildings (Paper II). Respondents were asked an open question in which they were requested to describe in their own words which aspects contribute to their comfort. The 10 most frequently mentioned aspects are presented in Table 4.2. Indoor environmental parameters (light, temperature, air quality and noise level) were mentioned most often as aspects contributing to comfort, together with peace and silence, contact with nature and view through a window, but also many other aspects were mentioned such as possibility of controlling the indoor climate, privacy and safety.

Table 4.2 *Ten most frequently used words in descriptions of aspects contributing to comfort.*

Aspect	Percentage of all responses
Light, sun	46%
Temperature, warmth	35%
Fresh/clean air, smell	21%
Sound, noise	16%
Peace, silence	15%
Nature	15%
View	14%
Size of room	9%
Family and friends	8%
Room interior, style, furniture	8%

4.3 Parameters influencing overall satisfaction with personal workspace

In office buildings overall satisfaction with personal workspace was influenced not only by satisfaction with indoor environmental parameters but also by satisfaction with workspace and building features (Papers III and V). The results of proportional odds logistic regression showed that satisfaction with all 15 environmental parameters and building features listed in the CBE occupant satisfaction survey contributed significantly ($p<0.001$) to overall satisfaction with personal workspace (Figure 4.2). The most important parameter for overall workspace satisfaction was satisfaction with the amount of space available for work and storage. Increasing satisfaction with the amount of space would increase 1.57 times the likelihood that overall workspace satisfaction is also increased compared to the case when satisfaction with the amount of space is not increased. Satisfaction with the amount of space was slightly correlated to satisfaction with visual privacy, ease of interaction, noise and sound privacy. However, the variance inflation factor was below 3 indicating that there was no problem of multicollinearity between predictor variables. The next most important parameters for overall satisfaction with personal workspace were satisfaction with noise level and visual privacy. Satisfaction with the amount of space for work and storage was ranked to be the most important parameter for overall satisfaction with the personal workspace, regardless of respondents' age group (below 30, 31-50 or over 50 years old), gender, type of office (single or shared office, or cubicles with high or low partitions), distance of workstation from a window (within 4.6 meters or further) or satisfaction level with personal workspace (satisfied including neutral responses or dissatisfied).

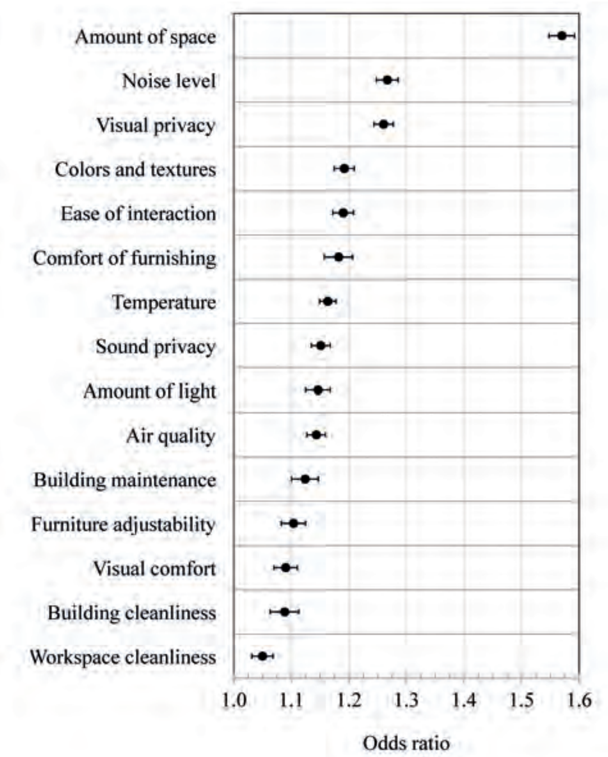

Figure 4.2 *Odds ratios together with 95% confidence intervals for satisfaction with indoor environmental parameters and building features included in the CBE occupant satisfaction survey. The response variable is overall satisfaction with personal workspace.*

4.4 Impact of satisfaction on self-estimated job performance

Simple linear regression showed that overall satisfaction with personal workspace affected significantly ($p<0.001$) the self-estimated job performance (Papers IV and V). Increasing overall satisfaction with personal workspace by one unit on a 7-point scale would correspond to increasing self-estimated job performance by 3.7%. Among indoor environmental parameters and building features listed in the CBE occupant satisfaction survey, satisfaction with cleanliness of workspace, amount of light and comfort of furnishings was not statistically significant ($p>0.05$) in the multivariate linear regression model (Figure 4.3), indicating that they cannot be considered to influence self-estimated job performance. The most important parameter for self-estimated job performance was satisfaction with temperature. Increasing satisfaction with temperature by 1 unit on a 7-point scale would increase the self-estimated job performance by about 1% while the satisfaction with all other parameters was kept constant. The next most important parameters for self-estimated job performance were satisfaction with noise level and air quality, which would increase the self-estimated job performance by about 0.8%.

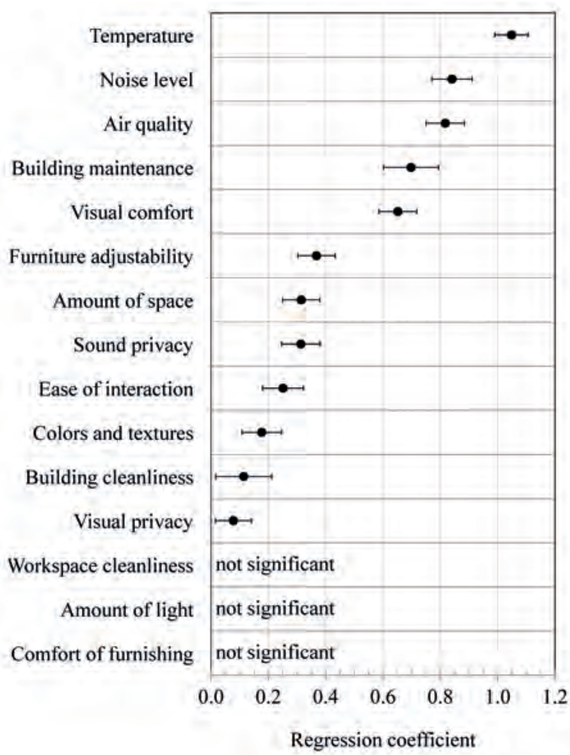

Figure 4.3 *Regression coefficients together with 95% confidence intervals for satisfaction with indoor environmental parameters and building features included in the CBE occupant satisfaction survey. The response variable is self-estimated job performance.*

4.5 Impact of office design on satisfaction and self-estimated performance

The results of the CBE occupant satisfaction survey showed that office type and distance from a window had an impact on satisfaction and self-estimated performance levels (Papers III and IV). Respondents sitting close to a window (within 4.6 m) and in single offices expressed significantly higher workspace satisfaction compared with those sitting further from a window and in shared offices and cubicles. Satisfaction with almost all indoor environmental parameters and building features was also significantly higher at workstations close to a window and in single offices than at workstations far from a window and in shared offices and cubicles. Respondents sitting close to a window (within 4.6 m) and in single offices estimated also their job performance to be significantly higher compared with those sitting further from a window and in shared offices and cubicles. All indoor environmental parameters and building features were assessed to enhance to a greater extent the ability of doing the job at workstations close to a window and in private offices compared with workstations far from a window and in shared offices and cubicles.

4.6 Behavioural aspects important for comfort

The results of the questionnaire survey conducted in Danish residential buildings (Paper II) showed that a vast majority of respondents preferred manual control over the indoor environment as opposed to automatic control, especially in the case of artificial light, window opening and solar shading (Figure 4.4). Respondents were more positive regarding automatic control or a combination of manual and automatic control in relation only to control of temperature. They also valued natural ventilation highly and it was very important for them to have the opportunity to open a window in their home. They indicated that the possibility to open the windows gave them a chance to take care of their own and their family's health as well as to air their homes. For many respondents it was not important that their homes are aired out with mechanical ventilation, suggesting that fresh air was associated with natural ventilation (window opening) and not mechanical ventilation systems.

Respondents indicated that they were aware of how their behaviour influenced energy use and indoor environment. They also felt confident in using the systems for controlling the indoor environment in their homes and indicated that they do not need any advice on their behaviour in relation to ventilating, cleaning and heating. If the advice would be accepted, respondents would rather prefer it in a form of an apparatus guiding them on how to obtain a good indoor climate while using as little energy as possible. The question about the apparatus was specifically asked to address the intension to develop the concept of control solutions maximizing comfort. It was intended to learn whether such an apparatus would be accepted and at what cost.

54% of respondents reported to have at least one problem related to indoor environmental quality and many respondents indicated that they had little or no knowledge as to whether the problems had any serious consequences on their health or building conditions. Among them, more than half did not try to find information on how to solve the problem that they faced, mostly because they considered that it was not serious enough to act upon. Among those who tried to find information, the most common source was the internet. Respondents avoided solving an indoor environmental quality problem due to financial reasons and because they believed that the problem was not serious enough to act upon.

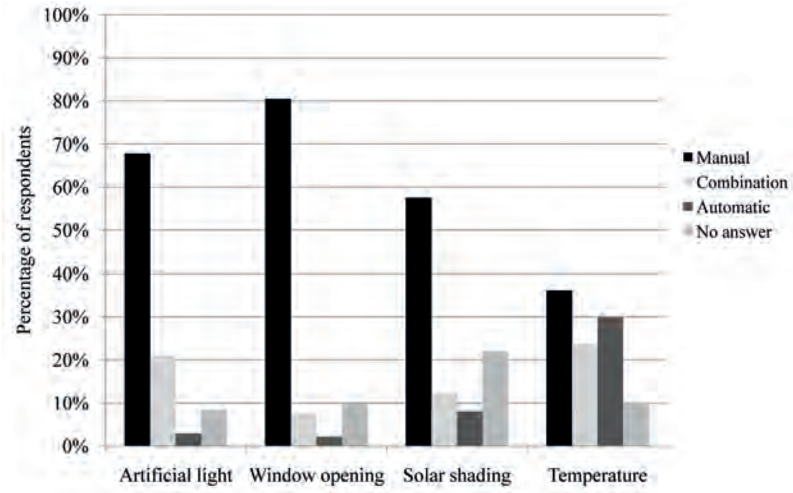

Figure 4.4 *Percentage of respondents preferring different types of control of indoor environmental parameters. Category 'No answer' includes both responses 'I do not know' and respondents who did not provide any answer.*

Chapter 5
Discussion and implications

In the following the implications of the results obtained in the present thesis (Papers I to V) are discussed among others in the context of the concepts of solutions promoting occupants' satisfaction and self-estimated performance. This is because the Ph.D. study is part of a larger research programme on user-driven innovation aiming to develop control solutions for indoor environments that maximize comfort and performance of building occupants and enhance their quality of life.

Questionnaire survey in Danish residential buildings (Paper II) investigated to what extent satisfaction with thermal, acoustic, visual environment and air quality contribute to satisfaction with overall indoor environment. Satisfaction was measured by asking people to rate acceptability on a continuous scale. European Standard EN15251 (2007) recommends overall classification of the indoor environment based on evaluation of each individual indoor environmental parameter and it does not provide any information on how to combine different environmental parameters into one index that can be used to classify the overall indoor environmental conditions in the building. However, occupants in buildings are exposed to all indoor environmental parameters simultaneously and their evaluation of the indoor environment is most likely a combination of the evaluation of different environmental parameters. The results from the Danish residential buildings (Paper II) showed that the correlation coefficients between acceptability of overall indoor environment and acceptability of thermal, visual and acoustic environment and air quality were of similar magnitude, suggesting that the acceptability of the overall indoor environment can be approximated by averaging acceptability of individual environmental parameters. This is valid when acceptability of thermal, acoustic, visual conditions and air quality are of a similar magnitude corresponding to less than 30% of dissatisfied (categories I to III according to Standard EN15251 (2007)) as these were the data obtained in Danish residential buildings. Thus it can be proposed to use this method until data are obtained showing otherwise; validation would, however, be recommended.

The results of the literature survey (Paper I) showed that there are other parameters not related to the indoor environment that influence whether the indoor environment will be evaluated as comfortable or not. Thermal comfort was influenced by building type and climate including seasonal changes. Occupants in naturally ventilated buildings accepted higher indoor temperatures in summer and lower temperatures in winter, suggesting that designing the systems for achieving thermal comfort requires a case-by-case approach, depending on the building type. Local outdoor climate should also be considered. Differences in neutral temperature between seasons were observed, suggesting that the temperature indoors should follow the change in outdoor temperature rather than be kept constant for the entire year. The differences between seasons were greater in hot and warm climates than in cold and moderate climates. Consequently, these results indicated that the decision as to what extent indoor temperature should follow seasonal change should be made with due consideration to local climate conditions. The findings of the literature survey (Paper I) support thus to some extent the principles used to develop an adaptive thermal comfort approach proposed by Brager and de Dear (1998).

The review article of Heijs and Stringner (1988) suggested that perception of thermal comfort may be influenced by psychological variables (such as knowledge and experience) and classificatory variables (such as gender, age). The results of the present literature survey (Paper I) were not consistent as regards the impact of individual characteristics of building occupants on the perception of comfort. Some surveyed studies showed that gender, job satisfaction, relationship with superiors and colleagues did influence comfort and some that they did not. Nevertheless, it seems reasonable to suggest that when the systems for controlling the indoor environment are designed, the possibility of customizing environmental conditions should be offered to building occupants in order to reflect their preferences. This is shown in the papers reviewed (Paper I) and in the study of Paciuk (1990) indicating that providing personal control over the environment to building occupants had a beneficial effect on the perception of comfort. The importance of individual control for achieving comfort was also underlined by the study of Karjalainen and Lappalainen (2011).

Responses from the CBE occupant satisfaction survey were used to investigate the satisfaction level and self-estimated performance in relation to indoor environmental parameters and building features (Papers III, IV and V). The highest dissatisfaction was observed for sound privacy, temperature, noise level and air quality. Despite the high dissatisfaction with privacy and indoor environmental parameters, building occupants were generally satisfied with their personal workspace. This may suggest that people may accept discomfort with some parameters and it will not have a strong effect on the overall satisfaction. When asked about the combined effect of indoor environmental parameters and building features on their job performance, 24% of respondents indicated that their job performance was neither increased nor decreased by the overall conditions related to environmental and building parameters. For each indoor environmental parameter and building feature evaluated separately, about 1/3 of respondents indicated that the parameter neither enhanced nor interfered with the ability to do their job. These results may suggest that many people do not associate indoor environmental parameters and building features with their performance.

Responses from the CBE occupant satisfaction survey were used to investigate which subjectively evaluated indoor environmental parameters and building features play a major role when people evaluate overall satisfaction with personal workspace (Papers III and V). Knowledge about people’s priorities may be used as guidelines when constructing and renovating buildings so that building occupants' satisfaction can be maximized. The results showed that in order to maximize overall satisfaction with personal workspace, investments should first be made which increase satisfaction with the amount of space for work and storage, noise level and visual privacy. When the parameters related to the interior design of the workspace that should be addressed in the design phase are only considered, then satisfaction with amount of space for work and storage, visual privacy and colours and textures are the most important. Among parameters related to the indoor environmental quality that have to be addressed in the operating phase of the building, satisfaction with noise level, temperature and amount of light are the most important. However, if self-estimated job performance is considered, then satisfaction with temperature, noise level and air quality should be first improved as they affect self-estimated job performance to the highest extent (Papers IV and V). Satisfaction with the amount of space and visual privacy (parameters highly important for workspace satisfaction) were of much lower importance for self-estimated job performance. The discrepancy between ranking of indoor environmental parameters and building features regarding their importance for overall workspace satisfaction and self-estimated job performance implies that the investments in improving conditions in indoor environments should depend on whether it is aimed to improve satisfaction (comfort) or self-estimated performance.

The results of the CBE occupant satisfaction survey (Papers IV and V) showed that increasing satisfaction with temperature by 1 unit on a 7-point scale, corresponding to a change of about 15% (assuming that the scale can be treated as linear), would increase the self-estimated job performance by about 1% while the satisfaction with all other parameters was kept constant. In the case of satisfaction with noise level and air quality, 1 unit change would correspond to about 0.8% and for the other parameters it was even smaller than the aforementioned. Although the magnitude of effects on the self-estimated job performance was quite small, the improvements of environmental quality and building features are still expected to be cost-effective, if only self-estimated performance reflects reasonably well the actual change in productivity. So far, there are no data providing evidence for this. The reason for cost-effectiveness of investments in environmental quality and building features is that for a typical office building, 82% of all costs are associated with building occupants (salaries and benefits of employees), while the remaining costs cover building construction and arrangement, technology support, maintenance and operations (Brill et al., 2001). Consequently, even a small increase in workers' productivity would justify the costs associated with investments for improving the indoor environment (Wargocki et al., 2006). This is further supported by previous cost-benefit analyses reported in the literature (Dorgan et al., 1994; Fisk and Rosenfeld, 1997; Fisk et al., 2011; Wargocki and Djukanovic, 2005).

Responses from the CBE occupant satisfaction survey were used to investigate whether satisfaction levels and self-estimated performance levels were affected by office type (single and shared offices, and cubicles with high and low partitions) and distance from a window (within 4.6 m from a window and further), enabling identification of the optimal office settings from the building occupants' point of view (Papers III and IV). Respondents sitting close to a window and in single offices expressed significantly higher self-estimated job performance and satisfaction with workspace and almost all indoor environmental parameters and building features compared with those sitting further from a window and in shared offices and cubicles.

All indoor environmental parameters and building features enhanced to a greater extent the ability to do the job at workstations close to a window and in private offices compared with workstations far from a window and in shared offices and cubicles. The results indicated that in order to maximize building occupants' satisfaction and job performance, their workstations should be located in single offices close to a window.

The study in Danish residential buildings (Paper II) indicated that there is a need to increase people's awareness regarding the consequences of poor indoor environment on their health and for improving people's knowledge on how to ensure a good indoor climate. Many of the respondents who had at least one problem related to indoor environmental quality at home judged mainly on their own how serious the problem was, without consulting any experts in the field. Regular inspections of homes with subsequent mandatory repairs would probably ensure that the indoor environment is at an acceptable level, but there is meagre evidence of their effectiveness, although analogous regular car checks are quite successful. Regular inspections of HVAC systems in public buildings are mandatory in Sweden (Boverket, 2009), while in Portugal regular energy audits imposed by Directive on the Energy Performance of Buildings (2003) are accompanied by measurements of indoor air quality that can identify potential problems. A diagnostic tool that will help to evaluate the seriousness of indoor environmental problems can also be developed. An internet-based tool might be effective since respondents in Danish residential buildings indicated the internet as the most common source of information when facing problems related to indoor environmental quality. Such a tool should provide an estimated cost of solving the problem as well as health- and building-related consequences of not doing so and should help people to make an informed decision as to whether or not the problem should be solved. A big challenge is to reach people who ignore the indoor environmental problems and fail to look for more information. These people may be addressed by educational campaigns. A survey among Danish citizens showed that increased knowledge may lead to change of behaviour (Zapera, 2007). Information about the indoor environment may also be described in the daily press and magazines in an easily understandable way for laymen. In this way, people will be addressed without actively looking for information, leading to increased awareness about ensuring a good indoor environment and to a positive change of behaviour.

Respondents of the survey in Danish residential buildings (Paper II) expressed preference for manual control over the indoor environment. As a result, two solutions for controlling the indoor environment can be considered:

- automatic control securing minimum acceptable conditions with the possibility of manual adjustment (override) of conditions to occupants' needs;
- manual control by building occupants.

In the former solution, the automatic system can be designed to ensure the minimum requirements for an acceptable indoor environment, and the occupants can adjust the indoor environment to their needs as required. In the latter solution, the building occupants are fully responsible for ensuring a good indoor environment. However, the relevant question is whether the occupants will always act when the situation arises. In the study of Price and Sherman (2006) in the U.S., nearly 50% of respondents indicated that they sometimes failed to use the bathroom fan even when conditions clearly required it, most often because they simply did not think of it. In such a situation, a basic automatic ventilation of the bathroom (e.g., a fan that turns on when the light is turned on or humidity is too high) could be an appropriate solution. A system that warns people when they should act, or a system that continuously visualizes whether indoor environmental quality conditions are good or poor, may be useful. The examples of such a system were presented by Jaffari and Matthews (2009), Boer (2011) and Kim and Paulos (2009). Jaffari and Matthews (2009) suggested an artificial plant that wilts at high CO_2 levels while low CO_2 levels make it rise back to the upright position, but no data describing the practical use of such a plant is available. Boer (2011) constructed a lamp that represents the levels of temperature, humidity, sound, light and CO_2 by means of light; he placed it in the home of one family for 9 days and the idea to visualize the indoor environment through lights seemed appealing to the family. Kim and Paulos (2009) designed a tool for continuous graphical visualization of indoor air quality (based on measurements of particles below 0.5 microns); they placed it in 5 homes for 2 weeks and observed that it had a positive impact on willingness to take action to improve the indoor environment. Many respondents of the survey in Danish residential buildings (Paper II) indicated that they would use an apparatus that could guide them on how to secure a good indoor climate while using as little energy as possible. They indicated that they would pay on average €230 (range between €0 and €2600) for such an apparatus.

5.1 Practical implications

Below the practical implications of the present work are underlined:

- Designing systems for achieving thermal comfort in the buildings requires a case-by-case approach with due consideration of building type (air-conditioned or naturally ventilated) and local climate conditions;
- When the systems for controlling the indoor environment are designed, the possibility of customizing environmental conditions should be offered to building occupants in order to reflect their preferences;
- In order to maximize overall satisfaction with personal workspace, investments should first be made which increase satisfaction with the amount of space for work and storage, noise level and visual privacy;
- In order to maximize self-estimated job performance, investments should first be made which increase satisfaction with temperature, noise level and air quality;
- In order to maximize building occupants' satisfaction and self-estimated job performance, the workstations should be located in single offices close to a window;
- A system that warns people when indoor environmental conditions are poor, or a system that continuously visualizes whether indoor environmental quality conditions are good or poor may be beneficial for increasing people's awareness about indoor environment and motivating them to act in order to improve indoor conditions.

5.2 Limitations

In the literature survey (Paper I), relatively few studies were found that examined the influence of factors unrelated to the indoor environment on overall comfort, compared for example with the number of studies discussing the same issue in relation to SBS symptoms. It is expected that there are more studies that provide information on this issue. They were not identified in the present survey, probably because this influence was not reported as a main result and therefore could have been omitted when searching the databases and screening the results using abstracts.

The main limitation of the questionnaire survey conducted in Danish residential buildings (Paper II) is a very low response rate (26%). The responses cannot be considered as representative for the Danish population due to the potential of selection bias. No non-respondents analysis was made to examine this bias. The respondents had a higher education status than an average Dane. In the sample tested there was also an underrepresentation of people younger than 52 years and an overrepresentation of people aged 52 years and older as compared to the Danish adult population. However, additional analysis showed that the differences between respondents younger and older than 52 years old were small, if any, which suggests that the overrepresentation of people older than 52 years in the tested sample had a small impact on the overall study results.

One of the limitations of the analysis of the CBE occupant satisfaction survey (Papers III, IV and V) is related to the selection of buildings in which the survey was conducted. There was no systematic randomized approach in relation to building selection. Almost 80% of the surveyed buildings were situated in the USA so the results relate primarily to American settings. Furthermore, the survey considered only the influence of satisfaction with 15 different indoor environmental parameters and building features on overall satisfaction with personal workspace and self-estimated job performance; there may be other parameters that affect overall workspace satisfaction or self-estimated job performance. Another limitation of the CBE occupant satisfaction survey is the absence of physical measurements. It would be preferable to relate subjective responses of building occupants to objective measures of indoor environmental parameters and building features. Moreover, productivity of office workers was not measured objectively and it is not known to what extent the self-estimated job performance represents actual change in workers' productivity. There are basically no data in the research literature on whether the two metrics are correlated but there are also no data showing that they are not correlated. The work of Clausen and Wyon (2008) did imply that the self-estimated performance was twice as much affected by improved indoor environmental quality as subjectively measured performance. But their results obtained in the laboratory need to be verified. Consequently the obtained quantitative figures between satisfaction and self-estimated job performance should be treated with caution.

The results of the Ph.D. study, although comprehensive, need further validation.

5.3 Recommendations for future studies

In Danish residential buildings it was observed that if acceptability of thermal, acoustic, visual conditions and air quality are of a similar magnitude corresponding to less than 30% dissatisfied, the acceptability of the overall indoor environment can be approximated by averaging acceptability of these individual parameters. Independent validation (both in climate chambers and in field studies) is needed. A corresponding study in an office environment is recommended.

The present study investigated the impact of satisfaction with 15 different indoor environmental parameters and building features on overall satisfaction with personal workspace and self-estimated job performance. There may be other parameters not included in the CBE occupant satisfaction survey that affect overall workspace satisfaction or self-estimated job performance, e.g. control over the indoor environment; the effect of such parameters should be investigated in future studies.

The present study focused on behavioural aspects of comfort creation in residential buildings. It is recommended to investigate this issue in office buildings, as the solutions proposed in the present study (e.g. an apparatus guiding how to ensure a good indoor environment) may not be directly applicable for offices.

Chapter 6
Conclusions

The results of the literature survey (Paper I) showed that thermal comfort was considered in the majority of cases to be of slightly higher importance for achieving overall comfort than acoustic and visual comfort and satisfaction with air quality. The data from the Danish residential buildings (Paper II) showed slightly different results, suggesting that if acceptability of thermal, acoustic, visual conditions and air quality are of a similar magnitude corresponding to less than 30% dissatisfied, the acceptability of the overall indoor environment can be approximated by averaging acceptability of these individual parameters.

The results of the literature survey (Paper I) showed that there are other factors unrelated to the indoor environment that influence whether the indoor environment is evaluated as comfortable or not. The studies surveyed were not consistent as regards the impact of personal characteristics on the perception of comfort. The type of building and outdoor climate including season influenced thermal comfort. Occupants in naturally ventilated buildings accepted higher indoor temperatures in summer and lower indoor temperatures in winter than in air-conditioned buildings. Neutral temperatures increased with increasing outdoor temperatures and differed between seasons. Providing people with the possibility to control the indoor environment had a beneficial effect on the perception of comfort. These results were further confirmed by findings from the questionnaire survey conducted in Danish residential buildings (Paper II), showing that not only indoor environmental parameters contributed to occupants' comfort but also a peaceful atmosphere, contact with nature and the view through a window.

In office buildings, occupant satisfaction with the personal workspace was influenced by not only satisfaction with indoor environmental parameters but also by satisfaction with workspace and building features (Papers III and V). The most important parameters for overall satisfaction with personal workspace were satisfaction with the amount of space for work and storage, noise level and visual privacy.

Overall satisfaction with personal workspace affected significantly the self-estimated job performance (Papers IV and V). Among indoor environmental parameters and building features listed in the CBE occupant satisfaction survey, the most important parameters for self-estimated job performance were satisfaction with temperature, noise level and air quality (Papers IV and V).

Office workers expressed higher satisfaction with their personal workspace and assessed their performance higher when working in a private office close to a window (within 4.6 m) compared with working in a shared office or cubicle with high or low partitions, or a workstation further from a window (Papers III and IV).

The results of the survey conducted in Danish residential buildings (Paper II) indicated that manual control of the indoor environment was highly preferred, and only in the case of temperature did respondents accept both manual and automatic control. The majority of respondents who reported having at least one problem related to the indoor environment, did not try to find information on how to solve the problem. This may suggest that there is a need for increasing people's awareness regarding the consequences of poor indoor environment on their health and for improving people's knowledge on how to ensure a good indoor climate.

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Paper I

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Literature survey on how different factors influence human comfort in indoor environments

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ABSTRACT

The present paper shows the results of a literature survey aimed at exploring how the indoor environment in buildings affects human comfort. The survey was made to gather data that can be useful when new concepts of controlling the indoor environment are developed. The following indoor environmental conditions influencing comfort in the built environment were surveyed: thermal, visual and acoustic, as well as air quality. The literature was surveyed to determine which of these conditions were ranked by building users as being the most important determinants of comfort. The survey also examined the extent to which other factors unrelated to the indoor environment, such as individual characteristics of building occupants, building-related factors and outdoor climate including seasonal changes, influence whether the indoor environment is evaluated as comfortable or not. The results suggest that when developing systems for controlling the indoor environment, the type of building and outdoor climate, including season, should be taken into account. Providing occupants with the possibility to control the indoor environment improves thermal and visual comfort as well as satisfaction with the air quality. Thermal comfort is ranked by building occupants to be of greater importance compared with visual and acoustic comfort and good air quality. It also seems to influence to a higher degree the overall satisfaction with indoor environmental quality compared with the impact of other indoor environmental conditions.

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1. Introduction

In developed countries people spend more than 90% of their time indoors. Indoor conditions have therefore far-reaching implications for their health, general well-being and performance. Numerous studies have explored how building users perceive the indoor environment and which conditions are considered to be comfortable. In indoor environments, a number of physical and chemical parameters have been identified that influence the comfort of building occupants. Standards dealing with indoor environmental quality have been developed to define the acceptable ranges of these parameters. Even though the requirements of these standards are met, not all building occupants are satisfied with the indoor environment. In addition, the same indoor conditions may lead to different subjective responses. One obvious reason is that people differ and therefore not all are satisfied by the same conditions. Another reason could be that not only physical conditions influence satisfaction with indoor environments. There may also be other factors, unrelated to environmental quality, that influence whether indoor environments are considered to be comfortable or not; these factors are usually not regulated by the standards.

Previous literature reviews examining the issue of comfort of building occupants in indoor environments were focused mostly on the effects of single environmental conditions on humans. For example, reviews were made investigating which conditions lead to satisfaction with the visual environment [1] or with the acoustic environment [2]. Some reviews examined which factors not related to the indoor environment may influence preference for indoor environmental conditions. These reviews again focused on satisfaction with a single environmental condition, e.g. the visual environment [3] or the thermal environment [4,5]. No review has been carried out summarizing the possible influence of different non-environmental factors on whether overall indoor environmental quality, being an interaction of thermal, visual and acoustic conditions as well as indoor air quality, is evaluated as comfortable or not. The present literature survey was performed to gather more information on this matter.

The objective of the present literature survey was to investigate what constitutes comfort for building occupants. This knowledge is

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Table 1
Summary of studies investigating the importance of environmental conditions on overall satisfaction with IEQ.

Study	Place of experiment	Population	Procedure	Data analysis	Results	Concluding remarks
[14]	Climate chambers	Untrained panel of subjects ($n = 48$)	Participants evaluated conditions in the chamber in the context of being exposed to those conditions all day at work; then the analyses were performed to compare the ranges of change of operative temperature, pollution level and noise level, which would correspond to equal change in % dissatisfied	Logistic regression analysis	A 1 °C change in operative temperature was found to correspond to a change of 3.8 dB(A) in sound pressure level or a change of perceived air quality by 7 decipol (measured at 26 °C) (Spearman rank–order correlation coefficient: 0.9)	The relationship was based on an average of 5 assessments made by each subject during their 30-min presence in the chamber. The study did not rank the environmental conditions, but quantitatively compared their impact on dissatisfaction
[15]	Secondary school in Italy, some of the classrooms were acoustically renovated	Students ($n = 852$, RR = 85%)	Participants filled out the questionnaires about their satisfaction with thermal, visual, acoustic conditions, air quality and overall environmental quality with reference to a typical, cold and sunny winter day; the analyses were then performed to find the correlation between each environmental condition with the overall satisfaction with IEQ	Analysis of consistency: Kolmogorov–Smirnov normality test and Mahalanobis and Cook distances; correlation: Pearson coefficient	In the acoustically renovated classrooms the highest correlation was found between the overall satisfaction with IEQ and thermal conditions (Pearson coefficient: 0.50), followed by acoustic conditions (0.39), air quality (0.32) and visual conditions (0.29). In non-renovated classrooms overall satisfaction with IEQ was highly correlated with acoustic conditions (0.50) and much lower correlations were observed with indoor air quality (0.31), thermal (0.28) and visual conditions (0.25)	Relative importance of environmental conditions on overall satisfaction with IEQ was not constant. The environmental conditions were ranked differently depending on acoustical properties of the classrooms. The ranking of conditions did not depend on satisfaction level with a particular condition – the lower level of satisfaction did not cause the condition to be considered more important
[16]	29 office buildings in the USA	Building occupants ($n = 492$, RR unknown)	Participants filled out questionnaires to rate their satisfaction with indoor air quality, thermal, acoustic and visual environment and overall satisfaction with IEQ; the analyses were then performed to find the correlation between satisfaction with each environmental condition and the overall satisfaction with IEQ	Two sample *t*-test; Pearson correlation coefficient	The highest correlation was found between the overall satisfaction with IEQ and satisfaction with air quality (Pearson coefficient: 0.52), followed by satisfaction with thermal (0.51), visual (0.45) and acoustic (0.43) conditions (all p-values <0.000)	The ranking of environmental conditions slightly differed between females and males, and between perimeter and interior zones. Women valued lighting higher than acoustics compared to men, who valued acoustics more than lighting. Those sitting in the interior zone ranked lighting higher than thermal conditions compared with those sitting in the perimeter zone, who ranked thermal conditions higher than lighting. The importance of conditions did not depend on the satisfaction level with a particular condition – the lower level of satisfaction did not cause the condition to be considered more important
[17]	Climate chambers	Untrained panel of subjects ($n = 16$)	Participants evaluated conditions in the chambers in the context of being exposed to these conditions in their daily work; the analyses were then performed to compare the range of changes of operative temperature, perceived air quality and noise level, which would cause equal change in % dissatisfied	Probit analysis and linear regression analysis	A 1 °C change in operative temperature caused the same % dissatisfied as a change in perceived air quality of 2.4 decipol (at 23.1 °C) or a change in sound pressure level of 3.9 dB(A)	The relationships were based on assessment after 1-min exposure in the chamber. The study did not rank the environmental conditions, but quantitatively compared their impact on dissatisfaction
[18]	26 office buildings in 5 European countries	Building occupants ($n = 4655$*, RR unknown)	Participants judged the environment quality using the preference scales (for warmth, air movement, humidity, light and noise), air quality scale and overall environmental satisfaction scale;	Multiple regression analysis	Contribution to overall satisfaction with IEQ was the highest for satisfaction with temperature (coefficient: 0.39) and air quality (0.36), followed by satisfaction	Participants were not asked directly about their satisfaction with environmental conditions, but the level of satisfaction was estimated based on the assessments indicating the extent to which people

(*continued on next page*)

Table 1 (*continued*)

Study	Place of experiment	Population	Procedure	Data analysis	Results	Concluding remarks
			their votes were converted into satisfaction levels to estimate how much satisfaction with individual environmental conditions contributed to overall satisfaction with IEQ		with air movement (0.16), humidity (0.12), noise (0.13) and light (0.05) (R^2 of the model = 0.26)	preferred other conditions compared with the conditions to which they were exposed. It can be one of the reasons that R^2 is so low. Different results were observed in different countries. Thermal conditions and air quality consistently had the highest contribution to overall satisfaction with IEQ while visual conditions had the lowest
[19]	32 typical residential apartments in Hong Kong	Residents of the buildings (n = 125, RR unknown)	Participants judged the satisfaction with air quality, thermal, visual and acoustic environment and overall satisfaction with IEQ using the dichotomous acceptability scales	Multivariate logistic regression analysis	The acceptability of thermal and acoustical conditions was found to contribute most to overall satisfaction with IEQ, followed by acceptability of visual environment. The acceptability of air quality had the lowest contribution (sample correlation coefficient: 0.9999)	If a particular environmental condition was judged to be more unacceptable, it was considered to have higher importance. Most people judged their environment as acceptable and there were only a few votes expressing unacceptability with the environmental conditions
[20]	Typical commercial buildings in Hong Kong	Office workers and visitors (n = 548, RR unknown; the usable sample fulfilling consistency requirements was 22% of all votes of participants)	Participants rated the relative importance of pairs of 4 environmental conditions (thermal comfort, air cleanliness, odour and noise) but it was not stated in relation to which context the votes should be made	Analytical hierarchy process (AHP); only those votes fulfilling the requirement for a consistency ratio of 9% were included in the analysis	Odour was perceived as the most important (AHP weight: 0.42) in contrast to thermal conditions, which were assessed as least important (0.11). Air cleanliness and noise were of comparable importance (0.23)	Perceived importance of environmental conditions depended slightly on the occupants' gender, purpose of stay in the building (worker/visitor) and duration of working in the building. Odour was always ranked as having the highest importance and thermal conditions as having the lowest. Votes provided by 78% of respondents were disregarded in the analyses as they did not fulfil the limit for consistency, suggesting that the majority of people had problems making consistent judgments
[21]	Private and public high-rise residential buildings in Hong Kong	Residents and visitors (n = 563, RR unknown; the usable sample fulfilling consistency requirements was 33% of all participants' votes)	Participants rated the relative importance of pairs of 4 environmental conditions (thermal comfort, air cleanliness, odour and noise) but it was not stated in relation to which context the votes should be made	Analytical hierarchy process (AHP); only those votes fulfilling the requirement for a consistency ratio of 9% were included in the analysis	Thermal comfort was valued the highest (AHP weight: 0.34), and odour the lowest (0.20). Air cleanliness and noise were rated similarly (0.23)	Importance of environmental conditions varied between private and public buildings, purpose of stay in a building (resident/visitor) and duration of living in the building. Thermal environment was always considered to have the highest importance. Votes provided by 67% of respondents were disregarded in the analyses as they did not fulfil the limit for consistency, indicating that the majority of people had problems making consistent judgments
[22]	Typical air-conditioned office buildings in Hong Kong	Building occupants (n = 293, RR unknown)	Participants judged satisfaction with air quality, thermal, visual and acoustic conditions and overall satisfaction with IEQ using the dichotomous acceptability scales; the contribution of satisfaction with single environmental conditions to the overall satisfaction with IEQ was estimated	Multivariate logistic regression analysis and χ^2-test	Satisfaction with the thermal environment was found to be the most important for overall satisfaction with IEQ, followed by satisfaction with air quality, noise and illumination (sample correlation coefficient: 0.99)	If a particular environmental condition was judged to be more unacceptable, it contributed to a larger extent to overall satisfaction with IEQ

* number of interviews or filled out questionnaires; in some buildings occupants responded more than once; RR – response rate.

important when solutions for controlling the indoor environment that maximize the comfort of building users need to be devised. After summarizing briefly how comfort is currently described in the literature, the paper discusses whether all environmental conditions contribute equally to achieving comfort, or whether they are ranked differently by building users. The article also attempts to identify which factors unrelated to the indoor environment influence whether indoor environmental quality is evaluated by building users to be comfortable. These factors include, for instance, individual characteristics of building occupants (occupants' gender, age, country of origin etc.), building-related factors (room interior, type of building and control over the indoor environment), and the outdoor climate (including seasonal changes).

The present paper attempts to examine the following hypotheses:

- hypothesis 1: the evaluation of whether overall indoor environmental quality is comfortable or not depends strongly on the indoor environmental conditions that are ranked by people to have high importance for achieving comfort,
- hypothesis 2: there are factors unrelated to the indoor environment that strongly influence whether indoor environmental quality is assessed as comfortable. This hypothesis is composed of 3 sub-hypotheses, each related to impact of a different group of factors: individual characteristics of building occupants (hypothesis 2.1), building-related factors (hypothesis 2.2) and outdoor climate (hypothesis 2.3).

2. Indoor environmental quality

There follows a short summary of how thermal, visual and acoustic comfort as well as good indoor air quality are currently defined in the literature and the requirements that exist in the standards regarding these parameters. This information provides a background for further discussion in the present paper.

2.1. Thermal comfort

Thermal comfort is "that condition of mind which expresses satisfaction with the thermal environment" [6]. When thermally comfortable, a building user will wish to feel neither warmer nor cooler, if asked about thermal state and preference. The definition applies to the thermal comfort of an individual. In buildings, however, a person usually shares the built environment with other occupants. Standard ISO 7730 [7] provides the indices predicted mean vote (PMV) and predicted percentage dissatisfied (PPD), which make it possible to predict the mean thermal sensation and mean satisfaction with thermal conditions of a group of people. The standard defines the thermal environment as a function of four physical variables (air temperature, mean radiant temperature, relative air velocity and air humidity) and two variables related to people (activity level and clothing). Additionally, requirements for thermal comfort can only be met if no local discomfort exists, i.e. if building users are not disturbed by draught, too high radiant temperature asymmetry, too low or too high internal surface temperatures, or too high vertical air temperature difference. While the above approach to the evaluation of thermal conditions is based on the heat exchange between a human body and the surrounding environment, an adaptive approach has since been proposed [8]. It assumes that people are able to adapt to the thermal environment by means of behavioural adjustments (e.g. by changing the insulation value of their clothing), relaxation of expectations and acclimatization to the conditions to which they are exposed. Building users are then able to feel comfortable in a wider range of conditions than the conditions prescribed by applying the PMV index.

2.2. Visual comfort

Visual comfort is defined as "a subjective condition of visual well-being induced by the visual environment" [9]. Although the definition implies that there is a psychological dimension of comfort, a number of physical properties of the visual environment are defined and used to evaluate its quality in an objective way. Visual conditions are characterized by such parameters as luminance distribution, illuminance and its uniformity, glare, colour of light, colour rendering, flicker rate and amount of daylight [10].

2.3. Acoustic comfort

Navai and Veitch [2] defined acoustic comfort as "a state of contentment with acoustic conditions". However, the term acoustic comfort is not commonly used and providing a good acoustic environment is mainly associated with preventing the occurrence of discomfort (annoyance). The quality of the sound environment is linked to numerous physical parameters, which include both the physical properties of sound itself and the physical properties of a room. Sound is characterized by the sound pressure level in a short-term and long-term period and by sound frequency. The acoustic environment is influenced by such physical room properties as sound insulation, absorption and reverberation time [11].

2.4. Good indoor air quality

The term comfort is not commonly used in relation to indoor air quality and it is mainly linked with the lack of discomfort due to odour and sensory irritation. Acceptable air quality is defined as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" [12]. Consequently most of the standards providing the requirements for indoor air quality define the conditions by providing the minimum percentage of persons dissatisfied with air quality. They are mainly based on the discomfort and annoyance caused for visitors to indoor spaces. Recently, some standards also deal with the requirements for occupants.

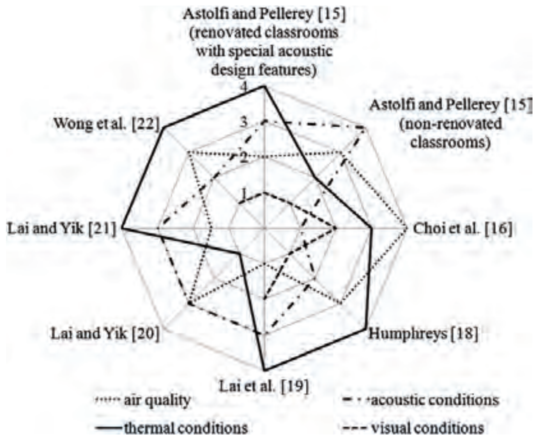

Fig. 1. Ranking of the importance of different environmental conditions for overall satisfaction with IEQ; the higher number indicates higher ranking (importance).

Table 2
Summary of studies examining the effects of individual characteristics of building occupants on satisfaction with IEQ.

Study	Place of experiment	Population	Data analysis	Results	Comments
[23]	11 residential multi-storey buildings	Building occupants ($n = 394^*$, RR unknown)	It was verified that there was no correlation between the personal variables and measured indoor conditions	No statistically significant differences in thermal sensation were observed between residents having different gender, age or length of residence in Israel	Study considered to have strong design
[16]	29 office buildings in USA	Building occupants ($n = 492$, RR unknown)	Two sample *t*-tests to verify that the differences in subjective responses were not caused by exposure to different indoor conditions; Pearson correlation coefficient to find correlation between environmental conditions and overall satisfaction with IEQ	Males expressed significantly higher satisfaction with the thermal environment ($p = 0.001$) and air quality ($p = 0.018$) than females. No differences between genders were found in satisfaction with acoustic ($p = 0.38$), visual ($p = 0.73$) and overall environmental conditions ($p = 0.39$). For both genders air quality and thermal environment were ranked highest. The ranking of acoustic and visual conditions differed slightly between genders. Women ranked visual conditions higher than acoustic conditions, compared to men, who ranked acoustic conditions slightly higher than visual conditions	Study considered to have strong design. It was verified that both genders were exposed to the same conditions
[24]	13 office buildings with lighting systems typical of lighting practice at the time the study was conducted	Building occupants ($n = 912$, RR unknown)	No statistical analysis to verify whether the differences in subjective responses were caused by exposure to different indoor conditions	Older occupants, males, managers or professionals and those with a larger workstation floor area were more satisfied with the lighting than younger occupants, females, those holding secretarial or clerical positions and workers with a smaller workplace area even though the former did not have noticeably higher task illuminance	Study considered to have weak design
[25]	34 air-conditioned office buildings in Australia	Building occupants ($n = 2463^*$, RR unknown)	Correlation of subjective responses to variations in indoor environmental conditions; multiple regression analysis	Gender, age, height and weight, health, pattern of smoking, coffee drinking or exercising, job satisfaction, hours worked per week and self-estimated environmental sensitivity had no significant effect on thermal sensation	Study considered to have strong design
[13]	Climate chamber	Danish college-age students ($n = 128$), elderly Danes ($n = 128$) and data from 720 college-age Americans [26]	Linear regression analysis	No significant differences in thermal comfort responses were found between people of different gender, age, body build or country of origin. Menstrual cycle had no influence on the thermal comfort responses	Study considered to have strong design
[27]	56 buildings in 9 European countries	Building occupants (n and RR unknown)	Correlation of perception of indoor conditions with measured physical conditions; multiple logistic regression analysis	Women and those performing secretarial work reported more adverse environmental perceptions than others. Nationality was a significant factor for the perception of the indoor environment. Individuals who worked many hours at a VDU perceived the air as more stuffy and the surroundings as noisier than the others (all observations: $p < 0.05$)	Study considered to have strong design

[28]	12 mechanically ventilated buildings	Building occupants ($n = 877^*$, RR unknown)	Pearson correlation coefficient	Job satisfaction correlated with satisfaction with air quality, thermal sensation, and acceptability of air movement. Correlation coefficients were very low, but significant ($r < 0.2$; $p < 0.003$). The weekly length of fitness had no significant impact on any evaluations	Study considered to have medium design. It was not checked whether the differences occurred due to variations in the indoor environment
[29]	10 office buildings with displacement ventilation	Building occupants ($n = 227$, RR unknown)	Results tested for statistical significance	Gender, fitness and age did not have a significant effect on the acceptability of the thermal environment ($p > 0.05$)	Study considered to have medium design. It was not verified whether the differences occurred due to variations of the indoor environment
			No statistical analysis to verify whether the differences in subjective responses were caused by different indoor conditions	Satisfaction with job and relationship with superiors and colleagues had a positive correlation with the acceptability of the thermal environment. Office workers subjected to time pressure in their job experienced higher discomfort due to draft than others exposed to similar velocities	Study considered to have weak design
[30]	Air-conditioned office building in Japan	Building occupants ($n = 406^*$, RR unknown)	Correlation of subjective responses with variations of the indoor environmental conditions; weighted linear regression analysis	Significant differences in neutral temperature between Japanese males and non-Japanese males ($p < 0.01$), Japanese females and non-Japanese males ($p < 0.01$), Japanese females and Japanese males ($p < 0.05$); the biggest difference between Japanese females and non-Japanese males	Study considered to have strong design. The data were correlated with mean seasonal operative temperature prior to statistical analysis
[31]	Open-plan office building in USA	Building occupants ($n = 86$, RR unknown)	It was verified that there was no correlation between the personal variables and measured indoor conditions; bivariate correlations between responses describing satisfaction	No significant influence of satisfaction with management, job satisfaction and job stress on satisfaction with lighting. Overall satisfaction with IEQ was correlated with job satisfaction ($r = 0.26$; $p < 0.01$) and satisfaction with management ($r = 0.33$; $p < 0.01$), but not with job stress	Study considered to have strong design
[32]	6 primary schools in Sweden	Teachers and other school employees ($n = 97$, RR = 91%)	Multiple linear regression analysis	Gender and age did not affect the perception of room temperature, air dryness and dustiness of air ($p > 0.05$). Work stress influenced the perception of air dryness ($p < 0.05$) and dustiness ($p < 0.01$) but not perceived room temperature ($p > 0.05$)	Study considered to have medium design. It is not known whether the environmental conditions were uniform
[33]	Climate chamber	Young persons ($n = 108$)	Analysis of variance	Men chose less noisy environments, while women decided to stay closer to thermally neutral (but noisier) conditions compared with men ($p < 0.01$)	Study considered to have strong design. The same experimental procedure was used for males and females
[34]	38 schools in Sweden	Teachers and other school employees ($n = 1303$, RR = 85%)	Multiple logistic regression analysis	The air quality was perceived to be worse by younger school employees and by those dissatisfied with the psychosocial atmosphere at work. No significant differences in subjectively assessed air quality between males and females and those with different smoking habits	Study considered to have medium design. It is not known whether the environmental conditions were uniform

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Table 2 (*continued*)

Study	Place of experiment	Population	Data analysis	Results	Comments
[35]	Office building in U.K. and office building in Pakistan	Building occupants ($n < 32$ in U.K., $n = 15$ in Pakistan, RR unknown)	No statistical analysis to study whether differences in subjective responses are caused by exposure to different indoor conditions	The number of U.K. workers dissatisfied with externally generated noise was higher than the number of Pakistani workers disturbed by externally generated noise, even though the sound level was lower in the U.K.	Study considered to have weak design. Small number of people participated
[36]	13 air-conditioned buildings in Thailand	Building occupants ($n = 1520$, RR unknown)	Linear regression analysis	The neutral temperature of males, workers with higher education and those using air conditioners at home was slightly lower than the neutral temperature of females, workers with lower education and those without air conditioners at home	Study considered to have weak design

* number of interviews or filled out questionnaires; some of the building occupants gave their response more than once; RR – response rate; Studies considered to have strong design are those in which the impact of changes in indoor environmental conditions on the effects of individual characteristics are controlled, and in addition provided testing for statistical significance of the observed effects. The studies considered to have medium design are those which provided only testing for statistical significance of the observed results; all other studies are considered to have weak design.

3. Methods

A literature search was undertaken for articles presenting the results of studies on how thermal, acoustic and visual comfort, as well as indoor air quality, are ranked by building users in connection with overall satisfaction with indoor environmental quality (IEQ) and its impact on human comfort, and whether factors unrelated to indoor environment play a role in this relationship. Throughout the article, comfort is defined as satisfaction with purely IEQ and does not include satisfaction with other aspects of the building such as furniture, colours, etc. The search was limited to the studies that were performed in non-industrial buildings (homes, offices and schools) or in the climate chambers in which environmental conditions resembled non-industrial buildings. Relevant articles were searched electronically in the databases of Science Direct, Compendex and Web of Science, and manually in the proceedings of Indoor Air and Healthy Buildings conferences. Besides the papers found during the literature survey, a "Thermal Comfort" book [13] was included as it comprehensively describes all the aspects related to the effects of the thermal environment on man that are relevant for the current survey. No other books were included.

The literature discussing how thermal, acoustic and visual comfort, as well as indoor air quality, are ranked by building users was searched using keywords that are related to the indoor environment and that describe such terms as contribution, prioritization, ranking and importance. The literature was searched to confirm or reject the following hypotheses: (1) Thermal, acoustic and visual comfort and indoor air quality do not equally contribute to whether overall IEQ is assessed to be comfortable or not; (2) This contribution of thermal, acoustic and visual comfort and air quality can be influenced by individual characteristics of the building users and the conditions in a building; (3) Building users can not make consistent judgment of how important the indoor environmental conditions are for their comfort. More than 10 articles were found that presented information relevant to at least one of the above hypotheses. From among these articles, only nine covering the period from 1993 to 2009 were included in the present survey. These articles discussed the importance of at least three environmental conditions for overall human comfort. The studies that discussed the importance of only two environmental conditions were considered to simply compare rather than rank the conditions; although they provide some valuable information, it was decided not to include them in the present survey.

The literature providing information on factors which are unrelated to the indoor environment but which may influence whether IEQ is comfortable or not was searched using keywords describing occupant perception, subjective response, human/personal factors and building factors. No articles reporting the influence of factors on health (including sick building syndrome (SBS) symptoms) or performance were included, even though they may contribute to comfort. The literature was first screened to identify the potential factors. More than 50 studies were found indicating the following factors: personal characteristics (occupants' gender, age, country of origin etc.), building-related factors (room interior, type of building and control over the indoor environment) and the outdoor climate (including seasonal changes). For the final analysis, only the data from 33 studies were included in which it was controlled that the differences in whether IEQ was evaluated to be comfortable or not were not actually caused by the variations in indoor environmental conditions. Articles reproducing the same data published elsewhere were excluded. The selected studies cover the period between 1977 and 2009.

Table 3
Summary of studies presented in Table 2 investigating how individual characteristics influence satisfaction with IEQ.

Study	Study design	Influencing factor (on the right) and influenced aspect (below)	Gender	Age	Country of origin	Height and weight	Fitness	Health	Self-estimated environmental sensitivity	Menstruation cycle	Pattern of smoking	Pattern of coffee drinking	Education level	Type of job	Job satisfaction	Relationship with superiors and colleagues	Psychosocial atmosphere at work	Job stress	Time pressure	Hours worked per week
		Impact on thermal conditions																		
[23]	S	Thermal sensation	O	O																
[16]	S	Satisfaction with temperature	+																	
[25]	S	Thermal sensation	O	O		O	O	O	O		O	O			O					O
[13]	S	Thermal comfort	O	O	O	O				O										
[28]	M	Acceptability of thermal environment					O								+					
[29]	M	Acceptability of thermal environment	O	O			O													
[29]	W	Acceptability of thermal environment													+	+			+	
[30]	S	Neutral temperature	+		+															
[32]	M	Perception of temperature	O	O														O		
[36]	W	Neutral temperature	+										+							
		Impact on perception of air quality																		
[16]	S	Satisfaction with air quality	+																	
[32]	M	Perception of air quality	O	O														+		
[34]	M	Subjective air quality	O	+							O						+			
		Impact on visual conditions																		
[16]	S	Satisfaction with visual environment	O																	
[24]	W	Visual satisfaction	+	+										+						
[31]	S	Satisfaction with lighting													O	O		O		
		Impact on acoustic conditions																		
[16]	S	Satisfaction with acoustic environment	O																	
[35]	W	Acoustic dissatisfaction and disturbance			+															
		Impact on other environmental aspects																		
[16]	S	Ranking of conditions	+																	
[27]	S	Adverse perception	+		+									+						
[31]	S	Overall satisfaction with environment													+	+		O		
[33]	S	Preference for conditions	+																	
		Number of O	9	6	1	2	3	1	1	1	2	1			2	1		3		1
		Number of +	8	2	3								1	2	3	2	1	1	1	
		Summary	?	O	+	OO	OO	OO	OO	OO	OO	OO	++	++	?	?	++	O	++	OO

Studies considered to have strong design (S) are those in which the impact of changes in indoor environmental conditions on the effects of individual characteristics are controlled, and in which there was statistical analysis of the results. The studies considered to have medium design (M) are those which provided only testing for statistical significance of the observed results; all other studies are considered to have weak design (W). O: no influence found; +: influence found; in the summary the studies considered to be (1) consistent indicate that all studies show the same result (++ or OO), (2) mostly consistent indicate that 70% of studies show the same result (+ or O), (3) inconsistent as less than 70% of studies show the same result (?).

4. Results

4.1. Hypothesis 1: the importance of different environmental conditions for comfort

Nine studies were examined. Four studies were performed in offices, two in residential buildings and climate chambers, and one in a school building. Their details are given in Table 1.

In two studies the impact of overall IEQ on comfort was modelled, based on the effects of single environmental conditions on comfort [14,17]. This was done to learn about physical conditions of the thermal and acoustic environments and air quality which lead to the same levels of overall satisfaction with IEQ and to estimate how much a change of each condition affects overall comfort. The results show that the change in thermal and acoustic conditions and air quality should be different in order to obtain the same change of the overall satisfaction with IEQ.

The other seven studies explored the importance of environmental conditions only in terms of the subjective evaluations of building users [15,16,18–22]. They examined the importance of indoor environmental conditions for comfort by asking the building users to rank the conditions according to their importance, or to fill out the questionnaires indicating their satisfaction with different environmental conditions or overall satisfaction with IEQ; these responses were used to estimate the contribution of satisfaction with each parameter to overall satisfaction with IEQ. The results of these studies show that thermal comfort was ranked to have slightly higher importance than acoustic comfort and satisfaction with air quality, and considerably higher importance compared with visual comfort (Fig. 1).

Women and men ranked the environmental conditions differently. Ranking depended also on whether the indoor environment was the workplace or home, whether a person was a visitor or occupant, whether a workstation was closer or further from the window, and on the duration of working or living in the building. Ranking was different in different countries, and depended on whether the building was private or public. No general conclusions regarding the influence of the above factors on ranking could, however, be formulated because these impacts were not systematic.

In two studies it was observed that the satisfaction level influenced how the condition was ranked - when people were more dissatisfied with a condition, this condition was considered to have higher importance [19,22]. These results could not, however, be confirmed by the results of two other studies [15,16].

In two studies the majority of people could not consistently rank which indoor environmental conditions are important for comfort [20,21]. In these studies participants chose the condition they perceived as the most important from among the pairs of 4 environmental conditions. Their responses were then analysed to create a final ranking of conditions for each person separately. The analysis showed that the responses of most people were not consistent enough to make the creation of such a ranking possible; these responses were disregarded and are not included in Fig. 1.

4.2. Hypothesis 2.1: impact of individual characteristics of building occupants on satisfaction with IEQ

Table 2 summarizes 15 studies providing information on the impact of individual characteristics of building occupants on thermal, visual and acoustic comfort and satisfaction with air quality and on overall satisfaction with IEQ. These studies were performed mainly in office buildings; two were performed in schools and climate chambers, and one in residential buildings.

The results of these studies presented in Table 3 show that thermal comfort was influenced by the level of education, the relationship with superiors and colleagues and time pressure, but not by gender, age, body build, fitness, health, self-estimated environmental sensitivity, menstruation cycle, pattern of smoking and coffee drinking, job stress or hours worked per week. Perception of air quality was influenced by the psychosocial atmosphere at work and job stress, but not by the pattern of smoking. Visual comfort was affected by occupants' age and type of job, but not by job satisfaction, relationship with superiors and colleagues or job stress. Acoustic comfort was affected by country of origin, but not by occupants' gender.

Table 3 shows also that age, body build, fitness, health, self-estimated environmental sensitivity, menstruation cycle, pattern of smoking and coffee drinking, job stress and hours worked per week had no influence on whether overall IEQ is assessed to be comfortable or not. It shows that country of origin, level of education, type of job, psychosocial atmosphere at work and time pressure do influence overall satisfaction with IEQ. Gender, job satisfaction and relationship with superiors and colleagues in some studies were shown to have an influence and in some studies to have no effect on whether overall IEQ was comfortable or not. The results are slightly different if only studies are selected which can be considered to have a strong design, i.e. in which the potential impact of indoor environmental conditions on the observed results was controlled and in which the results were tested using statistical methods. These studies show that most individual characteristics (occupants' age, body build, fitness, health, self-estimated environmental sensitivity, menstruation cycle, pattern of smoking and coffee drinking, job stress and number of hours worked per week) do not influence overall satisfaction with IEQ.

4.3. Hypothesis 2.2: impact of building-related factors on satisfaction with IEQ

Table 4 summarizes 18 studies examining the impact of building-related factors on human comfort in indoor environments.

Two studies performed in climate chambers examined the effect of room interior on thermal comfort. They found a very slight influence of colour of light on thermal comfort [37] and no effect of room decoration on thermal comfort [38].

The type of building was shown to have an impact on thermal comfort. People felt warmer at home and colder in the office in relation to the sensation predicted by PMV [42]; neutral temperatures were also different in homes and in offices [41]. Thermal sensation and comfort were different in naturally ventilated (NV) and air-conditioned (AC) buildings. In countries with warm climates such as Israel, Thailand, Singapore and the southern part of China, the comfort temperatures and neutral temperatures in warm periods were observed to be higher in NV buildings compared with AC buildings, both in homes and in offices. The difference was about 3 °C in Israel [23] and Thailand [39] and 0.6 °C in China [45]. In Singapore the difference in comfort temperature between NV residential buildings and AC office buildings was 4.3 °C [40]. In dwellings in Israel, residents felt much warmer in AC homes and slightly warmer in NV homes compared with the prediction made with PMV [44]. Opposite findings were observed in U.K., where neutral temperatures in the summer were lower in AC buildings compared with NV buildings [43]. In winter the comfort temperatures and neutral temperatures were higher in heated dwellings compared with non-heated dwellings, by 2 °C [23] and in NV offices compared with AC offices, by 1.4 °C [43]. People in AC buildings were observed to be more sensitive to temperature deviations away from the optimum compared to those staying in NV buildings. The range of acceptable temperatures was wider in NV buildings

Table 4
Summary of studies examining the effect of building-related factors on satisfaction with IEQ.

Study	Place of experiment	Population	Data analysis	Results	Concluding remarks
Room interior					
[37]	Climate chamber	College-age students ($n = 16$)	Analysis of variance	0.4 °C difference in preferred temperature between experiments when extreme blue and extreme red artificial lighting was provided in the chamber ($p < 0.05$)	Colour of light had small influence on thermal conditions which were judged by subjects as comfortable. The difference was so small that it is of no practical significance
[38]	Climate chambers (standard chamber and modified chamber with enriched room decoration)	College students ($n = 48$)	Results tested for statistical significance	Subjects felt significantly warmer when wood panels, pictures on the walls, red carpet and an indirect light were added, and furniture in the chamber was changed compared to thermal sensation in standard chamber ($p < 0.05$). There were no significant differences in thermal comfort	Even though the room decor had an effect on thermal sensation of subjects, the subjects felt equally comfortable in standard chamber and chamber with enriched room decoration. Thermal comfort can not be modified by changing the room decoration
Type of building					
[23]	189 heated and non-heated dwellings and 205 AC and NV dwellings in Israel	Habitants of the dwellings ($n = 394$*, RR unknown)	Results tested for statistical significance	No significant difference in thermal comfort votes between heated and non-heated dwellings in winter even though the operative temperature and the thermal sensation were significantly lower in non-heated dwellings. The estimated comfort temperature was 2 °C higher in heated than in non-heated dwellings. In summer, comfort temperature was 3 °C higher in NV than in AC homes	Even though the thermal sensation of occupants differed in heated and non-heated dwellings, the occupants felt equally comfortable. People who experience a different thermal sensation can feel equally comfortable. The comfort temperature was higher in heated and NV dwellings than in non-heated and AC dwellings
[39]	4 AC and NV office buildings in Thailand	Building occupants ($n = 1146$*, RR unknown)	Linear regression analysis	In warm seasons neutral effective temperature was higher in NV (27.4 °C) than in AC (24.7°) buildings	Occupants in NV buildings accepted higher temperatures than in AC buildings
[8]	160 buildings in 9 countries around the world	Building occupants (n ∼ 21000, RR unknown)	Weighted linear regression analysis	The occupants of centralized HVAC buildings were significantly more sensitive to temperature deviations away from optimum compared to the occupants of NV buildings ($p < 0.001$), in which the range of acceptable operative temperatures was almost twice as great as in buildings with centralized HVAC	Occupants in NV buildings accepted wider temperature ranges than in AC buildings
[40]	NV residential buildings and AC office buildings in Singapore	Building occupants ($n = 818$, RR unknown)	Probit regression technique	In summer neutral operative temperature in NV residential buildings was 28.5 °C and was 4.3 °C higher than in AC office buildings	The neutral temperature was higher in NV than in AC buildings and it was higher in homes than in offices
[41]	NV homes and office buildings in Iran	Building occupants (short-term study at homes: $n = 891$; long-term study in offices: $n = 3819$*, RR unknown)	Linear regression analysis	In summer the neutral temperature was 1.7 °C higher in homes than in offices. In winter the difference was very small (0.4 °C) and the neutral temperature was higher in offices	The study showed that the difference in neutral temperature occurred between home and office environment

(continued on next page)

Table 4 (*continued*)

Study	Place of experiment	Population	Data analysis	Results	Concluding remarks
[42]	Office building and homes of the office workers in U.K.	Employees of one institution ($n = 30$, chosen among 39 applicants)	Results tested for statistical significance	People felt warmer in homes and colder in offices in relation to the sensation predicted by PMV ($p < 0.05$)	Thermal sensation differed between home and office environment. It was not explored whether the comfort level was different for the two environments
[43]	4 NV and 4 AC office buildings in U.K.	Building occupants (winter: $n = 6050$*, RR = 63%; summer: $n = 5037$*, RR unknown)	Regression and probit analysis	Neutral temperature was lower in NV offices than in AC offices by 1.4 °C in winter and 2.2 °C in summer. The range of thermal acceptability was wider in NV offices than in AC offices in winter, while it was of a similar size in summer	In winter slightly more occupants in NV offices judged the conditions as acceptable and preferred no change compared with AC offices. In summer more occupants in AC offices perceived the conditions as acceptable compared with occupants in NV offices
[44]	117 AC and NV dwellings in Israel	Habitants of the dwellings (number and RR unknown)	Results tested for statistical significance	In summer residents felt much warmer in AC homes and slightly warmer in NV homes than predicted by PMV. All of the residents in AC dwellings and 92% of occupants of NV dwellings rated their thermal sensation within slightly cool and slightly warm even though the operative temperature in AC homes was significantly lower than in NV homes. More people felt comfortable in AC than in NV dwellings	Occupants in NV dwellings relaxed their expectations regarding their thermal sensation compared to the thermal sensation of occupants in AC dwellings. Most of them still preferred to feel cooler and the comfort level was significantly lower in NV than in AC dwellings
[45]	65 NV and 46 AC dwellings and office buildings in China	Building occupants ($n = 229$, RR unknown)	Linear regression analysis	In summer the neutral temperature was 0.6 °C higher in NV than in AC buildings. The range of acceptable temperature was slightly wider in NV than in AC buildings but the temperature ranges in NV and AC buildings overlapped to a large extent	The difference in neutral temperature between AC and NV buildings was rather small
Control of the indoor environment					
[24]	13 office buildings with lighting systems typical of lighting practice at the time the study was conducted	Building occupants ($n = 912$, RR unknown)	No statistical analysis	The possibility to control the lighting improved satisfaction with lighting quality. Occupants with task lighting expressed generally higher satisfaction than those without any task lighting	Providing occupants with possibility to control the environment improved satisfaction with indoor environment
[28]	12 mechanically ventilated buildings	Building occupants ($n = 877$*, RR unknown)	Pearson correlation coefficient	Providing users with a higher degree of control over their thermal environment improved satisfaction ratings with work area temperature and air quality and overall satisfaction with IEQ (p-value<0.0001)	Providing occupants with the possibility to control the environment improved satisfaction with the indoor environment. The beneficial effect of control on comfort was quite small
[29]	10 office buildings with displacement ventilation	Building occupants ($n = 227$, RR unknown)	Results tested for statistical significance	Possibility to control the environmental conditions had no significant effect on acceptability with the thermal environment	Providing occupants with the possibility to control the environment did not improve satisfaction with the indoor environment

[46]	Test room	Participants ($n = 120$, data from 94 participants analysed, the rest of participant excluded from analysis mainly due to insufficient English language skills)	Multivariate analysis of variance (MANOVA)	There was no significant difference in satisfaction with lighting between participants who could set the lighting at the beginning of the experiment and those who had no influence on lighting conditions and were exposed to the conditions chosen by their experimental partner, even though the perceived degree of control of the participants in the former group was much higher	Providing occupants with possibility to control the environment did not improve satisfaction with the indoor environment
[47]	Test rooms	People working in the building where the test rooms were built ($n = 14$)	No statistical analysis	More people assessed the lighting as comfortable when they were offered manual control or a combination of manual and automatic control of the visual environment	Providing occupants with the possibility to partially control the environment improved satisfaction with the indoor environment
[48]	Office buildings in England	Building occupants ($n = 497$, RR unknown)	No statistical analysis	People expressed higher satisfaction when they perceived that they had more control of the environment	The occupants were more satisfied with the environment when they perceived that they had control of environmental conditions
[49]	Building in USA	Building occupants ($n > 1000^*$, RR ~ 40%)	Results tested for statistical significance	In winter people with a higher degree of control reported higher satisfaction with temperature, air movement, air quality and sound than those with a lower degree of control ($p < 0.05$)	The occupants were more satisfied with the environment when they perceived that they had control of environmental conditions

* number of interviews or filled out questionnaires; some of the building occupants gave their response more than once; RR – response rate; AC – air-conditioned building; NV – naturally ventilated building.

compared with AC buildings either in all seasons [8] or only in summer [45] or in winter [43]; in one study the size of the acceptable temperature range in summer was actually similar in NV and AC buildings [43].

Five studies performed in office buildings and two studies carried out in a laboratory setting in test rooms examined how control of indoor environmental conditions influence satisfaction with IEQ. Providing people with control led to an increased satisfaction level with thermal, visual and acoustic environment as well as air quality [24,28,47–49] but only in two studies [28,49] was a formal statistical analysis made of the observed results. Two studies showed that access to control did not influence thermal [29] and visual comfort [46].

4.4. Hypothesis 2.3: impact of outdoor climate and season on satisfaction with IEQ

Table 5 summarizes 10 studies examining whether outdoor climate and season influence thermal comfort. No study was found that examined whether they affect satisfaction with other indoor environmental conditions or overall IEQ.

People staying indoors felt warmer in winter than in summer even though the indoor temperature was lower [54]. It was consistently observed that neutral and comfort indoor temperatures increased with increasing outdoor temperatures [8, 52, 53]. Comfort and neutral temperatures were higher in warmer climates compared with temperatures in colder climates [25]. They were higher in summer than in winter [23,41,50]. In three studies there was, however, almost no difference in neutral temperatures between winter and summer [43, 51, 55].

5. Discussion

The present literature survey is a part of a larger research programme on user-driven innovation aiming to develop control solutions for indoor environments that maximize the comfort of building occupants and enhance their quality of life. The present literature survey intended to collect information relevant to this aim. In particular, it was intended to learn whether comfort is predominantly controlled by any of the four environmental conditions related to thermal, visual and acoustic comfort, as well as satisfaction with air quality. It was also intended to find out which factors unrelated to the indoor environment should be taken into account where comfort is concerned. The focus was only on those factors that were considered by the authors to be important when developing innovative solutions for controlling the indoor environment in non-industrial buildings.

The studies surveyed used quantitative models and qualitative assessments to examine the importance of different environmental conditions for overall satisfaction with IEQ. Qualitative assessments provided ranking only of those environmental parameters considered by building users to be important. The quantitative models provided more information because they indicated the extent to which the environmental conditions should be changed in order to create a change in comfort. Further studies examining the quantitative models would be beneficial, as only a few studies have used this approach so far. This information would be useful when overall IEQ in buildings is classified according to satisfaction with the individual indoor environmental conditions, as recommended by standard EN15251 [56]. It would also be quite useful when remedial measures are taken regarding improvement of IEQ, indicating which of the indoor environmental parameters should be tackled first.

The studies surveyed showed that building users consider thermal comfort to be the most important parameter influencing

Table 5
Summary of studies on how outdoor climate and season affect satisfaction with IEQ.

Study	Place of experiment	Population	Data analysis	Results	Comments
[23]	394 dwellings in Israel	Habitants of the dwellings ($n = 394$*, RR unknown)	Linear regression analysis	Comfort temperature was 6.5 °C higher in summer than in winter in the dwellings without cooling and heating. The difference in comfort temperature was smaller (1.5 °C) in the case of dwellings with cooling in summer and heating in winter	Occupants in dwellings without cooling and heating accepted bigger variations of indoor temperature throughout the year than the occupants of dwellings with heating and cooling
[50]	22 AC office buildings in Australia	Building occupants ($n = 1229$*, RR unknown)	Probit analysis	The neutral operative temperature was 3 °C higher in summer than in winter	Building occupants accepted higher indoor temperatures when outdoor temperatures were higher
[8]	160 buildings in 9 countries around the world	Building occupants (n ~ 21000, RR unknown)	Linear regression analysis	An increase in neutral temperature with increasing mean outdoor daily effective temperature was observed ($p = 0.0001$). It was higher for buildings with NV than for buildings with centralized HVAC	Neutral temperature was not the same all around the world. It depended on outdoor climate. The neutral temperature in NV buildings followed closer the changes in outdoor temperature than in buildings with centralized HVAC
[51]	12 AC office buildings in Australia	Building occupants ($n = 1234$*, RR unknown)	Probit analysis	Neutral operative temperature was 0.4 °C higher in wet (warmer) than dry (cooler) season	The difference in neutral temperatures between seasons was very small
[25]	34 AC office buildings in Australia	Building occupants ($n = 2463$*, RR unknown)	Probit analysis	Neutral temperature was higher in buildings in a warmer climate than in a colder climate	The neutral temperature was not the same for different climatic zones
[41]	NV homes and office buildings in Iran	Building occupants (short-term study: $n = 891$; long-term study: $n = 3819$*, RR unknown)	Linear regression analysis	Neutral temperature increased with increasing mean monthly outdoor temperature. The difference in neutral temperature between hot and cool season was 7.6 °C for homes and 5.5 °C for offices	Neutral temperature was not constant throughout the year – it was higher in the warmer than in the cooler season
[52]	34 mostly free-running or heated buildings in Pakistan	Building occupants ($n = 7112$*, RR unknown)	Regression analysis	Comfort temperature increased with increasing (daily and monthly) mean outdoor temperature	Comfort temperature followed the changes in outdoor temperature
[53]	26 office buildings in 5 European countries, both free-running and with heated/cooled mode	Building occupants (number and RR unknown)	Regression analysis	Comfort temperature increased with increasing mean outdoor temperature, to a greater extent in free-running than in heated and cooled buildings	Strong influence of outdoor temperature on comfort temperature
[54]	Homes in U.K.	Building occupants (winter: $n = 515$, RR = 56%; summer: $n = 293$, RR = 71%)	Results tested for statistical significance	Thermal sensation votes of residents were higher in winter than in summer even though the indoor temperature was lower in winter ($p < 0.001$)	Thermal sensation of occupants was influenced not only by the indoor temperature but also because they judged their thermal sensation in relation to the outdoor temperature. Thus they felt warmer in winter than in summer
[43]	8 office buildings in U.K.	Building occupants (winter: $n = 6050$*, RR = 63%; summer: $n = 5037$*, RR unknown)	Regression and probit analysis	In AC buildings the neutral temperature was almost the same in summer and winter, while in NV buildings it was about 1 °C lower in summer than in winter	The difference in neutral temperature between summer and winter in NV buildings was inconsistent with expectations
[55]	16 office buildings in Germany	Building occupants (n ~ 1300*, RR~80%)	No statistical analysis	The neutral temperature was higher by 0.5 °C in summer than in winter	The differences in neutral temperature between summer and winter were very small

* number of interviews or filled out questionnaires; some of the building occupants gave their response more than once; RR – response rate; AC – air-conditioned building; NV – naturally ventilated building.

overall satisfaction with IEQ. Consequently, when control solutions for the indoor environment are developed, providing thermal comfort should be given the highest priority. Account should also be taken of other factors unrelated to IEQ, such as gender or position of workstation, as they can also affect whether thermal comfort, acoustic comfort, visual comfort or satisfaction with air quality have a dominant impact on satisfaction with IEQ. A general recommendation should be that controlling indoor environmental conditions needs a case-by-case approach and it may be difficult to adopt universal solutions that match all.

Surveyed studies do not provide clear answer to whether the importance of environmental parameters is influenced by their satisfaction level. Two studies implied that as the satisfaction with physical environment changes, the importance of the environmental parameters will change as well. This was not confirmed by two other studies discussing this topic. Too limited data collected through the present survey do not allow careful analysis of this aspect. Future studies should further examine this dynamic character of human response.

Thermal comfort was influenced by building type (homes and offices, NV and AC buildings) and climate including seasonal changes. It was not affected by room decoration or light colour. The occupants of NV buildings had a more forgiving attitude in relation to indoor thermal conditions compared with the occupants of AC buildings. They accepted higher indoor temperatures in summer and lower temperatures in winter, and they also accepted wider temperature ranges. These observations are in line with the adaptive model of thermal comfort proposed by de Dear and Brager [8]. This is another argument indicating that designing the systems for achieving comfort, in this case thermal comfort, requires a case-by-case approach, depending on the building type.

Local outdoor climate should also be considered. Differences in neutral temperature between seasons were observed, suggesting that the temperature indoors should follow the change in outdoor temperature rather than be kept constant for the entire year. The differences between seasons were greater in hot and warm climates than in cold and moderate climates. It should be noted that the differences in neutral temperatures between seasons were observed in areas with warm winters and hot summers, while in areas with cold winters and warm summers almost no differences between seasons were seen. This was probably because outdoor temperatures in the summer were not very high, causing small differences in neutral temperatures between summer and winter. Consequently, these results indicate that the decision as to what extent indoor temperature should follow seasonal change, should be made with due consideration to local climate conditions.

The surveyed literature showed that the neutral temperature depended on the building type (homes and offices, NV and AC buildings), climate and season. The observed differences in neutral temperature can also be partially explained by differences in other environmental parameters which influence neutral temperature (air velocity, clothing insulation, activity level and humidity). The extent to which other parameters may influence the observed differences in neutral temperature is unknown as it was not discussed in the surveyed articles. Lack of consideration of influence of other environmental parameters on neutral temperature causes that the conclusions about the influence of building type and climate on thermal comfort are less firm.

Even though thermal sensation (feeling warm/cold) differed among building users, the results of the studies surveyed showed that at the same time the building users felt equally comfortable. This observation implies that the systems for controlling the thermal environment should take into account thermal satisfaction votes and not only the thermal sensation votes.

Room decoration and colour of light were shown to have no significant effect on the perception of thermal comfort. These studies were performed in climate chambers. But it seems reasonable to assume that the same results would be observed in real buildings.

The studies found in the present survey focused exclusively on the impact of building type, climate and season as well as room interior on thermal comfort. Nothing is known on the potential influence of these factors on visual and acoustic comfort as well as on the satisfaction with air quality. Studies on these aspects are required.

Based on the results of the present survey, it is reasonable to suggest that when the systems for controlling the indoor environment are designed, the possibility of customizing environmental conditions should be offered to building users in order to reflect their preferences. This recommendation is made considering that the results of the studies surveyed were not consistent as regards the impact of individual characteristics of building users on comfort. Some showed that gender, job satisfaction, relationship with superiors and colleagues do influence comfort and some that they do not. Delegating customization of environmental conditions to building users is further supported by the studies showing that providing personal control over the environment to building users has a strong beneficial effect on the satisfaction with IEQ.

It is difficult to judge from the present data which individual characteristics of building users play the most important role for comfort. Many of the studies discussing this issue do not have a proper design and sufficient analysis of results. There are also too few studies on this issue. The available studies examine mainly the impact of gender, age, country of origin, physical fitness and job satisfaction. Further investigations on whether individual characteristics influence satisfaction with IEQ are required with more detailed analysis of the results than in past studies.

The results of the studies surveyed in the present paper seem to be consistent with previous literature reviews. This is particularly true as regards the impact on thermal comfort of outdoor climate and season [5] and of building type [4]. The positive impact of the possibility to control indoor environment vis-à-vis comfort seems also to give a reasonable result. On the other hand, it was surprising to observe that individual characteristics of building users did not influence comfort as expected, especially as regards the impact of gender and age on thermal comfort. In the case of gender, it was expected to find that women preferred a warmer environment, but no such differences in thermal sensation were observed in the studies surveyed. The reason could be the definition of keywords when searching for the studies in the databases, resulting in some omissions. Lack of the effect of age was probably due to the fact that most of the studies surveyed were carried out in offices where different age groups in general were not well represented.

In the present survey, relatively few studies were found that examined the influence of factors unrelated to the indoor environment as regards comfort, compared for example with the number of studies discussing the same issue in relation to SBS symptoms. It is expected that there are many more studies that provide information on this issue. They were not identified in the present survey, probably because this influence was not reported as a main result and therefore could have been omitted when searching the databases and screening the results using abstracts.

6. Conclusions

- Creating a comfortable thermal environment is often considered to be the most important factor for achieving overall satisfaction with IEQ.

- The type of building, outdoor climate and season influence thermal comfort. Compared with air-conditioned buildings, the neutral temperatures are generally higher in naturally ventilated buildings and they increase with outdoor temperature.
- The number of studies identified in the surveyed literature was too few to provide convincing evidence regarding the impact of personal characteristics on comfort implying that further work on this aspect is essential. Even so it is prudent to say that the literature included in the survey suggests that (1) the thermal comfort is influenced by the relationship with superiors and colleagues, level of education of building users, and time pressure, and not influenced by room interior or by colour of light; (2) that the perception of air quality is affected by the psychosocial atmosphere at work and by job stress; (3) that the visual comfort is influenced by age and type of job; and (4) that the acoustic comfort is affected by the country of origin.
- Providing people with the possibility to control the indoor environment improves thermal and visual comfort and overall satisfaction with IEQ as well as satisfaction with indoor air quality.
- Little information is available on modelling how individual environmental conditions related to thermal, acoustic and visual comfort, as well as satisfaction with indoor air quality influence the overall satisfaction with IEQ. This information would be important especially when remedial measures are implemented indoors.
- As a minimum, the solutions for controlling the indoor environment should include control of the thermal environment, the possibility of delegating control to occupants, and adjustments based on outdoor conditions, as well as the possibility of customizing the control. Control solutions may be different in naturally and air-conditioned buildings and should always be made on a case-by-case basis.

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Paper II

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Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing

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ABSTRACT

A questionnaire survey in Danish homes investigated the factors that influence occupants' comfort. The questionnaire contained questions on inhabitants' behaviour, their knowledge as regards building systems designed for controlling the indoor environment and the ways in which they achieve comfort. A total of 2499 questionnaires were sent to inhabitants of the most common types of housing in Denmark; 645 persons replied (response rate of 26%). The results show that the main indoor environmental parameters (visual, acoustic and thermal conditions, and air quality) are considered by occupants to be the most important parameters determining comfort. Manual control of the indoor environment was indicated by the respondents as highly preferred, and only in the case of temperature did they accept both manual and automatic control. The respondents indicated that they were confident about how the systems for controlling indoor environmental quality in their homes should be used. 54% of them reported to have had at least one problem related to the indoor environment at home. A majority of those respondents did not try to search for information on how to solve the problem. This may suggest that there is a need for increasing people's awareness regarding the consequences of a poor indoor environment on their health and for improving people's knowledge on how to ensure a good indoor climate.
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1. Introduction

In the developed part of the world people spend almost 90% of their time indoors [1,2]. Indoor conditions have serious implications for their health, comfort and general well being. More than half of the time spent indoors takes place in homes. It is therefore important to identify the parameters that influence the comfort of inhabitants in their homes and to see how their behaviour may influence their comfort, especially considering that information on this subject is not extensive. For example, in the majority of Danish homes, indoor environment is to a large extent controlled manually by the building users by, e.g. opening the windows to regulate ventilation or setting the thermostat levels to regulate heating. As a consequence building occupants, whether aware of it or not, are responsible for ensuring indoor environment and through their behaviour they influence their comfort and even health.

Many studies have investigated the behaviour of people in residential buildings [3–9]. The studies have resulted in defining patterns of human behaviour in relation to window opening, use of air-conditioning and control of temperature, lighting and solar shading, depending on outdoor and indoor conditions. Some of these studies recognized that it is not only physical conditions that influence the behaviour of building occupants. Andersen et al. [5] found that gender and ownership of the dwelling influenced the way in which people control the indoor environment. Guerra-Santin and Itard [9] observed that the duration for radiators to be turned on was associated with the type of thermostat, the presence of elderly people, and past residence. Brundrett [3] showed that the number of open windows was higher in families where a housewife stayed at home and that it increased with the size of the family. The study of Schweiker and Shukuya [7] indicated that the use of air-conditioning units differed depending on the origin of a person, experience from childhood and attitude towards air-conditioning. Besides the above-mentioned factors, the behaviour of building occupants is also influenced by their knowledge of and experience with using building systems for controlling the indoor environment. Peeters et al. [10] found that building occupants did not know how to operate thermostatic radiator valves and as a result overheating often occurred in households in Belgium. Also in China it was observed that people did not understand well how the thermostatic radiator valves function and used them as they would manually controlled valves [8]. In the U.K. people had problems with controlling a heating system [11]. A study in Denmark showed that people did not feel confident in regulating heating in homes and felt that they needed

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more information [12]. People experience difficulties in using other systems, e.g. room air-conditioners, as shown in studies in the U.S. [13,14]; in Japan they only used a limited number of features of the air-conditioners [15]. In contrast, Finnish occupants felt quite confident about their knowledge of heating and ventilation systems in homes [16]. The above results show that understanding how people behave indoors and how they operate the systems for controlling the indoor environment demands an in-depth knowledge which is crucial for developing systems that provide comfort for building occupants.

It is also important to understand what determines comfort for building occupants. The literature survey by Frontczak and Wargocki [17] concluded that 4 main indoor environmental parameters (thermal, visual, acoustic environment and air quality) contribute to a satisfying indoor environment; of the 4, thermal comfort was perceived by building occupants to be of greater importance for comfort compared with visual and acoustic comfort and good air quality. The literature survey also suggested that apart from indoor environmental parameters there are other factors that can influence satisfaction with the indoor air quality, among others, type of building, occupants' control over the indoor environment and outdoor climate, including season.

The objective of the present study was to understand what constitutes comfort in housing and to examine building users' preferred ways of achieving comfort. The survey also aimed at understanding how people act indoors, especially when they face indoor environmental problems, how much they know about using systems for controlling the indoor environment and where they find the information about how to deal with such problems. The study is part of a larger research programme on a user-driven innovation aiming to develop control solutions for indoor environments that maximize comfort for building occupants and enhance their quality of life. Thus the present survey is created also to gain feedback on how future solutions for controlling the indoor environment should be developed so as to secure comfort of building occupants and at the same time present to them a system which is acceptable and desirable.

2. Methods

Invitations to participate in the survey were sent by regular mail to 2499 addresses in Denmark. The addresses were obtained from a national building and housing database (BBR), which includes data of all buildings in Denmark. It was aimed to gather responses of inhabitants of the most common residential buildings in Denmark. Table 1 depicts seven groups representing the most common residential buildings, depending on the type of housing (apartments in a block of flats, twin- or row-houses and one-family houses) and on the ownership type (privately owned, cooperative housing association and private housing association). 357 addresses were requested to be randomly drawn from the BBR database for each housing type so that the responses would cover equally different types of residential building stock in Denmark. One-family houses in cooperative and private housing associations are very rare so no addresses were requested for these groups. Table 1 presents the number of addresses received from the BBR database for each group. 25 addresses (1%) represented another housing type than requested from the BBR database. These 25 addresses belonged to one-family houses owned by a cooperative housing association or private housing association as well as privately owned farmhouses, hotel, summer houses or other residential buildings. The questionnaires were sent nevertheless to their owners and included in the analysis since it was not the purpose of the present work to discuss differences in responses between various groups of buildings but to advance our knowledge about inhabitants' behaviour and knowledge as regards building systems designed for controlling the indoor environment and factors influencing their comfort at home. Among respondents answering the invitation to fill out the questionnaire, 2 rewards of 1000 DKK (ca. €130) were drawn.

A letter with the invitation to participate in the study contained a one-page description of the project and an invitation to fill out the survey online. The first reminder in the form of a postcard was sent 6 days after the first invitation letter to all 2130 non-respondents. The second reminder containing a paper-based questionnaire (only background questions and questions regarding homes) was sent 12 days after the first invitation to 1000 randomly chosen non-respondents. In total, 47 letters and postcards were returned due to wrong addresses, resulting in a final sample size of 2452 addresses. Of these, 533 persons filled out the questionnaire online (response rate 22%) and 112 persons filled out the paper-based questionnaire (response rate 4%); their responses were manually added to the database (twice to check for gross errors). The total response rate was only 26% despite 2 reminders. No non-respondent analysis was carried out.

The questions included in the questionnaire were selected in accordance with the objectives of the project, i.e. to gain inspiration for concepts of future solutions for controlling the indoor environment, which will secure comfort to building occupants and at the same time be solutions which are desired by them. The contents of the questionnaire were selected based on the results of earlier stages of the project: the literature survey [17] and field studies among 5 families [18,19]. During field studies the families were visited at their home, workplace and kindergarten (children). They were interviewed concerning their perception and knowledge about the indoor environment, their behaviour in relation to it and the way of dealing with indoor environmental problems if any.

The questionnaire was composed of 3 parts:

1. Background questions:
   - socio-demographic questions regarding age and gender of the respondent and co-habitants, education and type of work of the respondent, total income of the family;

Table 1
Number of people who were invited to participate in the study and who filled out the questionnaire per housing type.

	Invited				Responded			
	Apartment in a block of flats	Twin- or row-house	One-family house	Total	Apartment in a block of flats	Twin- or row-house	One-family house	Total
Privately owned	349 (14%)	357 (14%)	356 (14%)	1062 (42%)	82 (13%)	125 (19%)	139 (22%)	346 (54%)
Cooperative housing association	357 (14%)	352 (14%)	X	709 (28%)	39 (6%)	70 (11%)	X	109 (17%)
Private housing association	354 (14%)	349 (14%)	X	703 (28%)	80 (12%)	103 (16%)	X	183 (28%)
Total	1060 (42%)	1058 (42%)	356 (14%)	2474 (99%[a])	201 (31%)	298 (46%)	139 (22%)	638 (99%[a])

[a] 1% represented other housing type than requested.

- questions regarding evaluation of the indoor environment, perceived importance of single environmental parameters for achieving a good indoor climate;
- questions regarding current location, i.e. where they filled in the questionnaire (home, outdoors, office, etc.);
- open questions about a location where respondents feel comfortable and what factors contribute to comfort at this location.

2. Questions regarding home which addressed the following:
   - behaviour in relation to window opening, adjusting heating and turning the lights on;
   - preference for ways of controlling the indoor environment;
   - self-estimated level of knowledge about how to use heating and ventilation systems optimally and extent of benefiting from receiving advice on how their homes should be ventilated, cleaned and heated;
   - indoor environmental quality problems that respondents had and the methods used to solve them as well as how knowledge about the solution of problems was found;
3. Questions regarding workplace, addressing the same items as under point (2) above. This part of the questionnaire was presented only to those who filled out the questionnaire online and answered that they work in an office or children's institution (nursery, kindergarten, school, etc.). Only 195 respondents met these requirements resulting in a very low response rate, as indicated below.

The present paper reports results for background questions (part 1) and home environment (part 2). No analysis of responses regarding the work environment are included, one of the reasons being a very low response rate regarding workplace (6%).

Two questions were open type; the respondents described a location where they felt comfortable and identified the factors that contributed to comfort. Other questions were answered in one of the four following ways:

(A) on a continuous scale: Acceptability of indoor environmental parameters was assessed using continuous scales ranging from 'clearly acceptable' (coded as 1 in the analysis) to 'clearly unacceptable' (coded as −1); the scales are presented in Standard EN15251 [20], annex H. The question about acceptability of the indoor environment was formulated in the following way: "How do you assess thermal environment/air quality/sound quality/light quality/quality of indoor environment at the moment?";
(B) on a 'yes' and 'no' scale with additional 'I do not know' answer. Respondents could choose only one answer to each question;
(C) on a 3- to 6-point scale which e.g. evaluated the degree of importance of different parameters or frequency of different behaviours. Additionally in these questions respondents could choose 'I do not know' answer. Respondents could choose only one answer to each question;
(D) using a list of possible answers e.g. describing possible indoor environmental quality problems or reasons for different behaviours. Apart from background questions respondents could also choose answer 'I do not know' or add their own answer in the empty field if their reply was not mentioned in the list of possible answers. Typically respondents could choose more than one answer.

At first multivariate linear regression model was fitted to responses evaluating acceptability of individual indoor environmental conditions and an overall acceptability with the indoor environment. However, the assumptions of constant variance of error term and normal distribution of residuals were not satisfied even after transforming the overall acceptability with the indoor environment (dependent variable) with reciprocal squared or exponential transformations. Consequently, a different statistical analysis was used being a non-parametric Spearman correlation evaluating the relation between acceptability of the overall indoor environment and acceptability of air quality and thermal, visual and acoustic environment.

Statistical significance of differences in responses of different respondents was tested by Wilcoxon rank sum test (known also as Mann–Whitney test) or χ^2 test [21]. The analysis was carried out in the statistical software R [22]. The results were considered statistically significant when $p < 0.05$, 2-tailed.

3. Results and discussion

3.1. Response rate

Since the response rate was only 26% and a non-respondent analysis was not performed, the responses cannot be considered as representative for the Danish population due to potential of selection bias. Nevertheless, they carry important information regarding comfort and behaviour in Danish housing of which data is meagre. The lowest response rate was among people living in the apartments and in cooperative housing association (Table 1). The respondents had a higher education status than an average Dane. In our sample there was also an underrepresentation of people younger than 52 years and an overrepresentation of people aged 52 years old and older as compared to the Danish adult population as of April 2011 (http://www.statistikbanken.dk/statbank5a/default.asp?w=1280). This skewness could be caused by the fact that most of the paper-based questionnaires (79%) were filled out by respondents older than 52 years, which accounts for 72% of all respondents.

The influence of the overrepresentation of respondents older than 52 years old on the results of the study was verified by performing additional analysis. Respondents were divided into 2 groups: those younger than 52 years old and those aged 52 years and over (10 respondents were disregarded from additional analysis because they did not indicate their age). Statistical analysis showed that the differences between respondents younger and older than 52 years old are small, if any, which suggests that the overrepresentation of people older than 52 years in our sample has a small impact on the overall study results.

3.2. Comfort

Fig. 1 shows acceptability levels with indoor environmental parameters (air quality, thermal, visual, acoustic and overall environment) as assessed by the respondents. Respondents were generally satisfied with the overall indoor environment. The highest mean acceptability was observed for the air quality and the lowest for the thermal environment. Using the relationship of Gunnarsen and Fanger [23] the observed levels of acceptability correspond generally to less than 22% of dissatisfied.

To understand which parameters determine building occupants' comfort, acceptability of the overall indoor environment was correlated with acceptability of all 4 main indoor environmental parameters (Table 2). The correlations were based on between 564 and 569 responses due to the fact that some of the respondents did not evaluate all environmental parameters and only evaluations made at home were included. All correlations were significant and positive, indicating that an increase of acceptability with thermal, visual, acoustic environment or air quality will result in an increase of acceptability of the overall indoor environment; all parameters contributed thus to comfort as expected [17]. Correlations have the

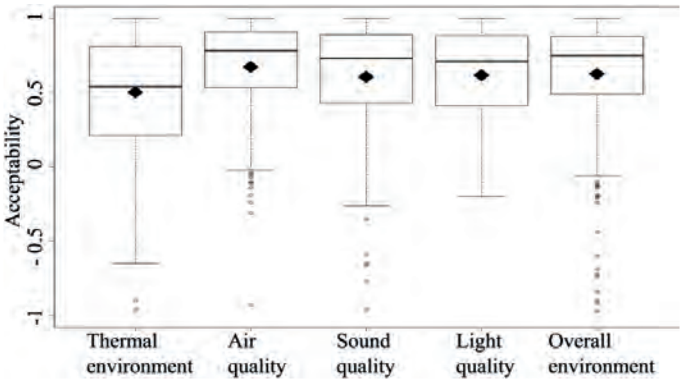

Fig. 1. Box plots for acceptability with indoor environmental parameters assessed in the questionnaire. Filled squares represent mean values. Thick lines represent median values. The extremes of boxes represent 25th and 75th percentile.

same range of magnitude, indicating that all 4 main environmental parameters are equally important for the assessments of the overall indoor environment and contribute equally much to the overall acceptability if only their acceptability levels are similar to the ones reported here (Fig. 1). Similar results were obtained when respondents were asked to compare pairwise which indoor environmental parameters were more important. Most respondents answered that the indoor environmental parameters were equally important (Table 3). The results differ slightly from recently published data collected in buildings in many different climate zones, which showed that the thermal environment is ranked to have slightly higher importance for overall comfort than acoustic and visual environment and air quality [17] and that noise conditions were more important for overall comfort than temperature, light and air quality [24]. It is not possible to examine whether the results disagree due to climatic or other differences.

305 respondents (47% of all respondents) indicated a location where they feel comfortable. Home was mentioned by most of the respondents (58%); they also felt comfortable outdoors (9%), in a summer house (7%), at holidays' destinations (4%) and in the office (4%). They described in their own words which factors contribute to comfort. The 10 most frequently mentioned factors are presented in Table 4. Indoor environmental parameters (light, temperature, air quality and noise level) were mentioned as parameters contributing the most to comfort, together with peace and silence, contact with the nature and view. This agrees with previous studies [24–27] which showed that also other factors not related to the indoor environment influence the perception of comfort. Considering the high importance of the indoor environment for comfort, it is surprising that in many Danish offices, providing a good indoor environment is not given high priority [28].

Table 2
Spearman correlation coefficients between acceptability of the overall indoor environment and acceptability of thermal, visual and acoustic environment and air quality.

Parameter	Coefficient
Air quality	0.64[a]
Visual	0.52[a]
Acoustic	0.52[a]
Thermal	0.48[a]

[a] $p<0.001$ (2-tailed test).

3.3. Classification of indoor environment based on comfort

Standard EN15251 [20] recommends overall classification of the indoor environment based on evaluation of indoor environmental parameters separately. It suggests an approach to classify and certify the buildings using the levels of individual environmental parameters (Appendix I, see Ref. [20]) but it does not provide any information on how to combine different environmental parameters into one index which can be used to classify the indoor environmental conditions in the building. The present analysis (Table 2) suggests that if acceptability of thermal, acoustic, visual conditions and air quality are of a similar magnitude corresponding to less than 30% dissatisfied, the acceptability of the overall environment can be approximated by averaging acceptability of these individual factors. Present results can thus be used to classify the indoor environment but only in buildings meeting at least category III in the Standard EN15251 [20]. Further studies should be used to examine how the individual parameters of indoor environment influence overall acceptability of indoor environment in case any of them cause more than 30% dissatisfied.

3.4. Windows opening vs. mechanical ventilation system

Respondents valued natural ventilation highly and it was very important for them that they could open a window in their home (Table 5). They indicated that the possibility to open the windows gave them a chance to take care of their own and their family's health and to air their homes. For many respondents it was not important that their homes are aired out with mechanical

Table 3
Summary of responses to the question 'What in your opinion is more important for a good indoor environment?'

Parameter A	Parameter B	A more important than B	A and B equally important	B more important than A	No answer[a]
Temperature	Air quality	18%	59%	13%	10%
Temperature	Lighting	32%	45%	12%	11%
Temperature	Acoustics	27%	42%	18%	13%
Air quality	Lighting	32%	44%	11%	13%
Air quality	Acoustics	30%	43%	14%	13%
Lighting	Acoustics	23%	45%	17%	15%

[a] Category 'No answer' includes both responses 'I do not know' and respondents who did not provide any answer.

Table 4
Ten most frequently used words in 305 descriptions of factors contributing to comfort.

Factor	Percentage of all responses
Light, sun	46%
Temperature, warmth	35%
Fresh/clean air, smell	21%
Sound, noise	16%
Peace, silence	15%
Nature	15%
View	14%
Size of room	9%
Family and friends	8%
Room interior, style, furniture	8%

ventilation (Table 5). However, supplying fresh air by mechanical ventilation was valued slightly higher by respondents who had mechanical ventilation than those without mechanical ventilation at home (Table 5); the difference being statistically significant ($p < 0.001$). It is interesting to observe that 43% of respondents with mechanical ventilation expressed that supplying fresh air from mechanical ventilation was not important for them and they valued highly the possibility of window opening. These results may be a consequence of a strong preference for manual control over the indoor environment as discussed later. They agree with the preference for natural ventilation also observed in the previous studies [4,15], which showed that Japanese people believed that natural cooling (window opening) was much better in respect to their health than air-conditioning. The results show also that respondents may associate fresh air with window opening rather than with mechanical ventilation, despite the increasing evidence of negative effects of outdoor air pollution on health, especially in cities [29], and despite increasing evidence that the installation of a mechanical ventilation system in homes reduces health problems especially related to asthma and allergy [30]. The majority of respondents live in houses, which in Denmark are generally situated in suburbs and rural areas outside the city centres and away from heavy traffic and pollution; we did not, however, ask the survey participants about their outdoor air quality, which is generally considered to be good in Denmark except for a few downtown areas.

No significant differences were found in the frequency of window opening in summer and winter between respondents with and without mechanical ventilation. A previous qualitative study among 29 families showed that window opening was embedded in practices of everyday life such as morning routines or cleaning [31]. It was a way of expressing love and care for the family and the house and connecting to nature. Social aspects and routine behaviours associated with window opening may explain why the respondents valued the possibility of window opening.

Table 6
Ranking of importance of different factors considered when respondents were arranging their homes based on responses from between 537 and 588 respondents (some of the respondents did not evaluate all the parameters).

Factor	Mean vote[a]
Creating cosy atmosphere	2.19
Purpose of the room	2.10
Daylight conditions	1.94
Privacy	1.83
Creating practical working conditions	1.83
Colours	1.82
Artificial lighting conditions	1.70
Price	1.67
View	1.63
Noise	1.62
Draught	1.61
Thermal conditions	1.59
Creating/showing your style	1.47
Location of heating sources (radiators, ventilation system, floor heating)	1.39

[a] 3 means very big influence; 0 means no influence.

3.5. Dealing with indoor environmental quality problems

54% of respondents reported to have at least one indoor environmental quality problem at home. Most of the problems were related to temperature. Respondents were disturbed by either cold floors (22% of all respondents) and/or too high temperature in the summer (20%). They also experienced condensation on windows (16%), too low temperature in winter (14%), noise from outside or neighbours (14%) and draught (12%). Very few reported to have mould (5%) or complained about too little daylight (4%).

It was investigated whether the way people arrange their homes may influence the occurrence of indoor environmental problems. Respondents were asked to evaluate the importance of different factors while arranging their homes. Table 6 shows that creating a cosy atmosphere, consideration of the purpose of the room and luminous conditions, especially daylight, had the highest influence on the arrangement of homes. Noise, draught and temperature conditions were considered to be much less important. It is interesting to observe that while arranging their homes, respondents paid least attention to factors that were later a reason for indoor environmental problems.

Among respondents who reported to have indoor environmental quality problems, more than half of them did not try to find information on how to solve the problem which they faced (Table 7, row A), mostly because they believed that the problem was not serious enough to act upon (Table 8). Among those who tried to find information, the most common source of information was the Internet (Table 9). Respondents avoided solving an indoor environmental quality problem due to financial reasons (30%) and because it was believed that the problem was not serious enough to act upon (29%). However, the behaviour of respondents depended on the kind of

Table 5
Summary of results showing the importance of being able to open windows or having mechanical ventilation system at home.

	Very important	Important	Not very important	Not at all important	No answer[a]
How important is it to have the possibility of opening a window?	86%	6%	1%	0%	7%
How important is it to always have fresh air supplied by a mechanical ventilation system? All respondents	10%	7%	21%	27%	35%
How important is it to always have fresh air supplied by a mechanical ventilation system? Respondents without mechanical ventilation system at home ($N = 439$)	5%	5%	21%	34%	35%
How important is it to always have fresh air supplied by a mechanical ventilation system? Respondents with mechanical ventilation system at home ($N = 145$)	25%	12%	28%	15%	20%

[a] Category ‘No answer’ includes both responses ‘I do not know’ and respondents who did not provide any answer.

Table 7
Distribution of responses regarding respondents' knowledge in relation to using ventilation and heating systems and their perceived need for more information on this matter.

Row nr	Question	Yes	No	No answer[a]
A	Did you try to find information about how to solve an indoor environmental problem you face? (*N* = 342; only respondents who indicated earlier that they had at least one indoor environmental quality problem were asked)	32%	59%	9%
B	Do you think you know enough to take good care of your home and use ventilation and heating systems properly? All respondents	74%	12%	14%
C	Do you think you would profit from being given advice on your behaviour in relation to ventilating, cleaning and heating? All respondents	36%	50%	14%
C1	Do you think you would profit from being given advice on your behaviour in relation to ventilating, cleaning and heating? (*N* = 347; only those respondents who indicated that they have at least one indoor environmental quality problem)	48%	46%	6%
C2	Do you think you would profit from being given advice on your behaviour in relation to ventilating, cleaning and heating? (*N* = 238; only those respondents who indicated that they do not have indoor environmental quality problems)	26%	65%	9%
D	Would you use an apparatus which could guide you on how to secure a good indoor climate while using as little energy as possible if such an apparatus existed?	46%	24%	30%

[a] Category 'No answer' includes both responses 'I do not know' and respondents who did not provide any answer.

problem they faced. Among those who observed mould at their home, a rather serious problem, 65% of them tried to find information on how to solve this problem. They mainly searched for information on the Internet (45% of respondents) or contacted their family and friends (27%). Only 14% consulted an expert in the field. The results suggest that mild problems are likely not to lead to any action and therefore it is of utmost importance that some guidance to the occupants is given because if not handled immediately it can lead to much more serious problems. One way of dealing with it is an apparatus informing the building users what to do.

The results show that respondents judged mainly on their own how serious the problem was without contacting the experts in the field. Regular inspections of homes with subsequent mandatory repairs would probably ensure that indoor environment is at acceptable level, but there is quite meagre evidence of their effectiveness, although analogous regular car checks are quite successful. Regular inspections of HVAC systems in public buildings are mandatory in Sweden [32], while in Portugal regular energy audits imposed by the Energy Performance of Buildings Directive (EPBD) [33] are accompanied by the measurements of indoor air quality which can identify potential problems. A diagnostic tool, which will help to evaluate the seriousness of indoor environmental problems, can also be developed. The results indicate that an internet-based tool might be effective since respondents indicated the Internet as the most common source of information. This tool should provide an estimated cost of solving the problem as well as health- and building-related consequences of not solving the problem, to help people make an informed decision as to whether or not the problem should be solved. In Denmark there are already some websites where different issues of the indoor environment are described and people can find information and advice, but we do not know on which basis people judge whether the information is credible or not. A big challenge is to reach people who ignore the problems and fail to look for more information. Among them, 58% indicated that they had little or no knowledge as to whether the problem had any serious consequences on their health or building conditions. These people may be addressed by educational campaigns. A survey among Danish citizens showed that increased knowledge may lead to change of behaviour (Zapera [34]). In Zapera's survey, around 40% of respondents indicated that they would open a window more often in winter and clean more often at home if they knew that it was good for their families' health and well being. Over 30% of respondents would open a window more often in winter if they knew that there are harmful compounds in the indoor air and if they knew that it would improve indoor environmental quality. Monetary consequences of ignorance can also create incentives. Information about the indoor environment may also be described in the daily press and magazines in an easily understandable way for laymen. In this way people will be addressed without actively looking for information leading to increased awareness about ensuring a good indoor environment and to positive change of behaviour.

3.6. Control over the indoor environment

A vast majority of respondents preferred manual control over artificial light, window opening and solar shading (Fig. 2). They were more positive regarding automatic control or a combination of manual and automatic control in relation to control of temperature in their homes. In the majority of Danish homes indoor environmental conditions are controlled manually apart from

Table 8
Distribution of responses regarding reasons why respondents did not try to find information on how to solve the problems which they faced (*N* = 201).

Answer	Percentage of respondents
The problem was not serious enough to act	51%
I already knew enough about the solution and I did not need additional information	20%
It is not my responsibility	7%
I did not know where to find relevant information	5%

Table 9
Distribution of responses regarding the source of information about how to solve the problems which respondents faced (*N* = 111).

Answer	Percentage of respondents
I searched on the Internet	41%
I contacted experts in the field	30%
I asked my family and/or friends for information	24%

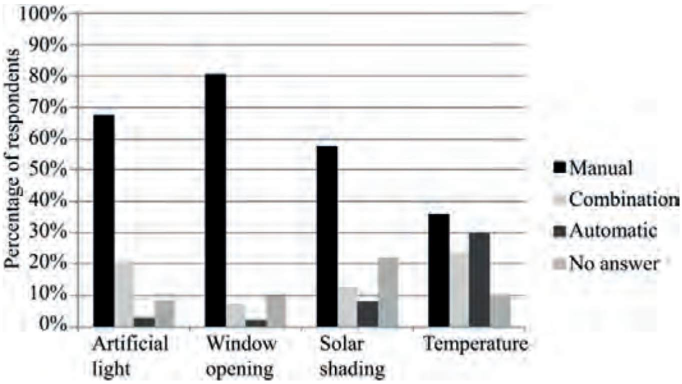

Fig. 2. Percentage of respondents preferring a different type of control of indoor environmental parameters. Category 'No answer' includes both responses 'I do not know' and respondents who did not provide any answer.

semi-automatic control of temperature by means of thermostatic radiator valves. In some homes there is also mechanical ventilation which can be considered as an automatic means to control the indoor climate. To examine whether the preference for manual control is caused by lack of it, preferred control was compared in homes with and without a mechanical ventilation system. No difference was found except for higher preference for non-manual control over artificial light among respondents with mechanical ventilation ($p = 0.014$). The reason for these results could be that many of the respondents could be unaware of the fact that they have automatic control of the indoor environment or that even though the automatic control is present in their homes they still prefer to manually control or override it.

70% of respondents indicated that they were at least a bit aware how their behaviour influenced energy use and indoor environmental quality and only 5% of respondents knew nothing or almost nothing about it. In the opinion of 75% of respondents it was easy to understand how the shading, ventilation and heating systems work and how to use them optimally. Respondents expressed belief that they had enough knowledge to use the systems for controlling the indoor environment correctly and to take good care of their home (Table 7, row B). Otherwise, they would contact a professional (technician or janitor; 48% of all respondents), ask their family and friends for advice (40%) or look for information on the Internet (33%). Only 2% of respondents did not know whom to contact or would not do anything, and the majority of them were over 52 years old.

Several questions were used to find out what is the preferred means of information about achieving good indoor environment. Most of the respondents indicated that they did not need any advice on their behaviour in relation to ventilating, cleaning and heating (Table 7, row C). Among respondents who faced indoor environmental quality problems there were significantly ($p < 0.01$) more respondents who indicated that they would profit from being given such advice, compared to the group of respondents who did not face any indoor environmental quality problem (Table 7, row C1 and C2). If the advice would be accepted, respondents would rather prefer it in a form of an apparatus guiding them on how to obtain a good indoor climate while using as little energy as possible (Table 7, row D). The question about an apparatus was hypothetical and did not specify the working principle of the apparatus. It aimed at investigating if people would prefer an advice from an instrument rather than a person. An apparatus could also provide a continuous feedback to the occupants, potentially avoiding serious problems in the future due to inadequate housing conditions. The vast majority of those who would use guidance from an apparatus believed that it could help them being more energy conscious (60% of respondents) and it would improve their indoor environmental quality (57% of respondents). The most common reason for not being willing to use such guidance was that respondents felt that they knew how to ensure a good indoor environment in an effective way and did not need any more guidelines regarding indoor air quality (65%). They also did not want their behaviour to be controlled by a special apparatus (14%) and would forget to look at an apparatus (13%). The results are in accordance with a general negative attitude towards automatic control of indoor environment discussed earlier and high confidence in own abilities to deal with problems. Also in studies of Karjalainen [16] and Price and Sherman [35] people felt quite confident regarding their knowledge on how a ventilation system works and how to operate it properly. However, Price and Sherman [35] concluded that respondents were not familiar enough with mechanical ventilation systems to meaningfully respond to questions about them. This to some extent agrees with the other studies which showed that people lack understanding of how to use systems properly for controlling the indoor environment and experience problems when operating them [8,10–15].

3.7. Potential solutions for controlling the indoor environment

Two solutions for controlling the indoor environment can be considered as a result of the present survey:

- automatic control guaranteeing minimum acceptable conditions with the possibility of manual adjustment (override) of conditions to occupants' needs;
- manual control by building occupants.

In the former solution, the automatic system can be designed to ensure the minimum requirements for an acceptable indoor environment, and the occupants can adjust the indoor environment to their needs as required. In the latter solution, the building occupants are fully responsible for ensuring a good indoor environment. However, the relevant question is whether the occupants will always act when the situation arises. In the study of Price and Sherman [35] in the U.S. nearly 50% of respondents indicated that they sometimes failed to use the bathroom fan even when conditions clearly required it, most often because they simply did not think of it. In such a situation, a basic automatic ventilation of the bathroom (e.g., a fan that turns on when the light is turned on or humidity is too high) could be an appropriate solution. Another solution is a system that warns when people should act, or a system that continuously visualizes whether indoor environmental quality conditions are good or poor. An attempt to create such a system was made by Jaffari and Matthews [18] who suggested an artificial plant that wilts at high CO_2 levels while low CO_2 levels make it rise back to the upright position. No data describing the practical use of such a plant is available. Broer [36] constructed a lamp that represents the levels of temperature, humidity, sound, light and CO_2 by means of light; he placed it in the home of one family for 9 days and the idea to visualize the indoor environment through lights seemed appealing to the family. Kim and Paulos [37] designed a tool for continuous graphical visualization of indoor air quality (based on measurements of particles below 0.5 μ); they placed it in 5 homes for 2 weeks and observed that it had a positive impact on willingness to take action to improve the indoor environment. In the present study, respondents were asked how much they are willing to pay for an apparatus that would guide them on how to ensure a good indoor climate while using as little energy as possible. They would pay on average €230 (range between €0 and €2600). To ensure that people's interest towards indoor air quality is attracted, it may be necessary to relate to some values that are important such as e.g. energy saving and financial consequences related not only to energy but also to health consequences associated with lost days from work, medical costs etc. [38].

4. Conclusions

Indoor environmental parameters were acknowledged by the respondents to influence comfort. Their responses suggest that acceptability of overall indoor environment can be approximated by averaging acceptability of thermal, visual and acoustic conditions and air quality but only at the acceptability levels which are reported in the present paper. Low response rate and lack of representativeness indicates the need for validating the present results.

Manual control of the indoor environment was preferred by the respondents compared with automatic control except for control of temperature where both manual and automatic control was accepted.

Respondents associated natural ventilation (window opening) and not mechanical ventilation systems with fresh air supply.

Respondents indicated that they were aware of how their behaviour influenced indoor environmental quality. They also felt confident in using the systems for controlling the indoor environment in their homes.

Most respondents who had a problem related to the indoor environment did not try to find information on how to solve it because they considered that it was not serious.

Consequently, increasing people's awareness about the consequences of poor indoor environmental quality on their health and the knowledge about how to ensure a good indoor climate would be needed.

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Paper III

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Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design

Abstract The article examines which subjectively evaluated indoor environmental parameters and building features mostly affect occupants' satisfaction in mainly US office buildings. The study analyzed data from a web-based survey administered to 52 980 occupants in 351 office buildings over 10 years by the Center for the Built Environment. The survey uses 7-point ordered scale questions pertaining to satisfaction with indoor environmental parameters, workspace, and building features. The average building occupant was satisfied with his/her workspace and building. Proportional odds ordinal logistic regression shows that satisfaction with all 15 parameters listed in the survey contributed significantly to overall workspace satisfaction. The most important parameters were satisfaction with amount of space (odds ratio OR 1.57, 95% CI: 1.55–1.59), noise level (OR 1.27, 95% CI: 1.25–1.29), and visual privacy (OR 1.26, 95% CI: 1.24–1.28). Satisfaction with amount of space was ranked to be most important for workspace satisfaction, regardless of age group (below 30, 31–50 or over 50 years old), gender, type of office (single or shared offices, or cubicles), distance of workspace from a window (within 4.6 m or further), or satisfaction level with workspace (satisfied or dissatisfied). Satisfaction with amount of space was not related to the gross amount of space available per person.

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Key words: Occupants' responses; Office buildings; Post-occupancy evaluation.

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Practical Implications
To maximize workspace satisfaction, designer should invest in aspects that increase satisfaction with amount of space and storage, noise level, and visual privacy. Office workers will be most satisfied with their workspace and building when located close to a window in a private office. This may affect job satisfaction, work performance, and personal and company productivity.

Introduction

Occupants' satisfaction in office buildings is associated with indoor environmental quality (thermal, visual, acoustic environment, and air quality) and workspace and building features including size, esthetic appearance, furniture, and cleanliness. The 10 studies in Table 1 identified the parameters that contribute to building occupants' satisfaction (Astolfi and Pellerey, 2008; Bin et al., 2011; Bluyssen et al., 2011; Choi et al., 2009; Humphreys, 2005; Lai et al., 2009; Marans and Yan, 1989; Schakib-Ekbatan et al., 2010; Veitch et al., 2007; Wong et al., 2008). The definition of occupants' satisfaction was not consistent among the studies, but all of them defined occupants' satisfaction in a broad perspective and related it either to satisfaction/comfort with indoor environmental quality or satisfaction/comfort with the workspace. Five studies (Astolfi and Pellerey, 2008; Bin et al., 2011; Humphreys, 2005; Lai et al., 2009; Wong et al., 2008) focused only on the impact of indoor environmental quality on building occupants' satisfaction. They found that thermal, visual, and acoustic environment and air quality contributed to building occupants' satisfaction. The importance of different indoor environmental parameters for building occupants' satisfaction varied slightly between studies, but the importance of the thermal environment for building occupants' satisfaction

Table 1 Summary of studies investigating which parameters influence building occupants' satisfaction

Study	Population	Data analysis	Results
Marans and Yan (1989)	Nearly 1000 occupants in 13 office buildings in USA (RR unknown)	Pearson correlation	Workspace satisfaction was correlated with satisfaction with lighting, noise, air quality, heating and drafts as well as amount of space, furniture quality, privacy, and color and area of walls and partitions
Humphreys (2005)	4655 responses[a] in 26 office buildings in five European countries (RR unknown)	Multiple linear regression	Overall comfort at workplace was affected by satisfaction with warmth, air quality, air movement, noise, humidity, and light
Veitch et al. (2007)	779 occupants in nine office buildings in Canada and USA (RR = 90%)	Exploratory and confirmatory factor analysis and structural equation modeling	Satisfaction with indoor environment at workstation was influenced by satisfaction with noise, air movement, air quality, temperature, lighting, privacy, view to outside as well as workspace's size, esthetic appearance, and degree of enclosure
Astolfi and Pellerey (2008)	852 students in a secondary school in Italy (RR = 85%)	Pearson correlation	Satisfaction with indoor environment was correlated with satisfaction with acoustic, thermal, visual environment, and air quality
Wong et al. (2008)	293 occupants of office buildings in Hong Kong (RR unknown)	Multivariate logistic regression	Acceptability of overall indoor environment was affected by acceptability of thermal environment, air quality, noise level, and illumination level
Choi et al. (2009)	492 occupants in 29 office buildings in USA (RR unknown)	Pearson correlation	Satisfaction with indoor environment was correlated with satisfaction with air quality, thermal environment, lighting, acoustics, and spatial conditions
Lai et al. (2009)	125 occupants in 32 residential apartments in Hong Kong (RR unknown)	Multivariate logistic regression	Acceptability of overall indoor environment was affected by acceptability of thermal environment, acoustics, lighting, and air quality
Schakib-Ekbatan et al. (2010)	867 occupants in 14 office buildings (RR = 79%)	Correspondence analysis and principal component analysis with optimal scaling	Workspace satisfaction was influenced by satisfaction with temperature, lighting conditions, air quality, acoustics, spatial conditions (privacy and individualization of workspace), office furniture, and office layout
Bluyssen et al. (2011)	5732 occupants in 59 office buildings in eight European countries (RR unknown)	Principal component analysis, Pearson correlation, and linear regression	Overall satisfaction was affected by satisfaction with thermal, acoustic and luminous environment, air quality, control over indoor environment, amount of privacy as well as office layout, decoration, and cleanliness
Bin et al. (2011)	500 occupants in five buildings in Beijing and Shanghai (RR unknown)	Multivariate linear regression	Overall satisfaction was influenced by satisfaction with thermal, acoustic and luminous environment, and air quality

[a]Number of filled out questionnaires; some of the building occupants gave their response more than once.
RR, response rate.

was generally ranked slightly higher than the importance of air quality and acoustic environment and much higher than the importance of visual environment. A literature survey by Frontczak and Wargocki (2011) concluded that apart from indoor environmental parameters, there are other factors unrelated to the indoor environment that can influence satisfaction within the buildings, among others occupants' control over the indoor environment. In addition, the five studies presented in Table 1 (Bluyssen et al., 2011; Choi et al., 2009; Marans and Yan, 1989; Schakib-Ekbatan et al., 2010; Veitch et al., 2007) include effects of parameters unrelated to indoor environmental quality. These studies show that building occupants' satisfaction was also affected by satisfaction with the view, control over the indoor environment, amount of privacy as well as layout, size, cleanliness, esthetics, and furniture of office.

Occupants' satisfaction was shown to be positively correlated (linear model *r*: 0.74–0.8) with the self-estimated productivity of office workers (Leaman et al., 2007; Thomas, 2010). Occupants uncomfortable with the overall environment reported much lower self-estimated productivity than those who felt comfortable with the overall environment (Leaman and Bordass, 2001). Occupants' satisfaction with workspace was also positively associated with job satisfaction (Donald and Siu, 2001; Oldham and Rotchford, 1983; Veitch et al., 2007; Wells, 2000). This may in turn have an impact on job performance: Judge et al. (2001) performed extensive meta-analysis of the relationship between job satisfaction and objective measures of job performance (mainly supervisory ratings) based on 54 417 responses from 312 independent samples, and they concluded that the mean correlation between job satisfaction and job performance is 0.30. Job satisfaction was also related to frequency and the duration of absenteeism (Hardy et al., 2003; Sagie, 1998), as well as intention to quit work (Hellman, 1997; Sagie, 1998; Shaw, 1999; Van Dick et al., 2004), issues, which may have financial consequences for employers. Therefore, there is much to gain from maximizing occupants' satisfaction.

Over a 10-year period, the Center for the Built Environment (CBE) at the University of California Berkeley has conducted roughly 600 post-occupancy evaluation surveys collecting information about satisfaction of building occupants in relation to several indoor environmental quality parameters and building features (Zagreus et al., 2004). The database created using these responses offers a unique opportunity to analyze specific contributors to building and workspace satisfaction from a broad perspective, providing input to a better understanding of occupants' satisfaction in the buildings. Such knowledge could guide investments in both new and retrofitted buildings to achieve the greatest increase in occupant satisfaction.

The aim of this study is to investigate which subjectively evaluated indoor environmental quality parameters and building features (office type and distance from a window) most affect occupants' satisfaction in office buildings based on the data collected by CBE.

Methods

Database description

The CBE occupant satisfaction survey is web based, collecting information about occupants' evaluation of indoor environmental quality and building features (Zagreus et al., 2004). More information with demo version of the CBE occupant satisfaction survey can be found at http://www.cbe.berkeley.edu/research/briefs-survey.htm. A comparison of the CBE post-occupancy evaluation survey and other available surveys is reported in Peretti and Schiavon (2011). The survey is comprised of a core survey and optional survey modules that are added depending on particular building's features and the building owner's interest. This study focuses only on the core survey questions, which were asked in all surveyed buildings. The core survey measures occupant satisfaction in the following categories: office layout, office furnishings, thermal comfort, air quality, lighting, acoustic quality, cleanliness and maintenance as well as overall satisfaction with workspace and building. The list of parameters evaluated in each category is presented in Table 2. These parameters are not sufficient to fully describe occupant satisfaction in the buildings, but according to the CBE team that developed the survey, all are relevant. Questions about satisfaction have the following structure: 'How satisfied are you with…'. The satisfaction questions are answered using a 7-point scale ranging from 'very satisfied' (+3) to 'very dissatisfied' (−3) with a neutral midpoint (0). In case respondents vote 'dissatisfied' (below the neutral midpoint) to a given satisfaction question, they are taken to a follow-up 'branching' page containing further questions aimed at diagnosing the source of dissatisfaction. This study focuses, however, on the satisfaction questions and contains no analysis of branching questions (which can be found in e.g., Moezzi and Goins, 2011). The CBE occupant satisfaction survey also collects background information about participants of the survey including gender, age group, type of work performed, office type, proximity of workstation to windows and external walls as well as the duration of working in the present building and at the present workspace. In addition, a building facility manager fills out a building information form providing descriptive information about the building and its systems such as the building's age, location and size, number of floors, number of occupants, type of HVAC system, solar shading and controls, buildings' LEED rating, energy use and cost of building construction, etc.

Table 2 List of parameters assessed by the CBE occupant satisfaction survey

Category	Questionnaire item
Office layout	Amount of space available for individual work and storage
	Level of visual privacy
	Ease of interaction with co-workers
Office furnishing	Comfort of office furnishings (chair, desk, computer, equipment, etc.)
	Ability to adjust furniture to meet your needs
	Colors and textures of flooring, furniture, and surface finishes
Thermal comfort	Temperature in your workspace
Air quality	Air quality in your workspace (i.e., stuffy/stale air, air cleanliness, odors)
Lighting	Amount of light in your workspace
	Visual comfort of the lighting (e.g., glare, reflections, contrast)
Acoustic quality	Noise level in your workspace
	Sound privacy in your workspace (ability to have conversations without neighbors overhearing and vice versa)
Cleanliness and maintenance	General cleanliness of the overall building
	Cleaning service provided to your workspace
	General maintenance of the building
General comments	Your personal workspace
	Building overall

CBE, Center for the Built Environment.

For each of the above parameters, the occupant also rates its effect on their ability to perform their work, and at the end, they also rate how the building affects their productivity. However, the responses regarding the self-rated productivity were not analyzed in this study.

The buildings in which the survey was conducted were identified in one of the following ways: CBE researchers contacted a building representative to obtain permission to perform the survey in the building, or a building representative contacted CBE with a request to perform the survey in the building.

As of June 2010, the CBE occupant satisfaction survey has been conducted in more than 600 buildings including offices, hospitals, schools and universities, research centers, assembly halls, commercial, governmental, residential, industrial and public (e.g., libraries), and prisons. The buildings varied in relation to their location, size, age, design, and HVAC system. In this study, only office buildings were of interest. The acceptance or rejection of each building to be included in this study was performed in multiple stages:

- Identification of office buildings based on reported descriptions of a building's purpose, provided by a building facility manager in the building characteristic form. Selected buildings were mainly governmental buildings, office buildings occupied by private companies, universities, and research centers. The following buildings were rejected: day care centers and elementary schools, residential buildings, customs office and border stations, airport, museums and libraries, hospitals, sport facilities, buildings in industrial settings (refinery, depot, and warehouse), fire station, and prisons. In some of the rejected buildings, there may be offices as well. Owing to the settings in which the buildings were situated, they were not considered as typical offices.

- Review of the workstation definition. Viewing the survey gave an understanding of how the workspace was defined in the particular building. Only the office-like workstations were of interest in this study. For some research centers and universities, it was not obvious whether the workspace corresponded to an office, laboratory, or classroom, as well as in some court houses, the workspace could be an office or a court room. In cases where the definition of a workspace was ambiguous, the building was rejected.
- Review of the survey response rate. Surveys with a response rate above 5% were accepted. The minimum response rate was set low as responses of an individual were the focus of this study. Despite low response rates in some buildings, those who responded are still a valuable source of information. One may fear that respondents in buildings with a low response rate may not be representative for the whole building and that they may have been more willing to fill out the survey than the other building occupants because of their high dissatisfaction in the building, but Zagreus et al. (2004) found no statistically significant relationship between response rate and occupant satisfaction levels (page 68) although statistical information on the applied tests was not reported.

The final dataset contains responses from 397 surveys performed in 351 different buildings. In 40 buildings, the survey was conducted more than once (e.g., before and after renovation) and all surveys are included in the analysis. Additionally, this study focuses on people performing office work. These people were identified based on the description of their personal workspace. Only responses of people working in offices (single offices, shared offices, cubicles, and open-space offices) are included in the analysis. The final dataset contains responses from 52 980 building occupants. It was not possible to identify people who participated in more than one survey and match their responses, so their responses were treated as independent in the analysis.

Statistical methods

Proportional odds ordinal logistic regression was applied to investigate the relationship between satisfaction with the workspace (response variable) and satisfaction with indoor environmental quality and building features (predictor variables). This method is applicable when the response variable is an ordinal variable: it takes only values that have a natural ordering (−3, −2, −1, 0, 1, 2, 3) but are not continuous (Baayen, 2008). The results of the regression model are presented in the form of odds ratios; confidence intervals are reported at 95% level. In this article, odds ratio (OR) describes the likelihood of increasing workspace satisfaction when one of the predictor variables is increased by one unit while the other variables are kept constant. The odds ratios were then used to rank the parameters regarding their importance for workspace satisfaction. The regression analysis was carried out with R software using the 'Design' package (R Development Core Team, 2009). Only the responses of people who answered all satisfaction questions were considered in the regression analysis, resulting in a sample of 43 021 responses. Statistical significance of each predictor variable in the regression model was tested by the Wald test (Sheather, 2009).

The Spearman rank correlation was used to estimate the correlation between satisfaction with the workspace and satisfaction with the building, and the correlation between satisfaction with the amount of space and area per person. Spearman rank correlation was used as the satisfaction votes were measured in ordinal scale (Siegel, 1956). The mean and median values of satisfaction with different indoor environmental quality parameters and building features were calculated by averaging satisfaction votes of each occupant in the whole dataset (N = 52 980). The statistical significance of differences in satisfaction with indoor environmental quality parameters and building features in different office types and for different distances from a window was tested by the Wilcoxon rank sum test (known also as Mann–Whitney test). Wilcoxon rank sum test is applicable when the variables have an ordinal character (Siegel, 1956). For all tests, the results were considered statistically significant when $P < 0.05$.

Results

Table 3 summarizes personal characteristics of respondents of CBE occupant satisfaction survey and workspace and building characteristics. Respondents varied in relation to their age, performed job, and the duration of working in the building. The majority of respondents worked at their current workspace for more than 12 months, full-time, in cubicles, and close to a non-operable window. They mostly worked in air-conditioned buildings with no LEED rating, situated in the USA.

Figure 1 shows the satisfaction levels with indoor environmental quality and building features assessed

Table 3 Characteristics of respondents, workspaces, and buildings

Parameter	Description					
Personal characteristics						
Gender	Female 47%	Male 36%	Unknown 17%			
Age	<30 years 7%	31–50 years 18%	>50 years 10%	Unknown 65%		
Job category	Admin. support 5%	Technical 5%	Professional 10%	Managerial 4%	Other 1%	Unknown 75%
Duration of working in the building	<1 year 13%	1–2 years 16%	3–5 years 18%	>5 years 34%	Unknown 19%	
Duration of working at the present workspace	<3 months 8%	4–6 months 8%	7–12 months 12%	>12 months 53%	Unknown 19%	
Time spent at workspace per week	<10 h 3%	11–30 h 14%	>30 h 73%	Unknown 10%		
Workspace characteristics						
Personal workspace	Private office 26%	Shared office 6%	Cubicles with high partitions[a] 39%	Cubicles with low partitions 22%	Other 7%	
Workstation's distance from a window	Within 4.6 m 63%	Further than 4.6 m 34%	Unknown 3%			
Building characteristics						
Country	Australia 7%	Canada 2%	Finland 6%	Italy 1%	USA 78%	Unknown 6%
Ventilation system	Air conditioned 50%	Non air conditioned 1%	Unknown 49%			
Operable windows	Yes 8%	No 41%	Unknown 51%			
LEED rating	None 86%	Pending 2%	Certified 1%	Silver 1%	Gold 8%	Platinum 2%
Year of construction	Minimum 1907	25th percentile 1969	Median 1982	75th percentile 2000	Maximum 2009	
Gross building area (excluding parking), m^2	Minimum 232	25th percentile 15 487	Median 30 463	75th percentile 52 397	Maximum 233 744	

[a]Higher than 1.5 m.

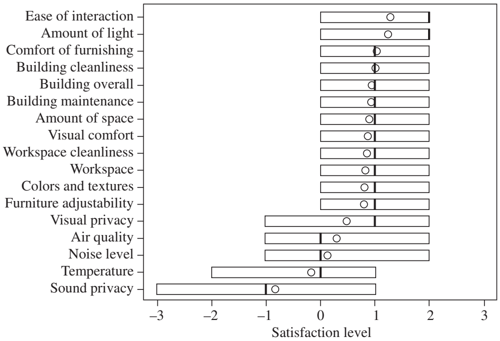

Fig. 1 Box plots for satisfaction with parameters assessed in the Center for the Built Environment occupant satisfaction survey. The extremities of the boxes are the 25th and 75th percentiles. Bold vertical lines indicate median values and dots represent mean values. For all the parameters, the minimum and maximum values are equal, respectively, −3 (very dissatisfied) and 3 (very satisfied)

in the survey (Table 2). Statistics are based on responses from between 45 464 and 52 138 building occupants as some of the building occupants chose not to evaluate some of the parameters listed in the survey. The parameters are depicted in order from the highest to the lowest mean satisfaction. The extremities of the boxes are the 25th and 75th percentiles. Bold vertical lines indicate median values, and empty dots represent mean values. Building occupants were generally satisfied with their workspace (mean $M = 0.84$) and with the building overall ($M = 0.95$). The highest satisfaction was observed for ease of interaction with co-workers ($M = 1.30$) and amount of light ($M = 1.25$). The highest dissatisfaction was observed for sound privacy ($M = -0.82$), temperature ($M = -0.16$), noise level ($M = 0.14$), and air quality ($M = 0.31$).

Workspace satisfaction and satisfaction with the building were strongly correlated (Spearman rank correlation $\rho = 0.7$, $P < 0.001$) indicating that one could be used instead of the other. In this study, the workspace satisfaction was selected as the response (outcome) variable. Workspace satisfaction better represents and better describes the immediate surroundings of building occupants rather than building satisfaction and is therefore more relevant for occupants' satisfaction.

Parameters affecting overall satisfaction

Proportional odds ordinal logistic regression was applied to investigate the relationship between the occupants' satisfaction with the workspace and satisfaction with indoor environmental parameters and building features. The results showed that satisfaction with all environmental parameters and building features listed in the CBE occupant satisfaction survey contributed significantly to workspace satisfaction ($P < 0.001$). Figure 2 depicts values of odds ratios (OR) together with 95% confidence intervals (CI) for satisfaction with each indoor environmental parameter and building feature separately. The parameters are organized in order of decreasing value of the odds ratio. The results showed that satisfaction with the amount of space available for individual work and storage (OR = 1.57, 95% CI: 1.55–1.59) was the most important parameter for workspace satisfaction. Increasing satisfaction with the amount of space would increase 1.57 times the likelihood that workspace satisfaction is also increased compared with the case when satisfaction with the amount of space is not increased. The next most important parameters for workspace satisfaction were satisfaction with noise level (OR = 1.27, 95% CI: 1.25–1.29) and visual privacy (OR = 1.26, 95% CI: 1.24–1.28). From these results, it seems that the satisfaction level with a particular parameter is not the strongest predictor of the relevance of this parameter to workspace satisfaction, i.e., even if occupants were very dissatisfied with

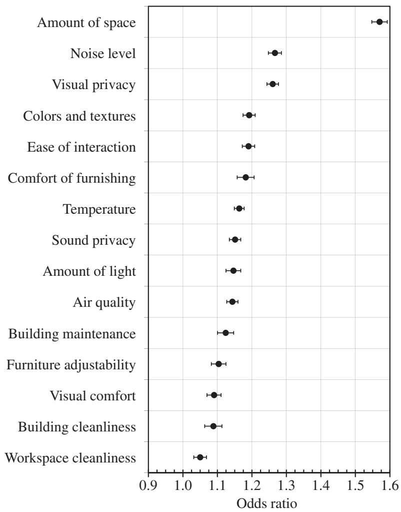

Fig. 2 Odds ratios together with 95% confidence intervals for satisfaction with indoor environmental parameters and building features included in the Center for the Built Environment occupant satisfaction survey

sound privacy, temperature, noise level, and air quality (see Figure 1), among those parameters, only satisfaction with noise level was one of the most important parameters for workspace satisfaction.

Personal factors and workspace features were examined to study their influence on the ranking of satisfaction with parameters presented in Figure 2. The following factors were examined: building occupants' age group and gender, type of office, and distance of workstation from a window. The whole dataset was divided into smaller groups according to the considered personal factors and building features (e.g., when the effect of gender was examined, the separate subsets with female and male survey participants were created). Proportional odds ordinal logistic regression models were fitted separately for each subset of data.

Table 4 presents satisfaction with indoor environmental parameters and building features that most influenced the workspace satisfaction in each subset of data. The results showed that satisfaction with the amount of space had the highest importance for workspace satisfaction in all subsets of data, regardless of building occupants' age group (below 30, 31–50, or over 50 years old), gender, type of office (single or shared office, or cubicles with high or low partitions), or distance of workstation from a window (within 4.6 m or further). The next most important parameters for workspace satisfaction in most of the data subsets were satisfaction with noise level and visual privacy. A similar analysis was performed for different satisfaction levels with the workspace. Respondents were divided into two groups: those satisfied with their workspace also including neutral responses (those who voted 0, 1, 2, or 3) and those dissatisfied with their workspace (those who voted −3, −2, or −1). Figures 3 and 4 depict values of odds ratios together with 95% confidence intervals for satisfaction with each indoor environmental parameter and building feature for respondents satisfied and dissatisfied with workspace, respectively. The parameters are organized in order of decreasing value of odds ratios estimated based on the whole sample (as in Figure 2). In both groups, satisfaction with the amount of space was the most important for workspace satisfaction. Among respondents dissatisfied with the workspace, satisfaction with building maintenance, visual comfort, and building cleanliness did not contribute significantly to workspace satisfaction, while the order of importance of other parameters for workspace satisfaction was similar to the order in the whole sample. Among respondents satisfied with the workspace, the importance of satisfaction with ease of interaction and amount of light was much higher compared with its importance in the whole sample.

The proportional odds assumption was verified for each regression model separately (Baayen, 2008). For each predictor variable, two lines were plotted in one

Table 4 Satisfaction with indoor environmental parameters and building features that influenced most the satisfaction with the workspace in each subset of data. In brackets are the number of responses in each group (*N*), odds ratios and 95% confidence intervals

Subset of data	1st most important parameter	2nd most important parameter	3rd most important parameter
Age group			
Below 30 years old (*N* = 2777)	Amount of space (1.49, 1.41–1.57)	Comfort of furnishing (1.31, 1.24–1.38)	Visual privacy (1.26, 1.20–1.33) Colors and textures (1.26, 1.19–1.34)
31–50 years old (*N* = 7714)	Amount of space (1.53, 1.48–1.58)	Ease of interaction (1.31, 1.27–1.36)	Visual privacy (1.30, 1.26–1.34) Noise level (1.30, 1.25–1.35)
Over 50 years old (*N* = 4397)	Amount of space (1.65, 1.57–1.73)	Noise level (1.33, 1.26–1.40)	Visual privacy (1.29, 1.24–1.35) Amount of light (1.29, 1.23–1.35)
Gender			
Female (*N* = 21452)	Amount of space (1.54, 1.51–1.57)	Noise level (1.25, 1.22–1.27)	Visual privacy (1.24, 1.22–1.27)
Male (*N* = 16805)	Amount of space (1.62, 1.58–1.66)	Visual privacy (1.29, 1.26–1.32)	Noise level (1.28, 1.25–1.31)
Type of office			
Single office (*N* = 11381)	Amount of space (1.62, 1.57–1.67)	Ease of interaction (1.30, 1.26–1.34)	Comfort of furnishing (1.28, 1.22–1.33)
Shared office (*N* = 2759)	Amount of space (1.58, 1.49–1.67)	Visual privacy (1.34, 1.27–1.42)	Amount of light (1.22, 1.15–1.29) Building maintenance (1.22, 1.14–1.30)
Cubicles with high partitions (*N* = 16166)	Amount of space (1.56, 1.52–1.59)	Noise level (1.30, 1.27–1.33)	Visual privacy (1.27, 1.24–1.29)
Cubicles with low partitions (*N* = 9645)	Amount of space (1.57, 1.53–1.62)	Visual privacy (1.35, 1.31–1.39)	Noise level (1.30, 1.26–1.34)
Distance of workspace from a window			
Within 4.6 m (*N* = 27175)	Amount of space (1.60, 1.57–1.63)	Noise level (1.26, 1.24–1.28)	Visual privacy (1.25, 1.23–1.28)
Further than 4.6 m (*N* = 14638)	Amount of space (1.52, 1.49–1.56)	Noise level (1.29, 1.26–1.32)	Visual privacy (1.26, 1.23–1.28)

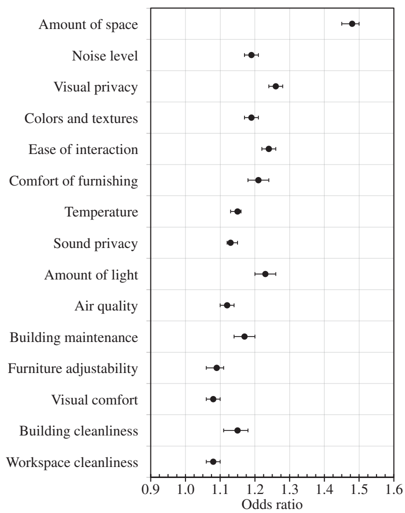

Fig. 3 Odds ratios together with 95% confidence intervals for satisfaction with indoor environmental parameters and building features in the group of respondents who were satisfied with the workspace ($N = 34\ 178$)

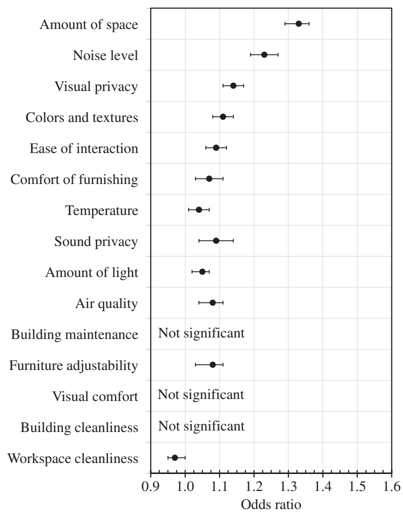

Fig. 4 Odds ratios together with 95% confidence intervals for satisfaction with indoor environmental parameters and building features in the group of respondents who were dissatisfied with the workspace ($N = 8991$)

graph: a line representing the observed mean values of a predictor variable for each level of response variable and a line representing mean values of a predictor variable as they would be if the proportional assumption would be satisfied perfectly. Small discrepancies were observed for most predictor variables in the part of the scale representing dissatisfaction votes with the workspace (−3, −2 and −1). But as the means were still very close, it was concluded that the proportional odds assumption was satisfied and the regression models were justified.

Amount of space

Among the factors tested, satisfaction with amount of space was the most predictive of occupants' satisfaction. Here, it is investigated whether a higher area available per person for work and storage increases satisfaction with the amount of space. Area per person was calculated by dividing the building gross area (excluding parking) by the current number of occupants in a building. Twenty-six buildings with extreme values of area per person were excluded from further analysis, resulting in a final sample of 35 704 responses. The gross area per person in the final sample varied between 8 and 86 m^2, with a median of 31 m^2. Correlation between satisfaction with the amount of space and gross area per person was almost negligible (Spearman rank correlation $\rho = 0.03$, $P < 0.001$). Despite statistical significance, the correlation is insignificant from an engineering point of view. Figure 5 confirms that satisfaction with the amount of space was almost independent of gross area per person.

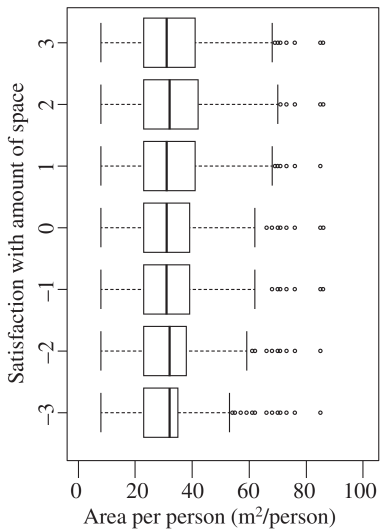

Fig. 5 Boxplot showing values of gross area per person for each level of satisfaction with the amount of space

Type of office and distance from a window

It was investigated whether office type and distance of workstation from a window affected occupants' satisfaction in office buildings. These two workspace characteristics were selected as information about them was provided by respondents and not by building manager, who could not describe each workspace in details in the general building characteristics form. The results showed that the type of office had an influence on satisfaction with the amount of space available for work and storage (Figure 6). Satisfaction with the amount of space in private offices (mean $M = 1.62$) was significantly higher ($P < 0.001$) compared with shared offices ($M = 0.81$) and cubicles with high ($M = 0.64$) and low partitions ($M = 0.66$). Satisfaction with the amount of space available for work and storage was also influenced by distance of workspace from a window (Figure 7). People sitting within 4.6 m from a window expressed significantly ($P < 0.001$) higher satisfaction with the amount of space ($M = 1.06$) than those sitting further from a window ($M = 0.62$). The results show that occupants in private offices and close to a window (within 4.6 m) were more satisfied with the amount of space available for work and storage than people in shared offices or cubicles and far from a window. Similar results were observed in relation to workspace satisfaction. Workspace satisfaction was significantly higher ($P < 0.001$) in private offices ($M = 1.45$) and close to a window ($M = 1.01$) than in shared offices ($M = 0.87$) or cubicles with high ($M = 0.59$) and low partitions ($M = 0.57$) and far from a window ($M = 0.49$) (Figures 8 and 9). A difference in workspace satisfaction was observed also between shared offices and cubicles with high (higher than 1.5 m) or low partitions ($P < 0.001$). Further analysis showed a similar trend for most indoor environmental parameters and building features (Table 5). Satisfaction with visual and sound privacy, ease of interaction with co-workers, furniture adjustability and comfort, colors and textures of surroundings, temperature, air quality, amount of light, visual comfort, noise level, building and workspace cleanliness was significantly higher ($P < 0.02$) in private offices and workstations close to a window than in shared offices or cubicles and far from a window. Satisfaction with building maintenance was significantly higher ($P < 0.001$) in private offices and close to a window compared with cubicles and far from a window. No difference in satisfaction with building maintenance was observed between private and shared offices. Most indoor environmental parameters and building features were also evaluated higher in offices shared with few people than in cubicles. Satisfaction

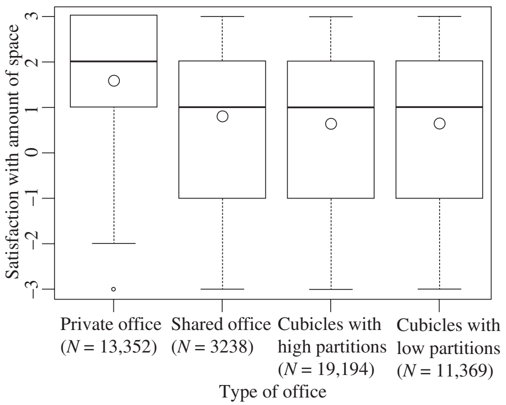

Fig. 6 Boxplot showing values of satisfaction with the amount of space in offices of different types. Large dots represent mean values. Brackets indicate the number of responses in each category

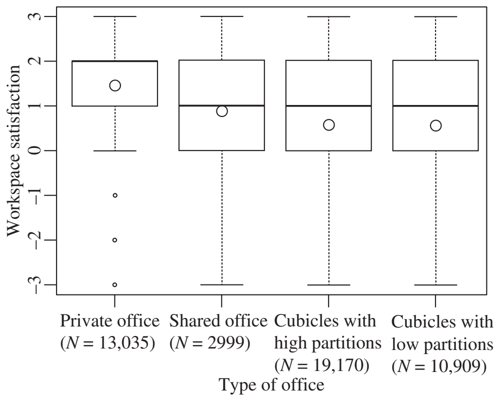

Fig. 8 Boxplot showing values of workspace satisfaction in offices of different types. Large dots represent mean values. Brackets indicate the number of responses in each category

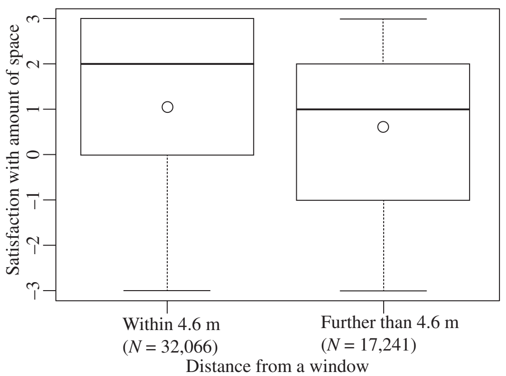

Fig. 7 Boxplot showing values of satisfaction with the amount of space depending on the distance of a workspace from a window. Dots represent mean values. Brackets indicate the number of responses in each category

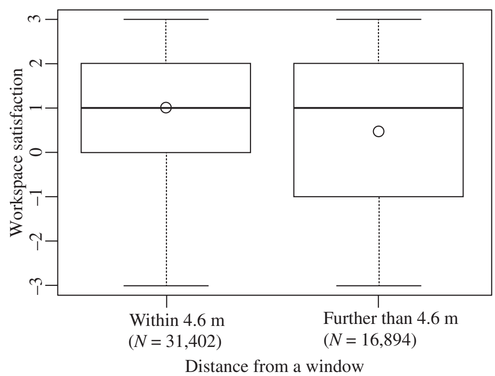

Fig. 9 Boxplot showing values of workspace satisfaction depending on the distance of workspace from a window. Dots represent mean values. Brackets indicate the number of responses in each category

with the amount of space, visual and sound privacy, ease of interaction, temperature, air quality, amount of light, visual comfort, noise level, and workspace cleanliness were significantly higher ($P < 0.05$) in shared offices than in cubicles with high or low partitions. People expressed higher ($P < 0.001$) satisfaction with furniture comfort and adjustability and building cleanliness in shared offices compared with cubicles with high partitions.

Additional analysis showed that workspace satisfaction in LEED-rated buildings (including certified, gold, platinum, silver, and pending; mean $M = 0.88$) was significantly ($P = 0.01$) higher than in buildings without any LEED rating ($M = 0.83$). The difference between buildings with and without LEED ratings although statistically significant was very small.

Discussion

Building occupants are the best source of information as regards their needs and comfort requirements. Thanks to its large number of responses, the CBE database makes it possible to draw general conclusions about building occupants' needs and satisfaction in different settings and enables the identification of the enquired indoor environmental parameters and building features that cause the highest dissatisfaction. Occupants of the office buildings in which the CBE

Table 5 Mean values of satisfaction with indoor environmental parameters and building features assessed in the CBE occupant satisfaction survey in different office types and different distances from a window

Satisfaction with parameter	Single offices	Shared offices	Cubicles with high partitions	Cubicles with low partitions	Close to a window	Far away from a window
Visual privacy	1.97	0.32*	0.15*,***	−0.26*,***	0.67	0.10*****
Ease of interaction	1.67	1.37*	1.09*,***	1.19*,***	1.40	1.09*****
Comfort of furnishing	1.34	0.99*	0.92*,***	0.97*	1.14	0.88*****
Furniture adjustability	1.00	0.79*	0.68*,***	0.79*	0.89	0.65*****
Colors and textures	0.94	0.70*	0.77*	0.78*	0.90	0.66*****
Temperature	0.18	0.04*	−0.35*,***	−0.26*,***	−0.07	−0.34*****
Air quality	0.55	0.32*	0.16*,***	0.25*,****	0.43	0.11*****
Amount of light	1.66	1.41*	1.02*,***	1.12*,***	1.43	0.90*****
Visual comfort	1.21	1.02*	0.71*,***	0.75*,***	1.01	0.64*****
Noise level	0.95	0.63*	−0.23*,***	−0.28*,***	0.27	−0.13*****
Sound privacy	0.63	−0.49*	−1.46*,***	−1.45*,***	−0.69	−1.10*****
Building cleanliness	1.21	1.05**	0.95*,***	1.02*	1.03	0.97*****
Workspace cleanliness	1.02	0.94**	0.75*,***	0.85*,***	0.88	0.79*****
Building maintenance	1.02	1.02	0.89*,***	0.92*,****	0.96	0.90*****

*,**Statistically significant difference in satisfaction level compared with single offices when $P < 0.001$ and $P < 0.05$, respectively.

,*Statistically significant difference in satisfaction level compared with shared offices when $P < 0.001$ and $P < 0.05$, respectively.

*****Statistically significant difference in satisfaction level compared with workstations close to a window when $P < 0.001$.

CBE, Center for the Built Environment.

occupant satisfaction survey has been conducted are generally satisfied with their workspace and with the overall building, even if they register high dissatisfaction with sound privacy, temperature, noise level, and air quality. The findings are consistent with earlier studies on smaller subsets of CBE data (Huizenga et al., 2006; Jensen et al., 2005), in which acoustics, thermal comfort and air quality received the lowest satisfaction ratings. In open-plan offices in Canada, building occupants expressed the lowest satisfaction with noise and conversational privacy (Veitch et al., 2002). Air quality, thermal comfort, and privacy were identified as the areas of greatest complaint in university buildings in New Zealand (Leifer and Gumbaketi, 1999). In this study, the lowest satisfaction level was observed for sound privacy. It may be caused by the fact that most of the responses were collected in open-plan offices. Earlier studies (Danielsson, 2008; Haapakangas et al., 2008; Jensen et al., 2005; Kaarlela-Tuomaala et al., 2009; Lee, 2010; Marans and Spreckelmeyer, 1982) indicated that satisfaction with acoustic privacy was much lower in open offices than in single offices. This study supports these findings. Satisfaction with sound privacy was highest in single offices, slightly lower in offices shared with few people, and the lowest in cubicles.

This study attempts to identify which subjectively evaluated parameters play a major role when people evaluate the overall satisfaction with their workspace. Knowledge about people's priorities may be used as guidelines when constructing and renovating buildings so that building occupants' satisfaction can be maximized. This study of 43 021 office workers showed that satisfaction with the amount of space was the most important for workspace satisfaction. This was in agreement with earlier findings of Marans and Yan (1989) performed among nearly 1000 office workers, but in contrast to the results of the study of Veitch et al. (2003) who carried out the study among 779 office workers in which parameters were ranked in the following order: air quality and ventilation, privacy, noise level, temperature, lighting, size of workstation, and window access. The differences in importance of the amount of space may be due to differences in methodology of the studies. In this study and the study of Marans and Yan (1989), statistical analyses were performed to estimate the extent of the relationship between workspace satisfaction and satisfaction with the amount of space. In the study of Veitch et al. (2003), office workers were asked to rank the parameters in order from the highest to the lowest importance.

Despite the large range of available area per person (8–86 m^2/person), surprisingly almost no effect of the available area per person was observed on satisfaction with the amount of space, which was not consistent with earlier findings of Marans and Spreckelmeyer (1982). One of the reasons for the lack of a stronger correlation between satisfaction with the amount of space and area per person may be that area per person was a rough estimation of real area per person in each building. The total building area used for calculating the area per person included not only the workstation area but also corridors and common areas like meeting rooms, copying rooms, and restrooms. Secondly, the estimated area per person was common for the whole building and did not account for differences in size between different workstations within the building. Thirdly, we are not sure how reliable are the estimates of building gross area provided by the facility managers. It may also be that the way in which building occupants perceive their space is much more important than the actual amount of space. In the study of Marans and Yan (1989), the subjective assessment of amount of space was strongly correlated with workspace satisfaction, while objective measures of amount of space influenced workspace satisfaction to only a small extent. The perceived amount of space for work and storage may also be influenced by storage space in a vertical direction, which would not be noticed via estimated area per person. A study of Skov et al. (1990) showed that the shelf factor, which approximates the amount of storage space, was related to the Sick Building Syndrome. More studies are needed on the relationship between amount of space and satisfaction with the amount of space. Knowledge about how to increase satisfaction with a given amount of space could lead to increased workspace satisfaction, job satisfaction, and productivity.

This study prioritized satisfaction with different indoor environmental parameters and building features in order of their importance for overall satisfaction with workspace, but it did not provide much information about physical characteristics of the workspace. More studies are needed on the link between satisfaction with a particular parameter and physical characteristics of the workspace. Such studies will supplement this study and result in guidelines how to (re)design physical aspects of the workspace to maximize occupants' satisfaction.

Different office settings also have a major influence on occupants' satisfaction. Satisfaction with the workspace and with almost all indoor environmental parameters and building features was higher in private offices than in shared offices and cubicles, which is consistent with previous studies (Brennan et al., 2002; Haapakangas et al., 2008; Marans and Spreckelmeyer, 1982). A recent study showed that shared offices increased also the risk of sickness absence (Pejtersen et al., 2011). The findings suggest that building occupants favor private offices. Preference for private offices may partly be associated with greater freedom to organize the office space, ability to control the indoor environment to a greater extent in a private office, and freedom from having to negotiate the conditions with co-workers. However, this study does not offer the possibility of verifying this hypothesis.

It is estimated that for a typical office building, 82% of all costs are associated with building occupants (employee salary and benefits) and the remaining costs cover building construction and arrangement, technology support, maintenance, and operations (Brill et al., 2001). Thus, it seems reasonable to take action to ensure high occupants' satisfaction. Despite this, a recent survey in Denmark showed that office workers think that their bosses do not prioritize high the good indoor environment (Camfil Farr, 2011). This study determined subjectively evaluated parameters that play a major role when people evaluate satisfaction with their workspace. If one accepts that there is a positive link between occupants' satisfaction and productivity of office workers (Leaman and Bordass, 2001; Leaman et al., 2007; Thomas, 2010), the study's results may be used not only to increase occupants' satisfaction but also to promote higher productivity.

Apart from proportional odds logistic regression, multivariable linear regression and linear mixed effects regression were applied to study the relationship between workspace satisfaction and satisfaction with indoor environmental quality parameters and building features. Both linear regression models confirmed that satisfaction with the amount of space was the most important for workspace satisfaction, followed by satisfaction with noise level and visual privacy. In the CBE database, the intraclass correlation coefficient showed that only 3.6% of total variability in responses was accounted for by the building in which people filled out the survey. The influence of the building itself on building occupants' responses was very small. The results of linear regression models were not reported extensively in this article, because proportional odds logistic regression was considered more relevant for the present data, and the results of proportional odds logistic regression and linear regressions were very similar.

Limitations

One of the limitations of the study is related to the selection of buildings. There was no systematic randomized approach in relation to building selection. Almost 80% of the surveyed buildings were situated in USA, so the results relate primarily to American settings.

The study considered only the influence of satisfaction with 15 different indoor environmental parameters and building features on workspace satisfaction. The study proved that all parameters listed in the CBE occupant satisfaction survey are relevant for workspace satisfaction. However, perception of other parameters, not included in the survey, may also be relevant for workspace satisfaction (e.g., outside view may be an important parameter but, up to now, it is not measured in the CBE core survey).

Another limitation of the study is absence of physical measurements. It would be preferable to relate subjective responses of building occupants to objective measures of indoor environmental quality parameters and building features.

Conclusions

Occupants were generally satisfied with their workspace and with the overall building. The highest levels of satisfaction were observed for ease of interaction with co-workers and amount of light. The highest levels of dissatisfaction were observed for sound privacy and indoor environmental quality (temperature, noise level, and air quality). The most important parameters for workspace satisfaction were satisfaction with the amount of space, noise level, and visual privacy. Satisfaction level with a particular parameter did not influence the relevance of this parameter for workspace satisfaction. Satisfaction with the amount of space was ranked to be the most important for workspace satisfaction regardless of age group, gender, type of office, distance of workspace from a window, or satisfaction level with workspace. Satisfaction with the amount of space was not related to an approximate evaluation of the amount of space available per person at the workspace. People sitting close to a window (within 4.6 m) and in single offices expressed significantly higher workspace satisfaction compared with those sitting further from a window and in shared offices and cubicles. Satisfaction with almost all indoor environmental parameters and building features was also higher in single offices and close to a window than in shared offices and cubicles and far from a window.

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Paper IV

Frontczak, M., Wargocki, P., Schiavon, S., Goins, J., Arens, E. and Zhang, H. Relationships between self-estimated performance and satisfaction aspects of indoor environmental quality and building design (manuscript).

RELATIONSHIPS BETWEEN SELF-ESTIMATED JOB PERFORMANCE AND SATISFACTION ASPECTS OF INDOOR ENVIRONMENTAL QUALITY AND BUILDING DESIGN

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ABSTRACT

Present work investigated how indoor environmental parameters and building features are considered by building occupants to affect their job performance, and quantified the size of effect of satisfaction with indoor environmental parameters and building features on self-estimated job performance. The analysis used subjective responses collected from the web-based survey administered by the Center for the Built Environment. The survey was distributed to 52,980 building occupants over the period of ten years mainly in the U.S. office buildings. 24% of respondents indicated that environmental conditions neither increase nor decrease their job performance, while 33% of respondents indicated that environmental conditions decrease their job performance by at least 5%. Multivariate linear regression analysis showed that increasing overall satisfaction with the workspace improved significantly self-estimated job performance (Regression Coefficient RC=3.72, CI: 3.67-3.78). Detailed analysis showed that improving satisfaction with temperature would have the biggest effect on the self-estimated job performance (RC=1.05, CI: 0.99-1.10), followed by improving satisfaction with noise level (RC=0.84, CI: 0.77-0.91) and air quality (RC=0.82, CI: 0.75-0.88). Generally the quantitative effect on the self-estimated job performance was rather small, below 1% to 4% for every 15% increase in the level of satisfaction.

KEYWORDS

Self-estimated performance, satisfaction, occupant's responses, post-occupancy evaluation, office buildings

PRACTICAL IMPLICATIONS

Present results can guide building users, operators and employers in making decisions which parameters should be improved to promote work performance. They show that satisfaction with indoor environmental quality, in particular satisfaction with thermal environment, air quality and acoustical environment, are the most important for promoting self-estimated human performance.

INTRODUCTION

Over the last two decades there has been increasing interest on the effects of indoor environmental quality on work performance. One of the reasons is that there is a growing body of evidence that the indoor environment does affect people's working performance (Wargocki et al., 2006). Additionally cost-benefit analyses show that even small improvements in working performance are highly profitable and quickly pay back for the costs invested in improving indoor environmental quality (Fisk and Rosenfeld, 1997; Fisk et al., 2011; Rohr and Brightman, 2003; Seppänen, 1999; Wargocki and Djukanovic, 2005).

So far, most of the research has been carried out to examine the effects of individual indoor conditions such as indoor air quality, ventilation, thermal comfort and air temperatures on human performance (e.g., Lan et al., 2011; Seppänen et al., 2006; Wargocki et al., 1999; Wargocki et al., 2000). Only few studies examined combined effects of indoor environmental parameters on performance (e.g., Clausen and Wyon, 2008; Witterseh et al., 2004). In these studies the performance of office work was measured either in the laboratory using predominantly tests simulating office work or in the work places by measuring actual work. There is also a large body of research, in which performance was measured by asking the employees how they assess their performance, so called self-estimated performance (Brightman et al., 2008; Kawamura et al., 2007; Rohr and Brightman, 2003; Sundstrom et al., 1980; Woods et al., 1987). Although there is no information on whether self-estimated job performance is a suitable tool to predict the effects of indoor environmental quality on performance and how it relates to actual performance measured with objective methods, it has been often used mainly because it can be easily presented to building occupants in form of the questionnaire. Also it can be considered as a 'proxy' for satisfaction with indoor environmental conditions.

The mechanisms behind the effects of indoor environmental quality on human performance are not clearly defined. It has been hypothesized that the effects do occur due to physiological responses (Bakó-Biró et al., 2005; Lan et al., 2011), health symptoms such as headache and fatigue (Raw et al., 1990; Wyon and Wargocki, 2011) as well as general discomfort. To this end satisfaction with indoor environmental parameters and building features has been shown to be strongly related to self-estimated performance (Table 1). Still the results of the studies (Table 1) are inconsistent as regards which conditions and parameters indoors have strongest effect on the self-estimated job performance. In the studies different authors used different expressions when describing the ability to perform work: self-estimated productivity and self-estimated performance. We feel that those expressions are equivalent and in the present paper the expression self-estimated job performance is used.

Table 1. Summary of studies investigating which parameters influence self-estimated performance of building occupants.

Study	Population	Data analysis	Results
Goins et al. (2010)	~2,200 responses in 13 buildings in USA (RR* unknown)	Ordered logistic regression specification	Self-estimated work performance was affected by satisfaction with speech privacy (exponentiated coefficient: 23%), noise level (19%), amount of light (15%), satisfaction with temperature (11%) and air quality (10%)
Humphreys and Nicol (2007)	More than 4,500 responses** in 26 office buildings in 5 European countries (RR unknown)	General Linear Model	The biggest impact on self-estimated productivity had evaluations of warmth, noise and air

			quality, while evaluations of air movement and lighting were less important
Kawamura et al. (2007)	Ten male college-aged subjects	Pearson's product moment correlation	Self-estimated performance was related (r=0.80) to satisfaction with indoor environment
Leaman and Bordass (2006)	Responses in 151 buildings (RR unknown)	Correlation	Self-estimated productivity was correlated (r=0.84) to overall comfort
O'Neill (1994)	541 workers in 14 companies (RR: 77%)	Principal components analysis and Pearson correlation	Self-estimated job performance was correlated to satisfaction with workspace adjustability (correlation coefficient: 0.15), storage capacity (0.15), privacy (0.15), visual and aural distractions (-0.13) and ease of communication (0.08)
Thomas (2010)	405 responses** in Australia (RR: 30% and 40% depending on a building)	Correlation	Self-estimated productivity was correlated (r=0.80) to overall comfort
Wiik (2011)	675 responses** in 12 companies in Norway (RR: between 44% and 100% depending on a company)	Multivariate regression analysis	Self-estimated productivity was influenced by air satisfaction (temperature, humidity, stuffiness; regression coefficient: 5.4), psychosocial satisfaction (leadership, cooperation, loyalty and control; 4.7), satisfaction with sound (2.8), office (2.5) and light (0.6)

* RR: response rate.
** number of filled out questionnaires; some of the building occupants gave their response more than once.

Since 2000 the Center for the Built Environment (CBE) at the University of California Berkeley has conducted roughly 600 post occupancy evaluation surveys in which respondents provided information about their satisfaction and job performance in relation to several indoor environmental quality parameters and building features (Zagreus et al., 2004); no physical measurements were taken. The database created using these responses offers a unique opportunity to evaluate how buildings perform in practice as assessed by building occupants. Recently, Frontczak et al. (2011) analyzed the results from these surveys to investigate how satisfaction of building occupants is related to indoor environmental parameters and building features. Their results show that the average building occupant was satisfied with his/her personal workspace and with the building, and that the most important parameters for overall workspace satisfaction were satisfaction with amount of space, noise level and visual privacy. The data collected through the CBE occupant satisfaction surveys allow also examining how indoor environmental parameters and building features affect job performance as assessed by the occupants of the buildings, i.e. how they affect the self-estimated job performance.

The present work attempts to investigate which indoor environmental parameters and building features are considered by building occupants to enhance and/or to interfere with the ability of getting their job done and to quantify the size of effect of satisfaction with indoor environmental parameters and building features on self-estimated job performance.

METHODS

As of June 2010, the CBE occupant satisfaction survey included data from more than 600 buildings including offices, hospitals, schools and universities, research centers, assembly halls, commercial, governmental, residential, industrial and public buildings (e.g., libraries) and prisons, which vary in relation to their location, size, age, design and HVAC system. The buildings in which the survey was performed were identified by either the CBE researcher who contacted a building representative to obtain permission to perform the survey in the building, or are the buildings from which a building representative contacted CBE with a request to perform the survey. The present analysis was carried out in the subset of these data including office buildings and people working in offices. The process of identifying office buildings and creating the database for the purpose of the present analysis is described in details in Frontczak et al. (2011).

Using the above selection criteria the present analysis contains responses from 52,980 building occupants from 397 surveys performed in 351 office buildings (governmental, private, at the universities and research centers). In 40 buildings the survey was conducted more than once (e.g., before and after renovation) and the data from all surveys performed in these buildings are included in the analysis. As it was not possible to indentify people who participated in more than one survey, all responses were treated as independent observations.

In the following only parts of the CBE occupant satisfaction survey relevant to the objectives of the present paper are described. For a more complete description of the database please refer to Frontczak et al. (2011). The CBE occupant satisfaction survey collects information on how the following conditions influence satisfaction: (1) amount of space available for individual work and storage, level of visual privacy, and ease of interaction with co-workers, all related to office layout; (2) comfort of office furnishings (chair, desk, computer, equipment, etc.), ability to adjust furniture to meet your needs, and colors and textures of flooring, furniture and surface finishes, all related to office furnishings and finishes; (3) temperature in the workspace; (4) air quality in the workspace (i.e., stuffy/stale air, air cleanliness, odors); (5) amount of light in the workspace, and visual comfort of the lighting (e.g., glare, reflections, contrast), all related to lighting; (6) noise level in the workspace, and sound privacy in the workspace (ability to have conversations without neighbors overhearing and vice versa), all related to acoustic quality; and (7) general cleanliness of the overall building, cleaning service provided to your workspace, and general maintenance of the building, all related to cleanliness and maintenance. Furthermore information on the impact of personal workspace and building on overall satisfaction is collected. Each of the above categories is presented on a separate page in the survey. The occupants are asked about satisfaction with a given environmental parameter or a building/workspace features as exemplified in Figure 1. The answers are subsequently coded as follows: “very satisfied” =+3, “very dissatisfied” = -3, and a neutral midpoint is coded as 0.

Figure 1. An example of the question and the scale that are used to collect information on the satisfaction with different environmental parameters and building/workspace features in the CBE occupant satisfaction survey.

The CBE occupant satisfaction survey collects also information on how the following conditions influence the ability to get the job done: (1) office layout; (2) office furnishing; (3) thermal comfort; (4) air quality; (5) lighting quality; (6) acoustic quality; and (7) cleanliness and maintenance of the building. It should be noted that these are the same categories as in the case of information collected on how different indoor environmental parameters and building features influence satisfaction, but the level of detail is lower and number of questions is smaller. The occupants are asked to indicate whether each of these parameters enhances or interferes with their job performance using the seven point scale presented in Figure 2. The seven point scale is coded as follows: “enhances” =+3, “interferes” =-3, while a neutral midpoint is coded as 0. Each category is presented on a separate webpage in the survey.

Figure 2. An example of the question and the scale used in the CBE occupant satisfaction survey which are used to collect information on whether different indoor environmental parameters and building features enhance or interfere with the self-estimated job performance.

The occupants are also asked to give a quantitative estimate on how much their job performance is increased or decreased by the effect of environmental conditions in the building (i.e., thermal, lighting, acoustics, cleanliness, etc). An estimate is given on a 7-point scale ranging from ‘increased’ to ‘decreased’ with each point defined as 20%, 10%, 5%, 0%, -5%, -10% and -20% (Figure 3).

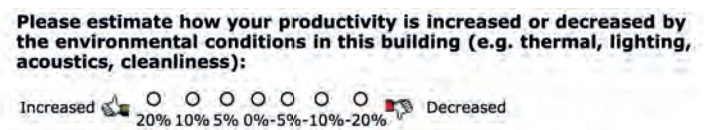

Figure 3. The question and the scale used in the CBE occupant satisfaction survey to estimate the size of effect of environmental conditions in the building on the self-estimated job performance.

As a part of the CBE occupant satisfaction survey respondents provided also information about gender, age group, type of work performed, office type, proximity of workstation to windows and external walls as well as duration of working in the building (in which responses were collected) and at the workspace (where responses were collected). A building facility manager was asked to fill out a building information form providing descriptive information about the building and its systems such as the building's age, location and size, number of floors, number of occupants, type of HVAC system, solar shading and controls, buildings' LEED rating, energy use and cost of building construction, etc.

Multivariate linear regression was applied to investigate the relationship between self-estimated job performance (response variable measured as illustrated in Figure 3) and satisfaction (predictor variables measured as illustrated in Figure 1). Only responses of people who responded to both the response variable and all predictor variables were considered in the regression analysis. The results of regression model were presented in form of regression coefficients together with 95% confidence intervals. For each predictor variable, which was included in the regression model ($p<0.05$; two-tailed t-test) the power analysis was performed and the effect size index was calculated (Cohen, 1988). While t-test provides information about statistical significance of predictor variables, the effect size index shows if the predictor variable has any practical significance. The effect size index is a dimensionless number that indicates how big effect a predictor variable has on a response variable. Cohen (1988) suggested the following criteria for effect size as regards multivariate regression: small: >0.02; medium: >0.15 and large >0.35.

The statistical analysis was carried out with R software (R Development Core Team, 2009).

RESULTS

Respondents of the CBE occupant satisfaction survey varied in relation to their age, job performed (administrative support, technical, professional and managerial) and tenure in the building. The majority of respondents worked at their current workspace (office) for more than 12 months (53% of respondents), full-time (73%), in cubicles (61%) and close to a window (63%). They mostly worked in air-conditioned buildings (50%) with no LEED rating (86%), situated in the US (78%) and with non-operable windows (41%). A detailed summary regarding personal characteristics of CBE occupant satisfaction survey respondents as well as workspace and building characteristics is provided in Frontczak et al. (2011).

Impact of indoor environmental parameters and building features on the self-estimated job performance

Figure 4 summarizes the responses of occupants describing whether indoor environmental parameters and building features enhanced or interfered with the ability to get their job done; the presented mean and median values were calculated using performance votes of every occupant in the whole dataset (as indicated by 'N' in the figure). The differences in number of responses for most of the questions are caused because some of the performance questions were not asked in some of the surveyed building and because respondents skipped some questions. Acoustic quality and thermal comfort were on average indicated by the occupants to interfere with the ability to get their job done, while the other parameters were on average indicated to enhance it. It is worth noting that if medians are considered, cleanliness and maintenance of the buildings, lighting quality, office furnishing and office layout were considered by the building occupants to equally enhance the ability to get the job done, but air quality, thermal comfort and acoustic quality were considered to neither enhance nor interfere with it.

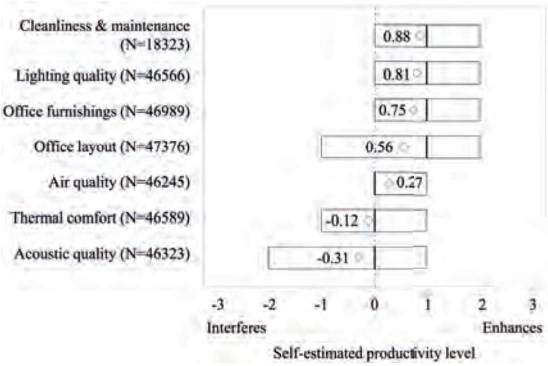

Figure 4. Box plots summarizing how respondents rated whether indoor environmental parameters and building features enhanced or interfered with the ability to get their job done. Dotted line indicates neutral midpoint of the scale. Bold vertical lines show median values and diamonds represent mean values. The boxes span from the 25th percentile to the 75th percentile. Numbers in the figure indicate mean values. N shows the number of responses.

The distribution of responses describing how respondents estimated how much their performance is increased or decreased by the environmental conditions in the buildings is showed in Figure 5. 24% of respondents indicated that environmental conditions neither increase nor decrease their job performance. 33% of respondents indicated that the environmental conditions in the building decrease their job performance by at least 5%, and 5% of respondents assessed that their job performance is reduced by 20%. 43% of respondents indicated that the environmental conditions in the building increase their job performance by at least 5%.

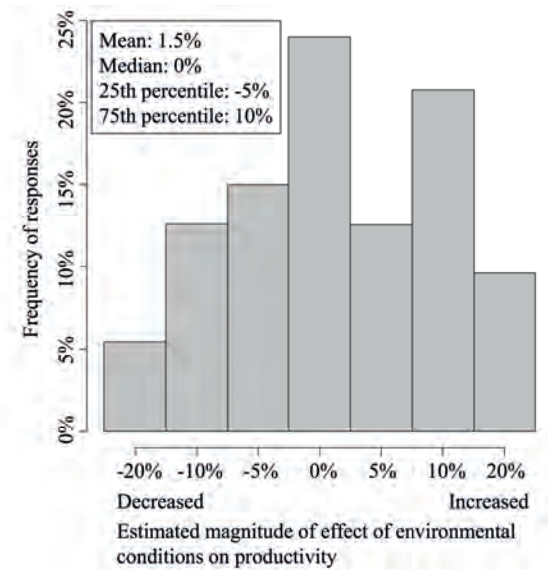

Figure 5. Distribution of responses (N=29927) to the following question: “Please estimate how your productivity is increased or decreased by the environmental conditions (e.g. thermal, lighting, acoustics, cleanliness) in this building”.

More detailed analysis showed that for each indoor environmental parameter and building feature about 1/3 of respondents indicated that the parameters neither enhanced nor interfered with the ability to do their job ('0' on a 7-point scale shown in Figure 2). Figure 6 shows how many times respondents answered that a given number of parameters neither enhanced nor interfered with the ability to do their job. 0.1% of respondents answered that all 8 parameters neither enhanced nor interfered with job performance. More specific analysis of responses showed that there was no considerable difference among different parameters and building features regarding the number of respondents who indicated that a specific parameter and building feature neither enhanced nor interfered with the ability to get the job done. Air quality was assessed slightly more often (35% of respondents) and office layout slightly less often (23% of respondents) to neither enhance nor interfere with the ability to do the job.

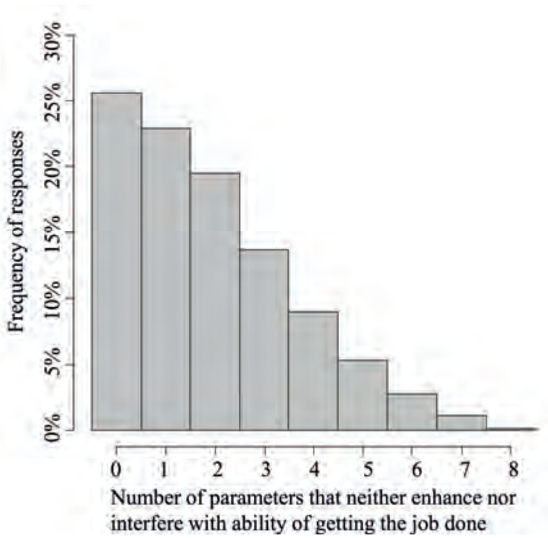

Figure 6. Distribution of responses showing how many respondents indicated that a given number of parameters neither enhanced nor interfered with getting the job done.

Effect of satisfaction with a personal workspace on the self-estimated job performance

The results of simple linear regression analysis between self-estimated job performance and the overall satisfaction with a personal workspace are shown in Table 2. The model was statistically significant ($p<0.001$) and explained 36% of variance in the self-estimated job performance; the effect size was large ($f^2>0.35$). The regression coefficient suggests that increasing overall workspace satisfaction by 1 unit on a 7-point scale (Figure 1), i.e. by about 15% assuming that the scale can be treated as linear, would increase the self-estimated job performance by about 3.7%.

Table 2. Linear regression model showing the relationship between self-estimated job performance and overall satisfaction with personal workspace.

Predictor variable	Regression coefficient (95% confidence interval)	p-value for predictor variable	Effect size index (f^2) for predictor variable
Satisfaction with personal workspace	3.72 (3.67-3.78)	<0.001	0.56

Model based on N=29,852; model $R^2=0.36$; model p-value<0.001

Effect of satisfaction with indoor environmental parameters and building features on the self-estimated job performance

The results of multivariate linear regression between self-estimated job performance and satisfaction with indoor environmental parameters and building features are presented in Table 3 with the descending order of regression coefficients. Satisfaction with cleanliness of workspace, amount of light and comfort of furnishings were not statistically significant in the model ($p>0.05$) thus they cannot be considered to influence the self-estimated job performance; they are not presented in the table. The remaining 12 independent variables were statistically significant ($p<0.001$) and explained 42% of variance. The effect size examining practical meaning of the observed results was small ($0.02<f^2<0.15$) for satisfaction with temperature, air quality and noise level. Increasing satisfaction with temperature by 1 unit on a 7-point scale (Figure 2), i.e. by about 15% (assuming that the scale can be treated as linear) would increase the self-estimated job performance by about 1% while the satisfaction with all other parameters are kept constant. In case of satisfaction with air quality and noise these effects would correspond to about 0.8%. Changing satisfaction with other parameters would have smaller effect on the self-estimated job performance and would have basically no practical significance, although statistically significant in the model, because of the very small effect size ($f^2<0.02$).

Table 3. Linear regression model showing the relationship between self-estimated job performance and satisfaction with indoor environmental parameters and building features.

	Linear model			Logistic model
Predictor variable (satisfaction with parameter)	Regression coefficient (95% confidence interval)	p-value for predictor variable	Effect size index (f^2) for predictor variable	Odds ratio (95% confidence interval)
Temperature	1.05 (0.99-1.11)	<0.001	0.045	1.30 (1.29-1.32)
Noise level	0.84 (0.77-0.91)	<0.001	0.020	1.22 (1.20-1.24)
Air quality	0.82 (0.75-0.88)	<0.001	0.021	1.24 (1.22-1.26)
Building maintenance	0.70 (0.60-0.79)	<0.001	0.009	1.19 (1.16-1.21)
Visual comfort	0.65 (0.59-0.72)	<0.001	0.013	1.18 (1.16-1.20)
Furniture adjustability	0.37 (0.30-0.43)	<0.001	0.005	1.10 (1.08-1.12)
Amount of space	0.31 (0.25-0.38)	<0.001	0.003	1.08 (1.06-1.09)
Sound privacy	0.31 (0.25-0.38)	<0.001	0.003	1.09 (1.07-1.11)
Ease of interaction	0.25 (0.18-0.32)	<0.001	0.001	1.06 (1.04-1.08)
Colors and textures	0.18 (0.11-0.25)	<0.001	0.001	1.06 (1.04-1.07)
Building cleanliness	0.11 (0.02-0.21)	0.020	0.001	1.03 (1.00-1.05)
Visual privacy	0.08 (0.02-0.14)	0.013	0.000	1.02 (1.00-1.03)

Model based on N=29,092; model $R^2=0.42$; model p-value<0.001

Table 3 shows also the results of the proportional odds ordinal logistic regression model in form of the odds ratios. Use of the logistic model did not change the general trends observed for the multivariate linear regression model. The logistic model was fitted to create connection between the present analysis and the analysis made by Frontczak et al. (2011)

in which the relationship between workspace satisfaction and satisfaction with indoor environmental parameters and building features was presented in the form of odds ratio.

DISCUSSION

Present analysis shows that the satisfaction with indoor environmental parameters and building features affects the self-estimated job performance; the effect was statistically significant but small. The present results showing the effect of satisfaction on the self-estimated job performance confirms the findings of previous studies presented in Table 1. However, it is not possible to conclude whether satisfaction with the same parameters is the most important for the self-estimated job performance as in different studies satisfaction with different parameters was considered.

The estimated quantitative effects on the self-estimated job performance, although statistically significant, were quite small. They are comparable with the effects observed in other studies in which the work performance was not assessed by asking building occupants but by using tests simulating office work or actual work performance. For example, the laboratory experiments with human subjects performing simulated office work showed that 10% less dissatisfied with the air quality corresponds to about 1% increase in performance (Wargocki et al., 1999; Wargocki et al., 2000), while in the present analysis 15% increase in satisfaction with air quality corresponds to about 0.8% increase in the self-estimated job performance. Lan et al. (2011) showed that a 1-unit change in thermal sensation vote would cause about 0.8% reduction in performance from the optimal level; in the present work the change of satisfaction with temperature by 15% was estimated to cause about 1% change in the self-estimated job performance. Clausen and Wyon (2008) reported that combined effect of improvement of six environmental conditions (temperature, air quality, noise level and type, and light level and type) resulted in increase of objectively measured performance of simulated office work by about 7% and increase of self-estimated performance by about 15%; it also reduced the overall dissatisfaction with indoor environment by about 40%. In the experimental study of Haneda et al. (2008) satisfaction with indoor environment (presumably combination of temperature and ventilation) was linearly correlated with the performance of multiplication task: performance increased by around 3% for every 10% increase in satisfaction. For comparison in the present work 15% increase in overall satisfaction with indoor environment and building features was estimated to improve self-estimated job performance by about 3.7% (Table 2), thus the magnitude of the effect was very similar to the one observed in previous studies. In the past research it was stipulated that the magnitude of effects of indoor environmental quality on performance of office work is no more than 10-15% even if combined effects of all indoor environmental parameters are considered (e.g., Wyon and Wargocki (2011). The present results confirm that the effect of indoor environmental quality on performance does not exceed 10-15% and suggest that the effect may be even smaller.

The results of the present analysis can be used to examine the combined effect of satisfaction with different parameters on self-estimated job performance. Wargocki et al. (2006) suggested that a combined effect of different factors on work performance should be either the highest effect among interacting factors or the sum of effects for single factors if they are independent. Based on the present results, the largest effect of changing satisfaction with one parameter (temperature) by 1 unit would yield 1.05% increase in the self-estimated job performance (Table 3). If we add the effects of all single parameters, the combined effect of increasing satisfaction with all indoor environmental parameters and building features by one unit on a 7-point scale would yield 5.67% increase in the self-estimated job performance

(Table 3). On the other hand improving overall satisfaction with indoor environmental parameters and building features would yield 3.72% increase in the self-estimated job performance (Table 2). The combined effect of increasing satisfaction with indoor environmental parameters and building features is between the highest effect among interacting parameters and the sum of effects for satisfaction with all single parameters. These results suggest that the satisfactions with different parameters may to some extent be dependent.

The results of Frontczak et al. (2011) showed that in order to maximize overall satisfaction with personal workspace, improving the satisfaction with amount of space, noise level and visual privacy should be given the highest priority, followed by satisfaction with colors and textures of surroundings, ease of interaction and comfort of furnishing. Present results show that improvements of satisfaction with temperature, noise level and air quality should be given the highest priority in order to improve the self-estimated job performance; satisfaction with amount of space, visual privacy and colors and textures of surroundings is of much lower importance (Table 3). The reason for the observed discrepancy can be that people focus on different aspects when they evaluate their satisfaction and their job performance. These results imply that when investing in improvements of indoor environments, satisfaction with different environmental parameters and building features may be modified depending on whether it is aimed to improve overall satisfaction or self-estimated job performance.

The high number of respondents indicated that one or more parameters neither enhanced nor interfered with ability to get the job done (Figure 6). This result is consistent with the previously reported findings by Humphreys and Nicol (2007) and Raw et al. (1990). In the latter study 25% of respondents said that physical conditions at their work had no effect on their self-estimated performance. In the former study building occupants were asked to evaluate to which extent their performance is affected by the quality of work environment and 79% of respondents indicated that there was no effect despite the fact that during the survey wide range of physical conditions was encountered. These results may suggest that many building occupants do not associate indoor environmental parameters and building features with their job performance or may not be aware that they do affect their work. Consequently the effects on the self-estimated job performance observed in the present work are small probably because they are not affected by the external factors such as expectations, past experience, awareness, anxiety, etc. It seems rather unlikely that many responses suggesting no impact of indoor environment and/or building features on job performance are due to unawareness and/or because the respondents did not understand the question in the questionnaire since only very few respondents (below 0.1%) answered that none of the factors specified in the CBE occupant satisfaction survey enhanced/interfered with their job performance (Figure 6).

Frontczak et al. (2011) found that overall satisfaction with personal workspace was the highest in private offices and at workstations close to a window. Similar trends were observed in the present work for the self-estimated job performance. Univariate analysis using the pairwise comparison with Wilcoxon rank sum test (Siegel, 1956) showed that self-estimated job performance was significantly higher in private offices than in shared and cubicles with high and low partitions ($p<0.02$). Similar analysis showed that respondents working within a distance of 4.6 m from a window indicated significantly higher self-estimated job performance compared with those working further from a window ($p<0.001$). Office type and proximity of window may be influenced by type of job, age, position in the company and duration of working in the company. Therefore, more detailed multivariate analysis controlling for number of coufonding factors are needed on the impact of office type and window proximity on the self-estimated job performance.

Limitations

One of the limitations of the present work is related to the selection of buildings. There was no systematic randomized approach in relation to building selection. Almost 80% of the surveyed buildings were situated in the USA so the results relate primarily to American settings.

Another limitation of the present study can be distribution of satisfaction levels with indoor environmental quality and building features. Although they were distributed over the entire satisfaction scale there were generally more votes towards increased satisfaction (Frontczak et al., 2011). Consequently it may be argued whether the observed effects can be extrapolated for the entire satisfaction scale. It can also be speculated whether the reason for the small effects on the self-estimated job performance are due to general high satisfaction with indoor environmental parameters and building features. Future validation of the effects observed in the present work would be required.

Among other limitations of the present work can be the inclusion of satisfaction with only 15 different indoor environmental parameters and building features on the self-estimated job performance. There are many other factors which may affect job performance (e.g. outside view) and also those not related to indoor environment and building features. The present analysis showed that coefficient of determination in regression model was only 0.42 confirming thus that other factors are also important. It may be considered to extend CBE occupant satisfaction survey by some additional factors which can influence job performance.

The present conclusions are entirely based on the self-estimated job performance. It is uncertain whether this metric can predict true effect on performance. There is basically no data in the research literature on whether the two metrics are correlated but there are also no data showing that they are not correlated. The work of Clausen and Wyon (2008) did imply that the self-estimated performance was twice as much as affected by improved indoor environmental quality than subjectively measured performance. But their results obtained in the laboratory needs to be verified. It was not the purpose of this work to discuss and speculate on the validity of using the self-estimated job performance. Whether or not being able to predict the actual performance, the self-estimated performance may approximate the working morale, inclination and/or enthusiasm to perform the job well. Future experiments should examine and elucidate whether it can also be used as a proxy for actual performance.

CONCLUSIONS

- Building occupants responded that the environmental conditions in their buildings have none or small effect on their self-estimated job performance. 24% of respondents assessed that all environmental conditions taken together neither increase nor decrease their self-estimated job performance, while 33% of respondents indicated that the environmental conditions decrease their job performance by at least 5%.
- Most of the environmental conditions were assessed by respondents to slightly enhance their job performance. Only acoustic quality and thermal comfort were considered to interfere with the ability to do the job.
- Overall satisfaction with the personal workspace was significantly related to the self-estimated job performance. Increasing satisfaction with personal workspace by one

unit on a 7-point scale would correspond to increase of self-estimated job performance by 3.7%.

- Among indoor environmental parameters and building features, satisfaction with temperature was most strongly related to self-estimated job performance followed by satisfaction with noise level and air quality. Increasing satisfaction with temperature, noise level or air quality by one unit on a 7-point scale would increase self-estimated job performance by approximately 1%.

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Paper V

Wargocki, P., Frontczak, M., Schiavon, S., Goins, J., Arens, E. and Zhang, H. (2012) Satisfaction and self-estimated performance in relation to indoor environmental parameters and building features, Proceedings of the 10th International Conference Healthy Buildings, Brisbane, Australia.

Satisfaction and self-estimated performance in relation to indoor environmental parameters and building features

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SUMMARY
The paper examines how satisfaction with indoor environmental parameters and building features affects satisfaction and self-estimated job performance. The analyses used subjective responses from around 50,000 occupants collected mainly in US office buildings using a web-based survey administered by the Center for the Built Environment (CBE) over the period of ten years. Overall satisfaction with the workspace significantly improved self-estimated job performance; increased satisfaction with temperature was estimated to provide the greatest improvement in self-estimated job performance, followed by increase in satisfaction with noise and air quality. The improvement of building features such as amount of space, visual privacy and noise level offered the highest chance to improve satisfaction with workspace. The study implies that it should be carefully considered how investments to upgrade indoor environmental quality and building design are used, and that they should consider whether comfort or working morale are expected to be improved.

KEY WORDS
Office buildings; Indoor environmental quality; Architectural and design features; Comfort; Self-estimated job performance

1 INTRODUCTION

In the developed parts of the world people spend substantial part of their time indoors, at home, at work and/or in schools, and also when commuting. Indoor conditions have therefore far-reaching implications for their health, general well-being and performance. Numerous studies have explored how building users perceive the indoor environment and what conditions are considered by building occupants to be comfortable (Frontczak and Wargocki, 2011). In indoor environments, a number of physical and chemical parameters have been identified that influence the comfort of building occupants. Standards dealing with indoor environmental quality have been developed to define the acceptable ranges of these parameters. Even though the requirements of these standards are met, not all building occupants are satisfied with the indoor environment. One of the possible reasons could be that not only physical conditions but also other factors, unrelated to indoor environmental quality, such as personal characteristics of building occupants, building-related factors and the outdoor climate, influence whether indoor environment is considered to be comfortable or not.

Occupants in buildings are exposed to all indoor environmental parameters simultaneously and their evaluation of the indoor environment is most likely to be a combination of the evaluation of different environmental parameters. Still many studies which examined the issue of building occupant comfort in indoor environments were focused mostly on the effects of single environmental conditions on humans or factors, not related to the indoor environment such as perceived control, adaptation, expectations and outdoor climate. Among others it was shown that workspace and building features such as view, control over the indoor environment, amount of privacy as well as layout, size, cleanliness, aesthetics and office furniture affect occupants' satisfaction.

Occupants' satisfaction was also shown to be positively correlated with the self-estimated performance of office workers. Occupants uncomfortable with the overall environment reported much lower self-estimated performance than those who felt comfortable with the overall environment. Occupants' satisfaction with the workspace was also positively associated with job satisfaction, which in turn had an impact on job and company performance. Job satisfaction was also related to frequency and duration of absenteeism as well as intention to quit work, issues which may affect working morale and consequently may have financial implications for employers.

The purpose of the present work was to investigate which subjectively evaluated indoor environmental quality parameters and building features mostly affect satisfaction and self-estimated job performance in office buildings, to examine the link between occupants' satisfaction with their personal workspace and self-estimated job performance, and to quantify the size of these effects.

2 METHODS

Over a 10-year period CBE has conducted post-occupancy evaluation surveys in more than 600 buildings using a web-based CBE occupant satisfaction survey (Zagreus et al., 2004). The subset of the data collected by CBE was analyzed in the present work comprising only office buildings and resulting in a dataset containing responses from 52,980 building occupants from 397 surveys performed in 351 different buildings (Frontczak et al., 2011; Kim and De Dear, 2012).

CBE occupant satisfaction survey collects information about occupants' satisfaction and self-estimated performance in different categories related to indoor environment and building features (Table 1). Questions about satisfaction have the following structure: "How satisfied are you with (e.g., temperature in your workspace)?". The answers are given on a 7-point categorical scale and coded as follows: "very satisfied" =+3, "very dissatisfied" = -3; a neutral midpoint is coded as 0. Questions about performance are as follows: "Overall, does (e.g., thermal comfort) enhance or interfere with your ability to get your job done?". The answers are given on a 7-point categorical scale coded as follows: "enhances" =+3, "interferes" =-3; a neutral midpoint is coded as 0. There is also a summarizing performance question, as follows: "Please estimate how your job performance is increased or decreased by the environmental conditions in this building (e.g., thermal, lighting, acoustics, cleanliness)". An estimate is given on a 7-point categorical scale ranging from 'increased' to 'decreased' with each point defined as 20%, 10%, 5%, 0%, -5%, -10% and -20%. Respondents provide also information about their gender, age group, type of work performed, office type, proximity of workstation to a window and external walls as well as duration of working in the present building and at the present workspace. A building facility manager is also asked to provide descriptive information about the building and its systems such as the building's age, location and size, number of floors, number of occupants, type of HVAC system, solar shading and controls, buildings' LEED rating, energy use and cost of building construction, etc.

Proportional odds ordinal logistic regression was applied to investigate the relationship between satisfaction with the workspace and satisfaction with indoor environmental quality and building features. Multivariate linear regression was applied to investigate the relationship between (1) self-estimated job performance and overall satisfaction with workspace and (2) self-estimated job performance and satisfaction with indoor environmental parameters and building features. The results were considered statistically significant when $p<0.05$.

Table 1. List of parameters assessed by the CBE occupant satisfaction survey.

Questionnaire item (satisfaction)	Questionnaire item (performance)
Amount of space available for individual work and storage	Office layout
Level of visual privacy	Office furnishings
Ease of interaction with co-workers	Thermal comfort
Comfort of office furnishings (chair, desk, computer, equipment, etc.)	Air quality
Ability to adjust furniture to meet your needs	Lighting quality
Colours and textures of flooring, furniture and surface finishes	Acoustic quality
Temperature in your workspace	Cleanliness and maintenance of the building
Air quality in your workspace (i.e. stuffy/stale air, air cleanliness, odours)	Job performance
Amount of light in your workspace	
Visual comfort of the lighting (e.g., glare, reflections, contrast)	
Noise level in your workspace	
Sound privacy in your workspace (ability to have conversations without neighbours overhearing and vice versa)	
General cleanliness of the overall building	
Cleaning service provided to your workspace	
General maintenance of the building	
Your personal workspace	
Building overall	

3 RESULTS

The levels of satisfaction with different indoor environmental parameters and building features are shown in Figure 1. The highest dissatisfaction was observed for indoor environmental factors such as sound privacy, temperature, noise level, air quality and visual privacy; building occupants were generally satisfied with their personal workspace and building features. Figure 2 summarizes the responses of occupants describing whether indoor environmental parameters and building features enhanced or interfered with getting their job done. Acoustic quality and thermal comfort were indicated by the occupants to interfere with their ability to get the job done, while the other parameters were indicated to enhance it; buildings' cleanliness and maintenance were considered to mostly enhance their ability to get the job done.

The results of proportional odds logistic regression showed that satisfaction with all 15 environmental parameters and building features listed in the CBE occupant satisfaction survey contributed significantly ($p<0.001$) to overall satisfaction with personal workspace (Figure 3). Modelling showed that there would be the highest chance to improve the overall workspace satisfaction if satisfaction with the amount of space available for work and storage were improved. The next parameters that would have the highest chance for improving the overall satisfaction with personal workspace were satisfaction with noise level and visual privacy. Increasing satisfaction with the amount of space would increase 1.57 times the likelihood that overall workspace satisfaction is also increased compared to the case when satisfaction with the amount of space is not increased. Satisfaction with the amount of space was slightly correlated to satisfaction with visual privacy, ease of interaction, noise and sound privacy. However, the variance inflation factor was below 3 indicating that there was no problem of multicollinearity between predictor variables.

Satisfaction with the amount of space for work and storage was ranked to be the most likely parameter for improving the overall satisfaction with the personal workspace, regardless of respondents' age group (below 30, 31-50 or over 50 years old), gender, type of office (single or shared office, or cubicles with high or low partitions), distance of workstation from a window (within 4.6 meters or further) or satisfaction level with personal workspace (satisfied including neutral responses or dissatisfied). A preliminary and rough estimation showed that satisfaction with the amount of space for work is probably also independent of gross area per person.

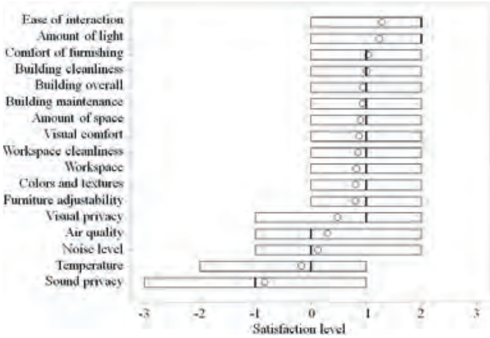

Figure 1. Satisfaction with parameters assessed in the CBE occupant satisfaction survey. The extremities of the boxes are the 25th and 75th percentiles. Bold vertical lines indicate median values and dots represent mean values

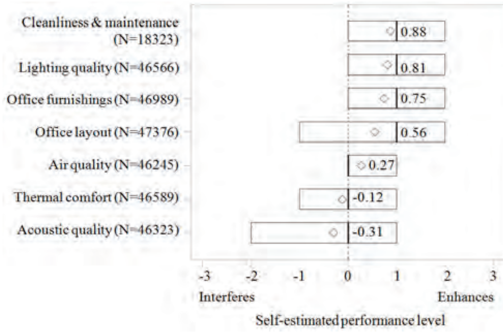

Figure 2. Ratings on whether indoor environmental parameters and building features enhanced or interfered with getting job done. Bold vertical lines show median values and diamonds represent mean values. The extremities of the boxes are the 25^{th} and 75^{th} percentiles. Numbers in the figure indicate mean values. N shows the number of responses

Simple linear regression showed that overall satisfaction with personal workspace correlated significantly with the self-estimated job performance ($p<0.001$). Increasing overall satisfaction with personal workspace by one unit on a 7-point scale would correspond to increasing self-estimated job performance by 3.7%. Among indoor environmental parameters and building features listed in the CBE occupant satisfaction survey, satisfaction with cleanliness of workspace, amount of light and comfort of furnishings were not statistically significant ($p>0.05$) in the multivariate linear regression model (Figure 4), indicating that their changes would not influence self-estimated job performance. The model showed that the highest increase in self-estimated job performance would be caused by improving satisfaction with temperature. Improving satisfaction with temperature by 1 unit on a 7-point scale would increase the self-estimated job performance by about 1% while the satisfaction with all other parameters was kept constant. Next highest increments of self-estimated job performance would be obtained by improving satisfaction with noise level and air quality; they would increase the self-estimated job performance by about 0.8%. Assuming fully additive effect, the combined effect of improving satisfaction with all indoor environmental parameters and building features examined in the present analysis by one unit on a 7-point scale would yield 5.67% increase in the self-estimated job performance. This is higher than 3.7%, as reported above, suggesting a hypo-additive effect which nature should be examined in the future studies.

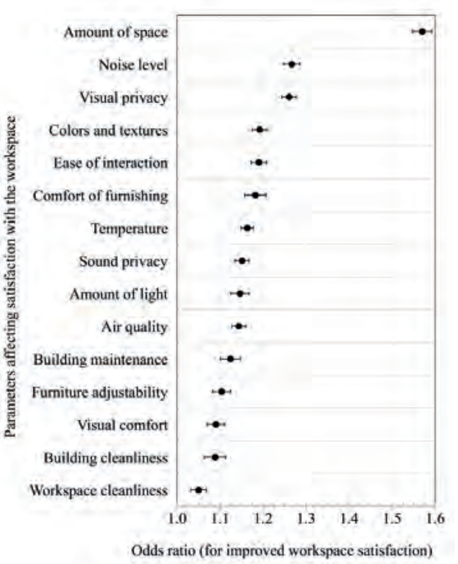

Figure 3. Odds ratios together with 95% confidence intervals indicating which changes to indoor environmental parameters and building features would have the highest effect on satisfaction with personal workspace

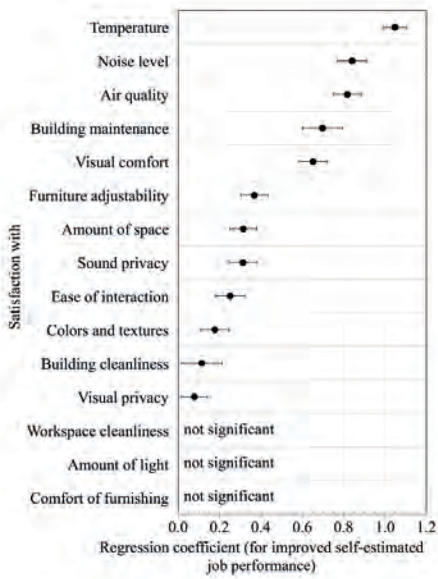

Figure 4. Regression coefficients together with 95% confidence intervals indicating how much self-estimated job performance will be improved when satisfaction with indoor environmental parameters and building features is increased

4 DISCUSSION

Present results showed that in order to maximize overall satisfaction with one's personal workspace, investments should first be made that lead to increasing satisfaction with the amount of space, noise level and visual privacy. If on the other hand self-estimated job performance is considered, then satisfaction with temperature, noise level and air quality should be first improved as they have the highest effect on self-estimated job performance. Satisfaction with the amount of space and visual privacy (parameters highly important for overall workspace satisfaction) were of much lower importance for self-estimated job performance. The discrepancy between ranking of indoor environmental parameters and building features regarding their importance for overall workspace satisfaction and self-estimated job performance implies that the investments in improving conditions in indoor environments should be well targeted in order to obtain the expected benefits. We do not have clear explanation of the reason of this discrepancy. It is however likely that the amount of space is related by building users to the status and position at work, the higher status the higher satisfaction. The improved status may not however necessarily be considered by an individual to have direct effect on job performance. On the other hand, changes to temperature, air quality and other indoor environmental factors can be much easily considered to affect performance as an individual can perceive whether he/she works effectively on days with, e.g. elevated temperatures, though more likely that they would be perceived to affect job performance stronger when the changes are in the negative direction (Fig.1). They can thus be much more easily "correlated" with job performance than can building factors such as amount of space or ease of interaction which are more or less constant. This could explain why increasing satisfaction with changes to temperature would be expected to improve the self-estimated job performance to a higher degree (Fig. 4), even though amount of space and other building factors have higher effect on satisfaction (Fig. 3). The observed discrepancy may have psychological, psychophysical and/or physiological origin, and its nature should be investigated further in future studies.

Self-estimated job performance in the present study may not necessarily reflect the actual performance and/or productivity of workers and probably was only a good marker of working morale, inclination and/or enthusiasm to perform the job well, etc. Productivity of office workers was not measured objectively and it is not known to what extent self-estimated job performance represents actual changes in workers' productivity. Consequently the obtained quantitative figures between satisfaction and self-estimated job performance should be treated with caution and cannot be directly used as a measure of productivity. As there is no clear reference level to which respondents estimated the effect on their job performance, the change (% decrease or % increase) in job performance as indicated by the respondents is somewhat ambiguous. Among other limitations of the present analysis is the lack of the systematic randomized selection of buildings in which the survey was conducted. Almost 80% of the surveyed buildings were situated in the USA, so the results relate primarily to American settings. Since the data were collected over 10-year period the changes in building design and regulations could affect outcomes and were not controlled for in the present analyses. The survey considered only the influence of satisfaction with 15 different indoor environmental parameters and building features on overall satisfaction with personal workspace and self-estimated job performance; there may be other parameters that affect overall workspace satisfaction or self-estimated job performance. Another limitation is the absence of physical measurements. It would be preferable to relate subjective responses of building occupants to objective measures of indoor environmental parameters and building features.

5 CONCLUSIONS

Present results can guide building users, operators and employers in making decisions on how working indoor environment can be improved most effectively by selecting these parameters which promote comfort and working morale at the most. The tool to perform such selection is described..

ACKNOWLEDGEMENTS

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Appendices

Appendix A

Questionnaire survey conducted in Danish residential buildings (background questions and questions addressing home environment).

Center for Indeklima & Energi
Danmarks Tekniske Universitet

Kode: «Kode»

Kære «navn»

Du kan stadig nå at vinde én af to præmier på 1000 skattefrie kroner ved at udfylde et spørgeskema om indeklima i boliger. Din deltagelse er meget vigtig for os.

«navn»
«adresse»
«postnr» «bynavn»

For et par uger siden blev du inviteret til at deltage i en spørgeskemaundersøgelse om indeklima i boliger. Din bolig er blevet tilfældigt udvalgt i et centralt register over bygninger i Danmark (BBR registeret).

Vi har brug for din deltagelse for at få større viden om brugen af danske bygninger. Denne viden kan bruges til at gøre vores bygninger sundere at leve i og nedbringe Danmarks samlede energiforbrug. Undersøgelsen består af det vedlagte spørgeskema, som du skal udfylde og sende retur i den vedlagte svarkuvert.

Hvis du hellere vil udfylde spørgeskemaet på internettet, kan du gøre det på adressen www.ie.dtu.dk/bolig10 (Du skal indtaste adressen i adresselinjen i din browser – ikke i et søgefelt som f.eks. Google)

Enhver person over 18 år, der bor på den adresse brevet er sendt til, kan udfylde spørgeskemaet. Men spørgeskemaet kan kun udfyldes én gang per husstand. Da spørgeskemaet indeholder spørgsmål om forholdene i boligen vil vi gerne have at du besvare spørgeskemaet mens du opholder dig i din bolig.

Besvarelserne vil blive behandlet fortroligt og resultaterne offentliggøres i en form, hvor enkeltpersoner ikke kan genkendes.

Det er naturligvis frivilligt at deltage i spørgeskemaundersøgelsen, men jo flere der besvarer spørgeskemaet, jo mere anvendelig bliver undersøgelsen. Vi vil derfor gerne opfordre dig til at besvare spørgeskemaet.

Alle der udfylder spørgeskemaet inden d. 07-04/2010 deltager i lodtrækningen om 2 præmier på 1000 skattefrie kroner.

På forhånd tak for hjælpen!

Rune Vinther Andersen, Ph.d., Forsker ved Center for Indeklima og Energi, DTU

Center for Indeklima og Energi
Institut for Byggeri og Anlæg

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spørgeskema om brugeradfærd og livskvalitet i boliger

1 Beboerne

1.1 Hvad er din alder?_________________

1.2 Er du? ☐ Kvinde ☐ Mand

1.3 Angiv venligst alder og køn på øvrige personer i boligen

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

Alder: _______ År Køn: ☐ K ☐ M

2 Arbejdsplads og opholdssted

2.1 Hvor arbejder du til daglig? (Hvis du har mere end et arbejde eller flere opholdssteder i dit arbejde skal du markere ud for dét sted du opholder dig mest)

- ☐ Jeg arbejder i et kontor
- ☐ Jeg arbejder i en børneinstitution (herunder vuggestue, børnehave, SFO, skole osv.)
- ☐ Jeg arbejder hverken i et kontor eller en børneinstitution
- ☐ Ved ikke

2.2 Hvor befinder du dig lige nu?

- ☐ Jeg opholder mig i min bolig
- ☐ Jeg opholder mig på min arbejdsplads
- ☐ Jeg opholder mig hos familie eller venner
- ☐ Andet______________
- ☐ Ved ikke

Forholdene lige nu

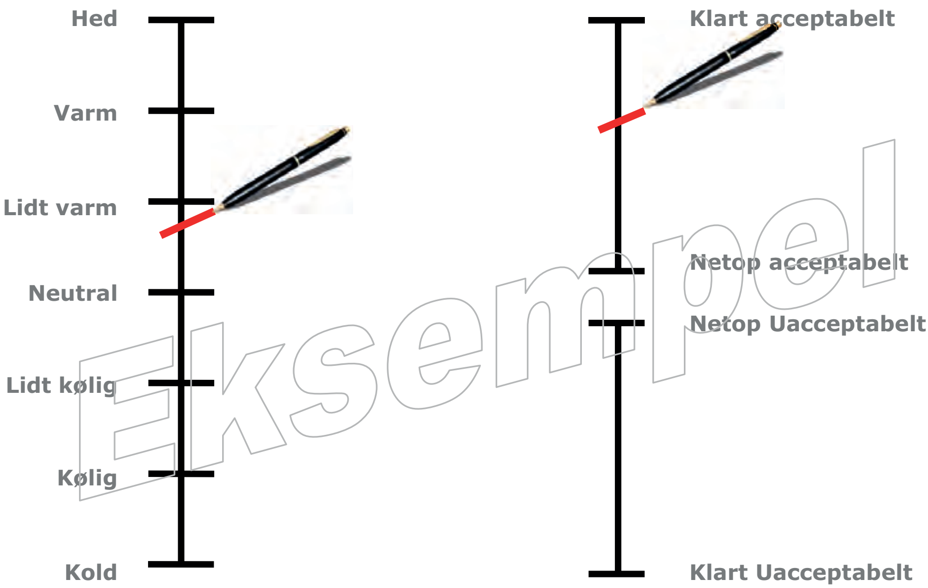
De følgende spørgsmål omhandler din oplevelse af indeklimaet dér hvor du opholder dig lige nu.

Hvis et spørgsmål indeholder en skala, skal du sætte en streg på skalaen på det sted, som svarer til din umiddelbare vurdering. Se et eksempel nedenfor:

Eksempel:

Hvordan føler du dig lige nu
(Markér venligst på skalaen)

Hvordan oplever du det termiske indeklima, dvs. de dele af inde-klimaet der har betydning for om du fryser eller har det for varmt.
(Markér venligst på skalaen)



3 Termisk indeklima

3.1 Hvordan føler du dig lige nu
(Markér venligst på skalaen)

Hed

Varm

Lidt varm

Neutral

Lidt kølig

Kølig

Kold

3.2 Hvordan oplever du det termiske indeklima, dvs. de dele af indeklimaet der har betydning for om du fryser eller har det for varmt. (Markér venligst på skalaen)

Klart acceptabelt

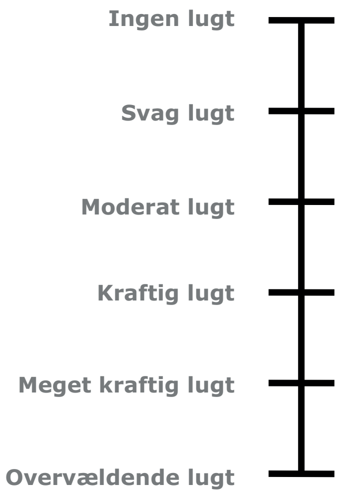
Netop acceptabelt

Netop Uacceptabelt

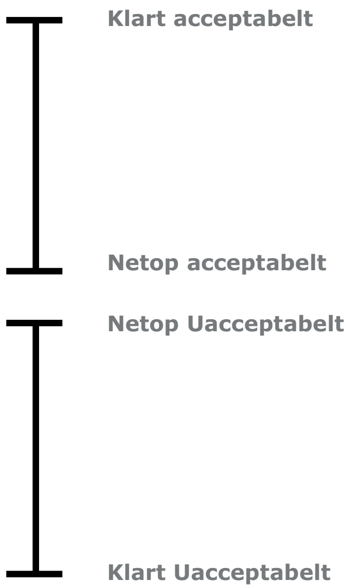
Klart Uacceptabelt

4 Luftkvalitet

4.1 Hvordan oplever du lugtintensiteten netop nu?
(Markér venligst på skalaen)



4.2 Hvordan oplever du luftkvaliteten netop nu?
(Markér venligst på skalaen)



5 Lyd

5.1 Hvordan oplever du lydintensiteten netop nu?
(Markér venligst på skalaen)

Ingen lyd

Svag lyd

Moderat lyd

Kraftig lyd

Meget kraftig lyd

Overvældende lyd

5.2 Hvordan oplever du lydkvaliteten netop nu?
(Markér venligst på skalaen)

Klart acceptabelt

Netop acceptabelt

Netop Uacceptabelt

Klart Uacceptabelt

6 Lys

6.1 Hvordan oplever du lysintensiteten netop nu?
(Markér venligst på skalaen)

Ingen lys

Svagt lys

Moderat lys

Kraftig lys

Meget kraftig lys

Overvældende lys

6.2 Hvordan oplever du lyskvaliteten netop nu?
(Markér venligst på skalaen)

Klart acceptabelt

Netop acceptabelt

Netop Uacceptabelt

Klart Uacceptabelt

7 Overordnet indeklima

7.1 Hvordan oplever du det samlede indeklima netop nu?
(Markér venligst på skalaen)

Rigtigt dårligt indeklima

Dårligt indeklima

Lidt dårligt indeklima

Lidt godt indeklima

Godt indeklima

Rigtigt godt indeklima

7.2 Hvordan oplever du kvaliteten af indeklimaet netop nu?
(Markér venligst på skalaen)

Klart acceptabelt

Netop acceptabelt

Netop Uacceptabelt

Klart Uacceptabelt

8 Indeklima

8.1 Hvordan opfatter du forholdene i det lokale, du lige nu sidder i? (Markér venligst på skalaerne)

Alt for lav lufthastighed	**For lav lufthastighed**	**Lidt for lav lufthastighed**	**Tilpas lufthastighed**	**Lidt for høj lufthastighed**	**For høj lufthastighed**	**Alt for høj lufthastighed**

Overvældende træk	**Meget kraftigt træk**	**Kraftigt træk**	**Moderat træk**	**Svagt træk**	**Ingen træk**

Alt for meget udsyn gennem vinduer	**For meget udsyn gennem vinduer**	**Lidt for meget udsyn gennem vinduer**	**Passende udsyn gennem vinduer**	**Lidt for lidt udsyn gennem vinduer**	**For lidt udsyn gennem vinduer**	**Alt for lidt udsyn gennem vinduer**

Alt for lidt privathed	**For lidt privathed**	**Lidt for lidt privathed**	**Passende privathed**	**Lidt for meget privathed**	**For meget privathed**	**Alt for meget privathed**

9 Situationen

9.1 Hvordan vil du bedst beskrive din situation lige nu?

Meget stresset		**Ikke stresset**
Ikke bevidst miljø-mæssigt ansvarlig		**Bevidst miljømæssigt ansvarlig**
Utryg		**Tryg**
Lav livskvalitet		**Høj livskvalitet**
Dårlig generel sundhed		**God generel sundhed**

9.2 Hvor højt vurdere du at stressniveauet er hos de(n) person(er) du bor sammen med?
(Besvares ikke hvis du bor alene)

Meget stresset		**Ikke stresset**

10 Et godt indeklima

10.1 Hvad er ifølge din mening mest vigtigt for et godt indeklima? (sæt ét kryds for hver linje. For hver linje skal du afgøre hvilken af de to egenskaber der er mest vigtige. Hvis du er tvivl kan du sætte kryds i 'Ved ikke')

	A er meget mere vigtig end B	A er mere vigtig end B	A og B er lige vigtige	B er mere vigtig end A	B er meget mere vigtig end A		Ved ikke
A) Passende temperatur	☐	☐	☐	☐	☐	B) Passende luftkvalitet	☐
A) Passende temperatur	☐	☐	☐	☐	☐	B) Passende belysning	☐
A) Passende temperatur	☐	☐	☐	☐	☐	B) Passende lydforhold	☐
A) Passende luftkvalitet	☐	☐	☐	☐	☐	B) Passende belysning	☐
A) Passende luftkvalitet	☐	☐	☐	☐	☐	B) Passende lydforhold	☐
A) Passende belysning	☐	☐	☐	☐	☐	B) Passende lydforhold	☐
A) Passende dagslys	☐	☐	☐	☐	☐	B) Passende elektrisk belysning	☐
A) Passende privathed	☐	☐	☐	☐	☐	B) Passende indeklima	☐
A) Passende miljømæssig ansvarlighed	☐	☐	☐	☐	☐	B) Passende indeklima	☐

11 Komfort

11.1 Tænk på et sted hvor du har følt dig komfortabel og beskriv det med dine egne ord.

____

____

____

____

____

☐ Ved ikke

11.2 Beskriv med dine egne ord hvad der gjorde stedet komfortabelt.

____

____

____

____

____

____

☐ Ved ikke

12 Din bolig

De følgende spørgsmål handler om din bolig: Det er vigtigt at du forsøger at svare så præcist som muligt på alle spørgsmålene. Hvis du ikke har nogen mening om spørgsmålenes indhold kan du sætte kryds i 'Ved ikke'.

12.1 Hvor gode synes du de følgende metoder er til at sørge for at du hverken kommer til at fryse eller have det for varmt i din bolig? (Sæt ét kryds for hver linje)

	Meget effektivt	Effektivt	Lidt effektivt	Ikke effektivt	Ved ikke
12.1 Åbne/lukke vinduet	☐	☐	☐	☐	☐
12.2 Trækker gardiner fra/for	☐	☐	☐	☐	☐
12.3 Regulere på varmen ved at dreje på en termostat	☐	☐	☐	☐	☐
12.4 Drikke noget varmt/koldt	☐	☐	☐	☐	☐
12.5 Ændre kropsholdning	☐	☐	☐	☐	☐
12.6 Ændre beklædning	☐	☐	☐	☐	☐
12.7 Flytter mig til et andet sted	☐	☐	☐	☐	☐

13 Indretning

Hvilke forhold var med i overvejelserne da du indrettede din bolig? (Sæt ét kryds for hver linje.)

	Meget stor indflydelse	Stor ind-flydelse	Lille ind-flydelse	Ingen ind-flydelse	Ved ikke
13.1 Formål med lokaler	☐	☐	☐	☐	☐
13.2 Vise/skabe sin stil	☐	☐	☐	☐	☐
13.3 Skabe hygge	☐	☐	☐	☐	☐
13.4 Skabe praktiske ar-bejdsvilkår	☐	☐	☐	☐	☐
13.5 Farver	☐	☐	☐	☐	☐
13.6 Udsigt	☐	☐	☐	☐	☐
13.7 Privathed	☐	☐	☐	☐	☐
13.8 Placeringen af varme-kilder så som radiatorer, ventilation, gulvvarme	☐	☐	☐	☐	☐
13.9 Temperatur forhold (varme/kulde)	☐	☐	☐	☐	☐
13.10 Dagslysforhold (med dagslys menes naturligt lys der kommer ind gennem vinduer, døre, ovenlys osv.)	☐	☐	☐	☐	☐
13.11 Belysningsforhold elektrisk lys	☐	☐	☐	☐	☐
13.12 Støj	☐	☐	☐	☐	☐
13.13 Træk	☐	☐	☐	☐	☐
13.14 Pris	☐	☐	☐	☐	☐

Andet forhold med stor betydning____

14 Vinduesåbning i boligen

14.1 Tænk på sidste gang du åbnede et vindue i din bolig. Hvad var årsagen til at du åbnede det? (sæt gerne flere krydser)

- ☐ Jeg havde det for varmt og mente at det ville køle mig af at åbne et vindue
    - Hvis ja: Åbnede du fordi du gerne ville have mere luftbevægelse?
        - ☐ Ja
        - ☐ Nej
        - ☐ Ved ikke
- ☐ Andre bad mig om det
- ☐ Jeg ville gerne lufte ud
    - Hvorfor ville du gerne lufte ud?
        - ☐ Jeg havde hørt at man skal lufte ud 2-3 gange om dagen.
            - Hvorfra har du fået den opfattelse?___________
        - ☐ Jeg er blevet opdraget til at lufte jævnligt ud
        - ☐ Jeg ville gerne have frisk luft fordi luften i lokalet føltes ubehagelig
        - ☐ Jeg ville gerne have frisk luft inden der kom gæster
        - ☐ Jeg tror det er sundt at lufte ud
        - ☐ Jeg tror det er vigtigt at lufte ud for at fjerne skadelige stoffer i luften
        - ☐ Jeg tror det er vigtigt at lufte ud for at bygningen og møbler ikke tager skade af skadelige bestanddele i luften
        - ☐ Jeg ville gerne lufte ud for at spare energi
        - ☐ Jeg luftede ud for at der ikke skulle blive for fugtigt.
        - ☐ Jeg luftede ud for at fjerne røgen fra tobak
        - ☐ Andet____________________
- ☐ Jeg åbner altid vinduet på det tidspunkt
- ☐ Jeg ville gerne have bedre kontakt til det, der foregår udenfor
- ☐ Jeg ville prøve at undgå, at der blev for varmt
- ☐ Jeg ville prøve at undgå, at luftkvaliteten blev dårlig
- ☐ Jeg eller en anden person havde lige været i bad
- ☐ Jeg eller en anden havde lige lavet mad
- ☐ Andet___________________
- ☐ Ved ikke

14.2 Tænk på sidste gang du lukkede et vindue i din bolig. Hvad var årsagen til at du lukkede det? (sæt gerne flere krydser)

- ☐ Jeg havde det for koldt
- ☐ Andre bad mig om det
- ☐ Jeg havde luftet ud og mente, at luften var blevet frisk nok
- ☐ Jeg lukker altid vinduet på det tidspunkt
- ☐ Jeg ville gerne afskærmes fra det, der foregik udenfor
- ☐ Jeg ville prøve at undgå, at der blev for koldt
- ☐ Jeg mente, at luftkvaliteten var blevet god nok
- ☐ Der var for megen luftbevægelse
- ☐ Andet__________________
- ☐ Ved ikke

15 Regulering af varmen i boligen

15.1 Tænk på sidste gang du skruede op for varmen i din bolig. Hvad var årsagen? (sæt gerne flere krydser)

- ☐ Jeg eller andre havde det for koldt/frøs
- ☐ Da jeg kom ind i lokalet var der for koldt
- ☐ Jeg vidste at det senere ville blive for koldt hvis jeg ikke skruede op.
- ☐ Jeg kunne mærke at vejret udenfor var blevet meget koldt
- ☐ Jeg trængte til at få varmen efter at jeg havde været udenfor
- ☐ Jeg tror ikke det havde været godt for bygningen, hvis jeg ikke skruede op for varmen
- ☐ Jeg tror der ville opstå problemer med fugt, skimmel, mug eller svamp hvis jeg ikke skruede op
- ☐ Der var fugtigt
- ☐ Jeg skulle have gæster
- ☐ Jeg skruer altid op på det tidspunkt
- ☐ Andet____________________
- ☐ Ved ikke

15.2 Tænk på sidste gang du skruede ned for varmen i din bolig. Hvad var årsagen? (sæt gerne flere krydser)

- ☐ Jeg eller andre havde det for varmt
- ☐ Da jeg kom ind i lokalet var der for varmt
- ☐ Jeg vidste at det senere ville blive for varmt hvis jeg ikke skruede ned.
- ☐ Jeg kunne mærke, at vejret udenfor var blevet varmere
- ☐ Jeg ville spare på varmen for miljøets skyld
- ☐ Jeg ville spare på varmeregningen
- ☐ Jeg tror ikke det havde været godt for bygningen, hvis jeg ikke skruede ned for varmen
- ☐ Jeg tror der ville opstå problemer med fugt, skimmel, mug eller svamp hvis jeg ikke skruede ned
- ☐ Der var fugtigt
- ☐ Jeg skulle have gæster
- ☐ Jeg skruer altid ned på det tidspunkt
- ☐ Andet____________________
- ☐ Ved ikke

16 Tekniske installationer i boligen

16.1 Forestil dig at du er usikker på hvordan man bedst bruger en af de tekniske installationer i din bolig (f.eks. en radiatortermstat eller dit fyr). Hvad ville du gøre? (Sæt gerne flere krydser)

- ☐ Jeg ville hente råd og vejledning i min bekendtskabskreds
- ☐ Jeg ville forsøge at finde information om det på internettet
- ☐ Jeg ville ringe til en håndværker/teknikker og forhører mig det
- ☐ Jeg ville kontakte kommunen
- ☐ Jeg ville prøve mig frem
- ☐ Jeg ville kontakte viceværten
- ☐ Jeg ville ikke foretage mig noget
- ☐ Jeg ved ikke, hvor jeg skulle henvende mig
- ☐ Andet__________________
- ☐ Ved ikke

16.2 Hvordan foretrækker du at det følgende styres i din bolig? (Sæt ét kryds for hver linje)

	Manuelt	Automatisk	Begge to i kombination/Automatisk med mulighed for at slukke automatik og styre manuelt	Ved ikke
Elektrisk belysning	☐	☐	☐	☐
Vinduesåbning	☐	☐	☐	☐
Solafskærmning	☐	☐	☐	☐
Temperaturindstilling	☐	☐	☐	☐

16.3 Er der ud over en emhætte i køkkenet og udsugning fra badeværelset et ventilationsanlæg i din bolig?

Et mekanisk ventilationsanlæg indeholder en ventilator, der blæser luft ind i bygningen, suger luft ud af bygningen eller begge dele. Luften bliver i nogle tilfælde fordelt til forskellige rum vha. kanaler. I andre tilfælde sidder ventilatoren i et hul i væggen og blæser/suger kun luft fra/til ét rum.

- ☐ Ja
- ☐ Nej
- ☐ Ved ikke

17 Adfærd i boligen

Hvor ofte gør du følgende i din bolig om sommeren? (Sæt ét kryds for hver linje)

	Flere gange om dagen	Flere gange om ugen	Flere gange om måneden	Én gang om måneden eller sjældnere	Ved ikke
17.1 Åbner/lukker vinduer	☐	☐	☐	☐	☐
17.2 Tænder og slukker lys	☐	☐	☐	☐	☐
17.3 Trækker gardiner fra/for fordi der ønskes uforstyrrethed	☐	☐	☐	☐	☐
17.4 Trækker gardiner fra/for fordi det er for varmt	☐	☐	☐	☐	☐
17.5 Tænder og slukker for bord eller gulv blæser/ventilator	☐	☐	☐	☐	☐

Hvor ofte gør du følgende i din bolig om vinteren? (Sæt ét kryds for hver linje)

	Flere gange om dagen	Flere gange om ugen	Flere gange om måneden	Én gang om måneden eller sjældnere	Ved ikke
17.6 Åbner/lukker vinduer	☐	☐	☐	☐	☐
17.7 Tænder og slukker lys	☐	☐	☐	☐	☐
17.8 Trækker gardiner fra/for fordi der ønskes uforstyrrethed	☐	☐	☐	☐	☐
17.9 Regulere på varmen fra varmeanlægget ved at indstille en termostat	☐	☐	☐	☐	☐

18 Muligheder i boligen

Hvor vigtigt er det for dig at have følgende muligheder i din bolig? (sæt ét kryds for hver linje)

	Det sætter jeg stor pris på	Det sætter jeg pris på	Det betyder ikke så meget for mig	Det betyder slet ikke noget for mig	Ved ikke
18.1 At kunne åbne og lukke et vindue	☐	☐	☐	☐	☐
18.2 At mærke luftbevægelser indendørs	☐	☐	☐	☐	☐
18.3 At kunne åbne en dør til det fri	☐	☐	☐	☐	☐
18.4 At kunne følge med i vejret udenfor	☐	☐	☐	☐	☐
18.5 At kunne få frisk luft uden at det trækker	☐	☐	☐	☐	☐
18.6 At kunne få frisk luft uden at der bliver koldt indenfor	☐	☐	☐	☐	☐
18.7 Altid at have frisk luft fra et ventilationsanlæg	☐	☐	☐	☐	☐

19 Vaner og indeklima i boligen

19.1 Hvor meget synes du selv du ved om hvordan dine vaner påvirker dit energiforbrug og indeklima i din bolig?

- ☐ Det ved jeg rigtig meget om
- ☐ Det ved jeg meget om
- ☐ Det ved jeg en del om
- ☐ Det ved jeg ikke så meget om
- ☐ Det ved jeg næsten ikke noget om
- ☐ Det ved jeg intet om
- ☐ Ved ikke

19.2 Hvor let er det at forstå hvordan installationerne i din bolig (ventilation, varmesystem, solpåvirkning, isolering…) virker bedst og hvordan du i din dag-ligdag får det bedste ud af dem?

- ☐ Det er meget let at forstå
- ☐ De er let at forstå
- ☐ Det er svært at forstå
- ☐ Det er meget svært at forstå
- ☐ Ved ikke

19.3 Tror du at du ville have gavn af at få råd og vejledning om vaner med hensyn til udluftning, rengøring og opvarmning?

- ☐ Ja, det ville jeg have stor gavn af
- ☐ Ja, det ville jeg have gavn af
- ☐ Nej, det ville jeg ikke have så stor gavn af
- ☐ Nej, det ville jeg ikke have gavn af
- ☐ Ved ikke

Vaner og indeklima i boligen - fortsat

19.4 Ville du benytte dig af et apparat der kunne vejlede dig om hvordan du opnår et godt indeklima ved at bruge så lidt energi som muligt, hvis et sådan fandtes?

- ☐ Ja
  - ▪ Hvis ja, hvor meget ville du være villig til at betale for et sådan apparat? ________________________Kr
  - ☐ Ved ikke
- ☐ Nej
  - ▪ Hvis nej, Hvorfor ikke?
    - ☐ Jeg ved selv hvordan jeg opnår et godt indeklima på en effektiv måde
    - ☐ Jeg er ligeglad
    - ☐ Jeg vil ikke have at mine handlinger skal dikteres af teknologi
    - ☐ Jeg ville glemme at kigge på apparatet
    - ☐ Andet________________
    - ☐ Ved ikke
- ☐ Ved ikke

19.5 Tror du at et sådan apparat ville kunne hjælpe dig og de andre beboere i din bolig med at være energi beviste?

- ☐ Ja
- ☐ Nej
- ☐ ved ikke

19.6 Tror du at et sådan apparat ville kunne hjælpe dig og de andre beboere i din bolig med at få/bevare et godt indeklima?

- ☐ Ja
- ☐ Nej
- ☐ ved ikke

19.7 Hvor meget tænker du over varmeregningen/energiforbruget når du skruer op eller ned for varmen?

- ☐ Det tænker jeg over hver gang
- ☐ Det tænker jeg over næsten hver gang
- ☐ Det tænker jeg tit over
- ☐ Det tænker jeg ikke så ofte over
- ☐ Det tænker jeg næste aldrig over
- ☐ Det tænker jeg aldrig over
- ☐ Ved ikke

20 Indeklima og sundhed

20.1 Hvor meget tænker du over egen/familiens sundhed når du skruer op eller ned for varmen?

- ☐ Det tænker jeg over hver gang
- ☐ Det tænker jeg over næsten hver gang
- ☐ Det tænker jeg tit over
- ☐ Det tænker jeg ikke så ofte over
- ☐ Det tænker jeg næste aldrig over
- ☐ Det tænker jeg aldrig over
- ☐ Ved ikke

20.2 Hvor meget tænker du over egen/familiens sundhed når du lufter ud om vinteren?

- ☐ Det tænker jeg over hver gang
- ☐ Det tænker jeg over næsten hver gang
- ☐ Det tænker jeg tit over
- ☐ Det tænker jeg ikke så ofte over
- ☐ Det tænker jeg næste aldrig over
- ☐ Det tænker jeg aldrig over
- ☐ Ved ikke

21 Problemer med indeklimaet i boligen

21.1 Hvilke problemer i forbindelse med indeklimaet, har du i dit hjem? (Sæt gerne flere krydser)

- ☐ Problemer med skimmelsvamp
- ☐ Problemer med træk
- ☐ Problemer med koldt gulv
- ☐ Problemer med støj udefra eller fra naboer
- ☐ Problemer med ubehagelig lugt udefra eller fra naboer
- ☐ Problemer med at der bliver for varmt i boligen om sommeren
- ☐ Problemer med at der bliver for koldt i boligen om vinteren
- ☐ Problemer med for lidt dagslys i boligen
- ☐ Problemer med vand (kondens) på vinduernes inderside om vinteren
- ☐ Sundhedsproblemer, som du kun oplever, når du er hjemme (hovedpine, løbende næse osv.)
- ☐ Andet: _________________
- ☐ Jeg har ingen problemer i forbindelse med indeklimaet i mit hjem
- ☐ Ved ikke

Hvis ja til problemer i 21.1:

21.2 I hvor høj grad ved du om problemet er sundhedsmæssigt eller bygningsmæssigt alvorlig?

- ☐ Det har jeg stor viden om
- ☐ Det ved jeg en del om
- ☐ Det ved jeg ikke så meget om
- ☐ Det ved jeg ikke noget om
- ☐ Ved ikke

21.3 Hvis der markeres i én af de tre første: Hvor har du fundet information om problemets alvor? (Sæt gerne flere krydser)

- ☐ På internettet
- ☐ På biblioteket
- ☐ På kommunen
- ☐ Ved at forhøre mig i min omgangskreds (familie, venner osv.)
- ☐ Der er almen viden
- ☐ Jeg vidste det inden problemet opstod
- ☐ Andet____________________
- ☐ Ved ikke

Problemer med indeklimaet i boligen - fortsat

21.4 Har du prøvet at finde oplysninger om, hvordan man løser de indeklima-problemer, du står over for

- ☐ Nej
  - ☐ Jeg ved, hvad der skal gøres, og jeg har ikke brug for mere information
  - ☐ Jeg ved ikke, hvor jeg skal lede efter oplysninger
  - ☐ Problemet er ikke stor nok til at handle
  - ☐ Det er ikke mit ansvar
  - ☐ Andet__________
- ☐ Ja
  - ☐ Jeg spurgte mine venner
  - ☐ Jeg spurgte min familie
  - ☐ Jeg kontaktede nogle eksperter (ikke familie) / et selskab, der har speciali-seret sig i dette område
  - ☐ jeg søgte på internettet
  - ☐ Jeg spurgte min læge
  - ☐ Jeg kontaktede kommunen
  - ☐ Andet__________
- ☐ Ved ikke

21.5 Har du undgået at løse et indeklimaproblem, selvom du vidste, hvad du skal gøre:

- ☐ Ja
  - ▪ Hvorfor har du ikke løst problemet?
    - ☐ På grund af finansielle årsager
    - ☐ Løsningen på problemet ville være for tidskrævende / besværlig
    - ☐ Problemet var ikke stor nok til at gøre en forandring
    - ☐ Løsningen havde nogle ulemper, som stoppede mig fra at gen-nemføre den
    - ☐ Jeg kan gøre det alene eller med min ven eller familie, men har ik-ke tid til det
    - ☐ Jeg har ikke tilladelse til at løse problemet/det må jeg ikke
    - ☐ Det er ikke mit ansvar
    - ☐ Andet_________________
    - ☐ Ved ikke
- ☐ Nej
- ☐ Ved ikke

21.6 Tror du, at du har nok viden til at passe godt på din bolig og anvende installationerne korrekt (fyr / ventilationsanlæg/gulvvarme/radiatorer osv.) i hjemmet:

- ☐ Ja, jeg ved, hvordan man skal håndtere alle installationer
- ☐ Ja, jeg ved, hvordan man bruger nogle installationer i hjemmet
- ☐ Nej, men der er en anden derhjemme, der gør det
- ☐ Nej, jeg er helt afhængig af hjælp fra andre
- ☐ Ved ikke

22 Husstanden

32.1 Angiv venligst husstandens samlede årsindkomst før skat

- ☐ Under 200.000 kr.
- ☐ 200.000 - 299.999 kr.
- ☐ 300.000 - 399.999 kr.
- ☐ 400.000 - 499.999 kr.
- ☐ 500.000 - 599.999 kr.
- ☐ 600.000 kr. og derover

32.2 Angiv venligst din senest afsluttede uddannelse

- ☐ Grundskole
- ☐ Gymnasial uddannelse
- ☐ Håndværksmæssig uddannelse
- ☐ Kort videregående uddannelse
- ☐ Lang videregående uddannelse

32.3 Hvad er din beskæftigelse

- ☐ Ansat som ufaglært
- ☐ Ansat som specialarbejder eller lignende
- ☐ Ansat som faglært arbejder, håndværker, montør eller lignende
- ☐ Ansat som funktionær, tjenestemand eller lignende (f.eks. i kommunen eller som lærer)
- ☐ Ansat som overordnet funktionær, akademiker, konsulent eller lignende
- ☐ Selvstændig eller medarbejdende ægtefælle
- ☐ Modtager dagpenge, kontanthjælp eller lignende
- ☐ Pensionist eller efterlønsmodtager
- ☐ Under uddannelse og modtager SU
- ☐ Andet (skriv gerne hvad)___________________________

Appendix B

Core part of the CBE occupant satisfaction survey. Full survey can be found at http://www.cbe.berkeley.edu/research/survey.htm.

Background

How many years have you worked in this building?

- ○ Less than 1 year
- ○ 1-2 years
- ○ 3-5 years
- ○ More than 5 years

How long have you been working at your present workspace?

- ○ Less than 3 months
- ○ 4-6 months
- ○ 7-12 months
- ○ More than 1 year

In a typical week, how many hours do you spend in your workspace?

- ○ 10 or less
- ○ 11-30
- ○ More than 30

How would you describe the work you do?

- ○ Administrative support
- ○ Technical
- ○ Professional
- ○ Managerial/supervisory
- ○ Other

What is your age?

- ○ 30 or under
- ○ 31-50
- ○ Over 50

What is your gender?

- ○ Female
- ○ Male

Continue

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Personal Workspace Location

On which floor is your workspace located?

In which area of the building is your workspace located?

To which direction do the windows closest to your workspace face?

Are you near an exterior wall (within 15 feet)?

- Yes
- No

Are you near a window (within 15 feet)?

- Yes
- No

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Personal Workspace Description

Which of the following best describes your personal workspace?

- ◯ Enclosed office, private
- ◯ Enclosed office, shared with other people
- ◯ Cubicles with high partitions (about five or more feet high)
- ◯ Cubicles with low partitions (lower than five feet high)
- ◯ Workspace in open office with no partitions (just desks)
- ◯ Other:

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Office Layout

How satisfied are you with the amount of space available for individual work and storage?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the level of visual privacy?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with ease of interaction with co-workers?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the office layout enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Please describe any other issues related to the office layout that are important to you.

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Office Furnishings

How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with your ability to adjust your furniture to meet your needs?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the colors and textures of flooring, furniture and surface finishes?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Do your office furnishings enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

Please describe any other issues related to office furnishings that are important to you.

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Thermal Comfort

Which of the following do you personally adjust or control in your workspace? (check all that apply)

- ☐ Window blinds or shades
- ☐ Operable window
- ☐ Thermostat
- ☐ Portable heater
- ☐ Permanent heater
- ☐ Room air-conditioning unit
- ☐ Portable fan
- ☐ Ceiling fan
- ☐ Adjustable air vent in wall or ceiling
- ☐ Adjustable floor air vent (diffuser)
- ☐ Door to interior space
- ☐ Door to exterior space
- ☐ None of the above
- ☐ Other:

How satisfied are you with the temperature in your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does your thermal comfort in your workspace enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

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Air Quality

How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

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Lighting

Which of the following controls do you have over the lighting in your workspace? (check all that apply)

☐ Light switch
☐ Light dimmer
☐ Window blinds or shades
☐ Desk (task) light
☐ None of the above
☐ Other:

How satisfied are you with the amount of light in your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the lighting quality enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

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Acoustic Quality

How satisfied are you with the noise level in your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Overall, does the acoustic quality in your workspace enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

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Cleanliness and Maintenance

How satisfied are you with general cleanliness of the overall building?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with cleaning service provided for your workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

How satisfied are you with general maintenance of the building?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Does the cleanliness and maintenance of this building enhance or interfere with your ability to get your job done?

Enhances ○ ○ ○ ○ ○ ○ ○ Interferes

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General Comments

All things considered, how satisfied are you with your personal workspace?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Please estimate how your productivity is increased or decreased by the environmental conditions in this building (e.g. thermal, lighting, acoustics, cleanliness):

Increased ○ 20% ○ 10% ○ 5% ○ 0% ○ -5% ○ -10% ○ -20% Decreased

How satisfied are you with the building overall?

Very Satisfied ○ ○ ○ ○ ○ ○ ○ Very Dissatisfied

Any additional comments or recommendations about your personal workspace or building overall?

Thank you for participating in this Survey!

Exit

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The main objective of the Ph.D. study was to examine the occupants' perception of comfort in homes and offices. The results showed that comfort in indoor environments is influenced by indoor environmental parameters (thermal, visual and acoustic conditions and air quality) together with building factors (e.g. building type, having a control). The study also showed that in office buildings the most important parameter for overall satisfaction with personal workspace is satisfaction with amount of space for work and storage, followed by satisfaction with noise level and visual privacy. Furthermore, the study showed that in residential buildings many people ignored problems related to indoor environment, which may suggest that there is a need for increasing people's awareness regarding the consequences of poor indoor environment on their health and for improving people's knowledge on how to ensure a good indoor climate.

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