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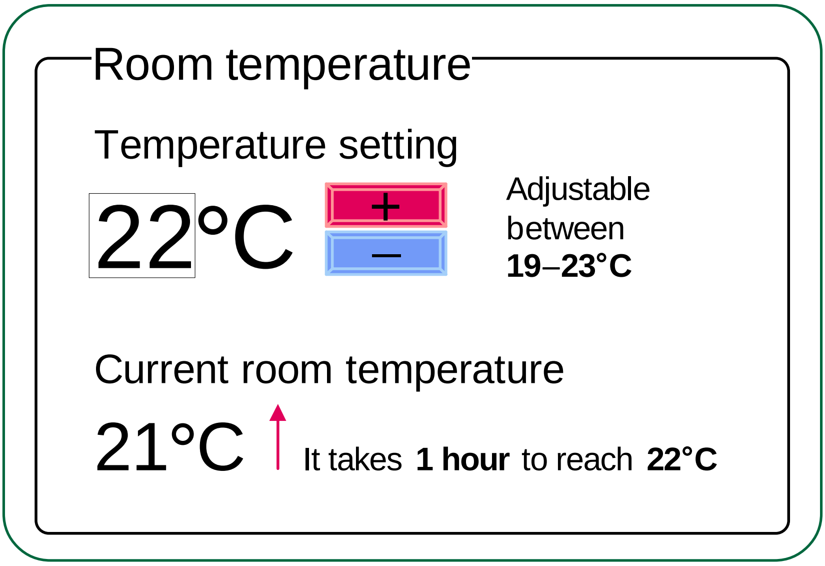

Sami Karjalainen

The characteristics of usable room temperature control

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Sami Karjalainen

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Keywords room temperature, thermal comfort, user interface, usability, usability guidelines

Abstract

Individual thermal control is important for handling individual differences in thermal preference. Several studies have shown that comfort, health and productivity in offices can be improved by individual thermal control. Local controls for temperature are commonly available in modern office buildings. However, office occupants are often still dissatisfied with thermal environments and control options.

The overall aim of the work is to improve office occupants' control over room temperature by improving the usability of interfaces of heating and cooling systems. Both qualitative and quantitative methods were employed to study office occupants as users of room temperature controls. The work started with qualitative interviews taken in actual context, in the offices of the participants. Twenty-seven office occupants were asked to show and tell us how they use the controls in offices. The problems with thermostats were found to be diverse and fundamental. Office occupants do not always even know they have a possibility to individually control the room temperature, because the device is not recognised at all, or the purpose of the device remains unclear. Although the room thermostats in offices are simple, symbols in the user interface are often not understood correctly, and it is not always known whether the temperature control is operating or not. In general, users are not satisfied with the feedback they get from the systems. The main reason for many of the problems is that the systems are planned and constructed without a realistic view of their users, i.e. users are supposed to have knowledge they do not have.

Next, in a quantitative interview survey, users were studied with a large and nationally representative sample: 1 000 Finnish office occupants answered questions concerning the office environment. Additionally, to simulate the real

use of thermostats, controlled experiments were taken. The quantitative interview survey and the controlled experiments revealed statistically significant differences between the genders: females tend to be more critical of their thermal environments and are more sensitive to both cold and hot room temperatures. It was also found in the quantitative interview survey that most of occupants have a false idea of the absolute Celsius values of comfortable room temperatures in the summer season, i.e. they think that in the summer season room temperatures should be lower than in the winter season.

Based on the results of the preceding user studies, user interface prototypes for room temperature control were next developed with a user-centred approach. Usability tests were conducted several times during the development process. The results show that novice users are able to use the user interface prototypes with high effectiveness, high efficiency and high satisfaction, and all the 42 participants in the usability tests would like to have that kind of user interface for their own use.

As the definitive result of the work, usability guidelines for room temperature controls were developed. The usability guidelines are based on the user research performed in this work and the experiences gained from the user interface development. The usability guidelines are: (1) keep occupants in the loop, (2) visibility, identification and reachability of temperature controls, (3) shared temperature controls with heating and cooling systems, (4) acceptable default settings, (5) simplicity of interface, (6) clear way to adjust room temperature, (7) advice on comfortable room temperatures, (8) clear and sufficient feedback after adjustment, (9) fast effect on room temperature, (10) adequate effect on room temperature, (11) informative help, (12) aesthetic design and (13) females as test users in real-life situations. The usability guidelines help designers to create user interfaces that enable office occupants to adjust the room temperature of their own office with high effectiveness, high efficiency and high satisfaction.

Karjalainen, Sami. The characteristics of usable room temperature control [Huonelämpötilan hallinnan käyttöliittymät. Käytettävyyden tarkasteluja toimistoympäristössä]. Espoo 2007. VTT Publications 662. 133 s. + liitt. 71 s.

Avainsanat room temperature, thermal comfort, user interface, usability, usability guidelines

Tiivistelmä

Koska lämpöolosuhteiden kokeminen on yksilöllistä, tarvitaan yksilöllisiä mahdollisuuksia hallita lämpöolosuhteita. Useat tutkimukset ovat osoittaneet, että yksilöllinen vaikutusmahdollisuus lämpöolosuhteisiin edistää viihtyvyyttä, terveyttä ja tuottavuutta toimistotyössä. Vaikka uudenaikaisissa toimistorakennuksissa on yleensä mahdollisuus vaikuttaa huonelämpötilaan paikallisesti, toimistotyöntekijät ovat yhä tyytymättömiä lämpöolosuhteisiin ja vaikutusmahdollisuuksiinsa.

Työn kokonaisvaltaisena tavoitteena on parantaa toimistotyöntekijöiden mahdollisuutta vaikuttaa huoneensa lämpötilaan parantamalla lämmitys- ja jäähdytysjärjestelmien käyttöliittymien käytettävyyttä. Työssä tutkittiin toimistotyöntekijöitä huonelämpötilan hallintalaitteiden käyttäjinä sekä laadullisilla että määrällisillä menetelmillä. Ensin tehtiin laadullisia haastatteluja oikeassa ympäristössä, toimistotyöntekijöiden työhuoneissa, jolloin 27 toimistotyöntekijää näytti ja kertoi, kuinka he käyttävät huoneolosuhteiden hallintalaitteita. Käyttäjillä havaittiin olevan monenlaisia ja perustavanlaatuisia ongelmia termostaattien kanssa. Toimistotyöntekijät eivät usein edes tiedä, että heillä on mahdollisuus vaikuttaa huoneensa lämpötilaan yksilöllisesti, koska termostaattia ei ole havaittu ollenkaan tai sen tarkoitusta ei ole ymmärretty. Vaikka huonetermostaatit ovat yksinkertaisia, käyttöliittymien symboliikkaa ei usein ymmärretä oikein, eikä aina edes tiedetä, onko termostaatti toiminnassa vai ei. Yleisesti ottaen käyttäjät ovat tyytymättömiä palautteeseen, jonka järjestelmät heille antavat. Pääsyy moniin ongelmiin on, että järjestelmät on suunniteltu ja rakennettu ilman todenmukaista kuvaa niiden käyttäjistä: toimistotyöntekijöillä oletetaan olevan tietämystä, jota heillä todellisuudessa ei ole.

Käyttäjiä tutkittiin seuraavassa vaiheessa määrällisellä haastattelututkimuksella, jonka otos oli laaja ja suomalaisia edustava. 1 000 suomalaista toimistotyöntekijää vastasi toimistoympäristöä koskeviin kysymyksiin. Lisäksi järjestettiin kontrolloituja kokeita termostaattien käytön simuloimiseksi. Määrällinen haastattelututkimus ja kontrolloidut kokeet paljastivat tilastollisesti merkitseviä sukupuolten välisiä eroja: naiset ovat kriittisempiä sisälämpötilaa kohtaan ja kärsivät miehiä useammin sekä kylmyydestä että kuumuudesta. Lisäksi määrällisellä haastattelututkimuksella havaittiin, että suurimmalla osalla ihmisistä on väärä käsitys mukavan huonelämpötilan kesäaikaisesta Celsius-arvosta. Yleisesti virheellisesti luullaan, että mukava huonelämpötila on kesällä matalampi kuin talvella.

Edeltävään käyttäjätutkimukseen pohjautuen ja käyttäjäkeskeistä lähestymistapaa soveltaen työssä kehitettiin käyttöliittymäprototyyppejä huonelämpötilan hallintaan. Käytettävyystestejä tehtiin useassa kehitysprosessin vaiheessa. Tulokset osoittavat, että ensimmäistä kertaa käyttävät kykenevät hyödyntämään prototyyppejä tuloksellisesti, tehokkaasti ja tyytyväisinä. Kaikki 42 testikäyttäjää haluaisivat tämänkaltaisen käyttöliittymän omaan käyttöönsä.

Työn lopullisena tuloksena luotiin käytettävyysohjeisto huonelämpötilan hallinnan käyttöliittymille. Käyttävyysohjeisto pohjautuu työssä tehtyyn käyttäjätutkimukseen ja käyttöliittymäkehitykseen. Käytettävyysohjeisto on seuraava: (1) anna mahdollisuus vaikuttaa huonelämpötilaan, (2) helposti tunnistettava laite näkyvässä ja helposti ulotuttavassa paikassa, (3) yhteinen käyttöliittymä lämmitys- ja jäähdytysjärjestelmän hallintaan, (4) hyväksyttävät oletusasetukset, (5) yksinkertainen käyttöliittymärakenne, (6) selkeä tapa muuttaa huonelämpötilan asetusta, (7) tieto miellyttävästä huonelämpötilan tasosta, (8) selkeä ja riittävä palaute käytön jälkeen, (9) nopea vaikutus huonelämpötilaan, (10) riittävä vaikutus huonelämpötilaan, (11) informatiivinen opastus, (12) esteettinen ulkoasu ja (13) naiset testikäyttäjinä todellisissa kohteissa. Käytettävyysohjeiston tarkoituksena on auttaa suunnittelijoita kehittämään käyttöliittymiä, joilla toimistotyöntekijät kykenevät hallitsemaan huoneensa lämpötilaa tuloksellisesti, tehokkaasti ja tyytyväisinä.

Preface

I had over ten years of experience as a researcher on HVAC (heating, ventilation and air conditioning) control systems before I started this work in 2003. Before 2003, with my colleagues, I created many control solutions and tested their performance with computer simulations. In these simulations users had a role: they were treated as indoor gain as they emit heat and humidity to the environment, i.e. occupants were seen as passive recipients of indoor environments, and the control systems were examined from a technology point of view only.

I got interested in issues of usability at the beginning of the decade. At first I did not realize there was any possibility to apply usability methodology to my work with HVAC systems. Gradually I realized the possibilities and started my post-graduate studies majoring in usability. Changing the point of view from the technology itself to users of technology led me to more important research questions than I had faced before. And I'm happy the research questions are not only of academic interest but also have practical importance. Now I am sure I have convinced many of my colleagues in the HVAC field and also some actors in the industry about the importance of usability research of building systems. But the work still continues…

I am very grateful to my supervisor Marko Nieminen, professor of usability and user interfaces in the Department of Computer Science and Engineering at TKK. Discussions with him were very helpful in every step of the work! I an indebted to the pre-examiners of this thesis, Professor Derek Clements-Croome, University of Reading, and Professor Minna Isomursu, University of Oulu, for their valuable comments.

Many people were involved in the work in one way or another. I thank Raino Vastamäki (earlier TKK and later Adage Corporation) whose ideas and comments were very valuable at the beginning of this work. I also thank my other co-authors Olavi Koistinen, Marjaana Siivola and Mikael Johnson, all from TKK, for their work. I thank Asko Piironen (VTT) and Seppo Vasarainen (VTT) for building the prototype of phase 5 and Ismo Heimonen (VTT) and Janne Peltonen (VTT) for co-operation in creating the specifications. I thank the colleagues who gave comments on my manuscripts: Ismo Heimonen, Mervi

Himanen (VTT), Satu Paiho (VTT), Professor Jouko Pakanen (TKK), Merja Penttinen (VTT) and Pekka Tuomaala (VTT). I also thank our partners in industry, Juhani Hyvärinen (Fläkt Woods), Pekka Saikkonen (ARE) and Tapani Salo (Halton), for their comments. I am thankful also to Veijo Lappalainen and Kalevi Piira, my colleagues at VTT, for their co-operation.

The work of the thesis has been performed at VTT in several research projects. The financial support of Tekes – Finnish Funding Agency for Technology and Innovation and VTT is gratefully acknowledged. At VTT, the projects concerning human interaction with HVAC systems have been supported by Ismo Heimonen, Professor Matti Kokkala, Markku Leivo, Jari Shemeikka and Markku J. Virtanen.

I received a personal grant from the Finnish Work Environment Fund (Työsuojelurahasto) and from the Foundation for Advancement of Technology (Tekniikan Edistämissäätiö, TES, K. ja A. Lipan erikoisrahasto) for finalising the thesis, which is gratefully acknowledged.

I could not have been able to perform this work without people participating in the interviews and usability tests. I thank them and I will participate in other researchers' studies as a volunteer.

Every time I had a really hard problem concerning this work, I asked comments from my wife, Satu. Yes, there really is a woman behind every man. Actually, in my case, there are two: Satu and our daughter Vilma.

Publications

Although the field of this thesis is usability and user interfaces, and although the methodology is largely adopted from that field, I have chosen to publish the results mainly in the field of building science. The reason for that is that the results offer more benefit to the readers in the field of building science.

The thesis consists of this overview and the following publications.

I Karjalainen, S. and Koistinen, O. 2007, User problems with individual temperature control in offices, *Building and Environment*, Vol. 42, No. 8, pp. 2880–2887. http://dx.doi.org/doi:10.1016/j.buildenv.2006.10.031

II Karjalainen, S. 2007, Why it is difficult to use a simple device: an analysis of a room thermostat, in *Human-Computer Interaction*, Part I, ed. J. Jacko, HCII 2007, LNCS 4550, Springer-Verlag Berlin, Heidelberg, pp. 544–548. (Proceedings of HCI International 2007, Peking, 22–27 July 2007.) http://dx.doi.org/10.1007/978-3-540-73105-4_60

III Karjalainen, S. 2007, Gender differences in thermal comfort and use of thermostats in everyday thermal environments, *Building and Environment*, Vol. 42, No. 4, pp. 1594–1603.
http://dx.doi.org/doi:10.1016/j.buildenv.2006.01.009

IV Karjalainen, S. and Vastamäki, R. 2007, Occupants have a false idea of comfortable summer season temperatures, in *Proceedings of Clima 2007 WellBeing Indoors*, 9th REHVA World Congress, eds. O. Seppänen and J. Säteri, Helsinki, 10–14 June 2007, abstract book p. 496, full paper on CD-ROM (A11B1073.pdf).

V Karjalainen, S., Siivola, M., Johnson, M. and Nieminen, M. 2007, *User requirements and user interface solutions for individual control of temperature in offices*, Software Business and Engineering Institute, Helsinki University of Technology, Preprints 14 (HUT-SoberIT-B14), Espoo, Finland, pp. 1–22.

Author’s contribution

I am the sole author of Publications II and III.

I am the principal author of Publications I, IV and V as well. I have prepared the research designs and written the manuscripts by myself, taking into account comments by the co-authors. The interviews and observation in Publication I were carried out together with the second author who also participated in the analysis of the data. I have designed all of the user interface prototypes in Publication V except the alternative solution in Figure 8, which is designed by the third author. The usability tests and interviews in Publication V were carried out and analysed in five phases by me and the other authors; the second author participated in the work in phase 2, the third author in phases 3 and 4, and the fourth author in phase 4.

Contents

Publications I–V of this publication are not included in the PDF version. Please order the printed version to get the complete publication (http://www.vtt.fi/publications/index.jsp).

Terms and definitions

ASHRAE: The American Society of Heating, Refrigerating and Air-Conditioning Engineers

Context of use: users, tasks, equipment, and the physical and social environments in which a product is used (ISO 9241-11 1998; ISO 13407 1999).

HVAC: heating, ventilation and air conditioning.

Prototype: representation of all or part of a product or system that, although limited in some way, can be used for evaluation (ISO 13407 1999).

Temperature controls: user-adjustable controls of heating and cooling systems, for example, room thermostats, thermostatic and non-thermostatic valves and software interfaces. In this work, other kind of temperature controls, such as operable windows and personal fans, are excluded.

Thermal comfort: that condition of mind which expresses satisfaction with the thermal environment (ISO 7730 2005).

Thermal environment: the characteristics of the environment that affect a person's heat loss (ASHRAE Standard 55 2004).

Thermal inertia: the ability of a material to conduct and store heat. In the context of room temperature control it refers to the delay in room temperature change: because of the building materials and the heating/ cooling system itself, the rate of room temperature change is slow.

Thermostat: a device that is a part of a control system. It senses room temperature and desires to maintain a set point temperature. The set point can be adjusted by an occupant.

Thermostatic valve: a kind of thermostat that is used in circulating water (fluid) systems and is installed in a radiator or convector (see examples in Fig. 1, p. 18).

Room thermostat: a kind of thermostat that is typically installed on a wall (see examples in Fig. 1, p. 18). It is connected to a heating and/or cooling system.

Ubiquitous computing: making many computers available throughout the physical environment, while making them effectively invisible to the user (Weiser 1993).

Usability: extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (ISO 9241-11 1998; ISO 13407 1999).

Effectiveness: accuracy and completeness with which users achieve specified goals (ISO 9241-11 1998; ISO 13407 1999).

Efficiency: resources expended in relation to the accuracy and completeness with which users achieve goals (ISO 9241-11 1998; ISO 13407 1999).

Satisfaction: freedom from discomfort, and positive attitudes to the use of the product (ISO 9241-11 1998; ISO 13407 1999).

Usability characteristics: essential elements of a system to ensure high usability.

Usability guidelines: rules and principles that give designers resources for developing interactive systems to ensure high usability.

Usable (*adjective*)**:** [a product or a system that] has high usability (see usability).

User: individual interacting with the system (ISO 9241-10 1996; ISO 13407 1999).

User-adaptive system: an interactive system that adapts its behaviour to individual users (Jameson 2003).

User-centred design: the attitudes and approaches used for developing usable systems (Karat 1997). User-centred design is characterised by the following: a) the active involvement of users and a clear understanding of user and task requirements, b) an appropriate allocation of function between users and technology, c) the iteration of design solutions, and d) multi-disciplinary design (ISO 13407 1999).

User requirement: any function, constraint, or other property that is required in order to satisfy user needs (Kujala 2002).

1. Introduction to thermal comfort and individual temperature control

1.1 Need for individual temperature control

According to the seminal work by Fanger (1970), there are individual differences in experiencing thermal environments, and no thermal environment can satisfy everybody. The need for individual control of thermal environments is now widely recognised. It is agreed that individual control of local thermal environments is needed from the standpoint of comfort and satisfaction (Fountain et al. 1996).

In addition to comfort, productivity and health reasons also support individual thermal control. The relationship with room temperature and productivity in office work is well documented (Seppänen et al. 2006), and individual control of room temperature is seen one of the central issues in improving working conditions and productivity (Raw et al. 1990; Lorsch and Abdou 1994; Wyon 1996; Wyon 2000; Leaman and Bordass 2000; Clements-Croome 2000). It has also been found that individual control of room temperature in office buildings reduces sick building syndrome (SBS) symptoms (Jaakkola et al. 1989) and sick leave days (Preller et al. 1990).

Humphreys and Nicol (1998) note that exactly the same room temperature may be acceptable or unacceptable, depending on whether it is chosen or imposed. People are more tolerant if they have control over their thermal environment (Leaman and Bordass 2000; Humphreys and Nicol 1998; Brager et al. 2004). According to Leaman and Bordass (2001), most people are satisfiers not optimisers: people want conditions that are “good enough”, and tolerate offsets if they have opportunities to make interventions. Nicol and Humphreys (2002) state that discomfort increases if control is not provided, or if the controls are ineffective, inappropriate or unusable.

Wyon (1996) studied the necessary range of individual control and estimated that 99% would be thermally comfortable if the room temperature could be adjusted over a range of 6 ºC (±3 ºC). Individual control equivalent to 4 ºC (±2 ºC) satisfies more than 90%. The necessary control range should be increased if a dress code makes it more difficult to adjust clothing insulation. Palonen et al. (1993) suggest individual temperature control with temperature range of 22 ±2 °C.

1.2 User interfaces for individual control of temperature in offices

Lessons have been learned from studies that prove the benefits of individual temperature control: nowadays occupants typically have local temperature controls in modern offices. There are two main kinds of temperature controls commonly available in Finnish offices: thermostatic valves and room thermostats (Fig. 1).

Fig. 1. Examples of typical thermostats in Finnish offices. First row: thermostatic valves. Second row: room thermostats.

Both kinds of thermostats sense room temperature and desire to maintain a set point temperature. If the system is working fine, room temperatures should satisfy a large part of the occupants without adjusting the thermostats. The thermostats give occupants a possibility to alter room temperature by adjusting the set point over a range of 4 ºC (±2 ºC), at best. The range depends on the properties of the building and its systems, and is often smaller than 4 ºC.

There are many different kinds of room thermostats available, some of them are very complex, but the ones typically found in rooms of office occupants are quite simple. Room thermostats are typically installed on walls. Thermostatic valves are part of a heating system, but room thermostats can be connected to a heating or cooling system (or can be shared).

Graphical interfaces for room temperature control (and for other environmental control) in offices have been introduced by several companies, but they are still very rare in real use.

1.3 Use of temperature controls

Information on how temperature controls (thermostats, etc.) are used is valuable for the developers of such systems (see principles of user-centred design, Section 2.1). A wide range of thermal comfort studies has been performed but surprisingly little is known on how temperature controls are used. It is well known that thermal environments are still often unsatisfactory, and several studies (Bordass et al. 1993; What Office Tenants Want 1999; Lehto and Karjalainen 1996) have shown that the perceived level of control is low. It would be valuable to know how occupants act in thermal discomfort and how often they use temperature controls and what kind of problems they have with them.

It is easy to suppose that giving people local temperature controls will improve thermal comfort. However, a survey of nine office buildings (Lehto and Karjalainen 1996) showed that thermal comfort was no better in the buildings equipped with room thermostats than in the buildings with more limited possibilities for temperature control. The individual temperature control seemed not to fulfil the expectations. The reasons why the individual temperature control did not succeed remained unclear, although it was noted that room thermostats were often installed so high up on the wall that they could not be reached easily.

An analysis of programmable home heating controls by Dale and Crawshaw (1983) revealed a need for considerable improvement. The problems found with the heating controls included hard-to-understand abbreviations and manners of time representation, illogical positioning of interface elements and markings that were too small.

The available information on use and user problems with temperature controls is scattered and mostly concerns residential buildings. In addition, the papers published in a special issue of Energy and Buildings in 1992 (Vol. 18, No. 3–4) devoted to the interplay of air-conditioning, culture and comfort concern mostly homes, see the next paragraph.

The use of residential room air conditioners was studied in the United States (Kempton et al. 1992; Lutzenhiser 1992) and in Japan (Fujii and Lutzenhiser 1992). There are remarkable similarities with the results but also cultural differences. In Japan the goal is to cool people rather than living spaces (Fujii and Lutzenhiser 1992), but in the United States (and in Finland) the target is to cool (and heat) rooms. It was found that in most households room air conditioners are used manually, switching the units on and off, instead of relying on thermostats (Kempton et al. 1992; Lutzenhiser 1992; Fujii and Lutzenhiser 1992). It is typical that room air conditioners are used with maximum power: "I always turn it on super" (Kempton et al. 1992). Several usability problems of thermostats were recognised in these studies. In one case the interface was so obscure that the control options were not understandable by most of the users (Fujii and Lutzenhiser 1992). Many air-conditioning users were not aware their units had thermostats (Kempton et al. 1992). Problems with the terminology of thermostats were also recognised (Lutzenhiser 1992).

Kempton (1987) analysed folk theories for home heating control and found two common theories of how a thermostat works: a feedback theory and a valve theory. In the feedback theory a thermostat senses room temperature, but this approach is not understood in the valve theory, in which a thermostat dial is like a gas pedal and controls the amount of heat. The misconceptions affect the use of thermostats. In the study on use of room air conditioners, Kempton et al. (1992) found that the operation of them was governed by multiple overlapping systems of belief and preferences concerning health, thermal comfort, folk theories about how air conditioners function, etc., in addition to economic factors.

Woods (2006) observed thermostat set point changes in 96 Californian households. He found that set point behaviour is complicated and people change cooling and heating set points frequently, which has significant energy implications.

Heerwagen and Diamond (1992) studied in seven offices how people cope with discomforts: how do they make themselves warmer or cooler? The highest percentage of occupants responded to thermal discomfort by adjusting their behaviour (e.g. adding or taking off clothing, drinking). Changes in environment, such as adjusting thermostats, were less frequent.

Vastamäki et al. (2005) give three reasons for why it is difficult to adjust room temperature: temperature controls are difficult to understand correctly, the natural feedback (actual change in temperature) is delayed (because of thermal inertia, see Section 1.5), and people have incorrect mental models about good indoor temperatures. A behavioural model of temperature control use and energy saving (Fig. 2) explains that a user's action "can be extinguished" at various points of the circle.

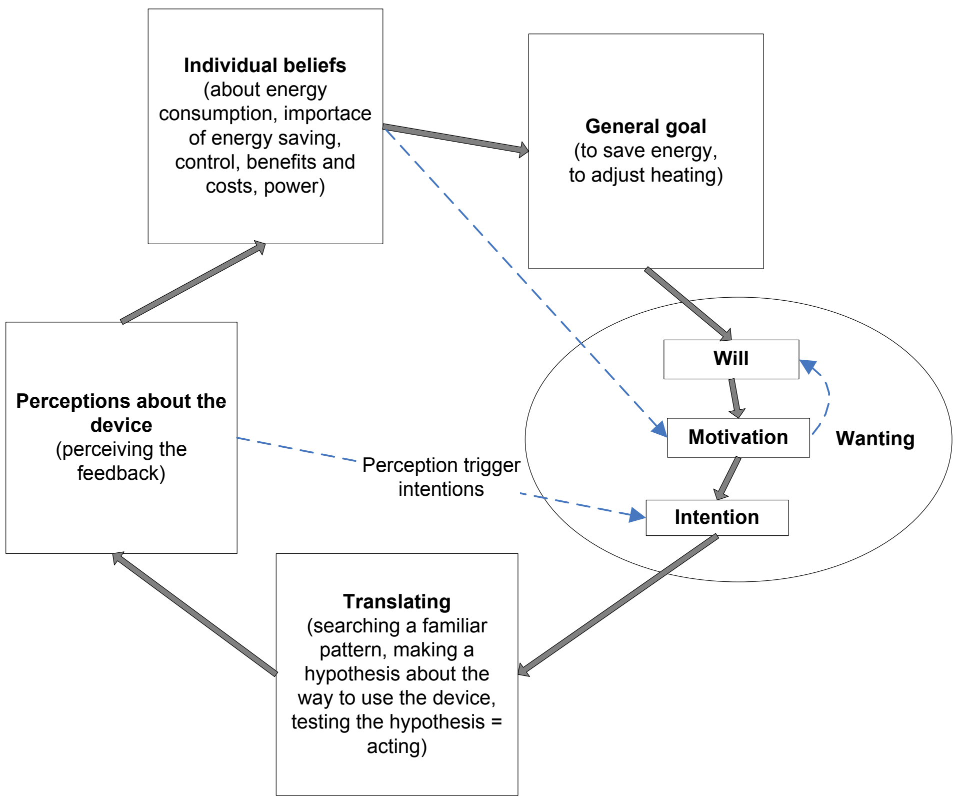

Fig. 2. A behavioural model of temperature control use and energy saving, simplified from Vastamäki et al. (2005).

1.4 Thermal comfort models

Thermal comfort models explain human responses to thermal environments. Next, two main kinds of thermal comfort models are briefly presented.

1.4.1 Heat balance models of thermal comfort

Heat balance models of thermal comfort models explain the response of people to the thermal environment in terms of physics and physiology of heat transfer (Nicol and Humphreys 2002). These models rely on the idea that the sensation of warmth or coolness is an indication of an imbalance between heat generated by the body and heat loss to the environment (Baker 1996).

The heat balance model by Fanger (1970) is the most commonly used of all thermal comfort models, and it is the basis of thermal comfort standards (ISO 7730 2005; ASHRAE Standard 55 2004). Fanger explains that thermal comfort is dependent on air temperature, mean radiant temperature, air humidity, relative air velocity, activity level and clothing insulation (Fig. 3). Predicted mean vote (PMV) and predicted percentage of dissatisfied people (PPD) indexes are calculated from these values. The model is based on extensive laboratory experiments in climate chambers. The PMV model by Fanger (1970) is presented as universally applicable: it is applied to all populations, to both genders, to all climatic zones, and to all building types[1].

[1] Fanger and Toftum (2002) have introduced an extension of the PMV model to non-air-conditioned buildings in warm climates.

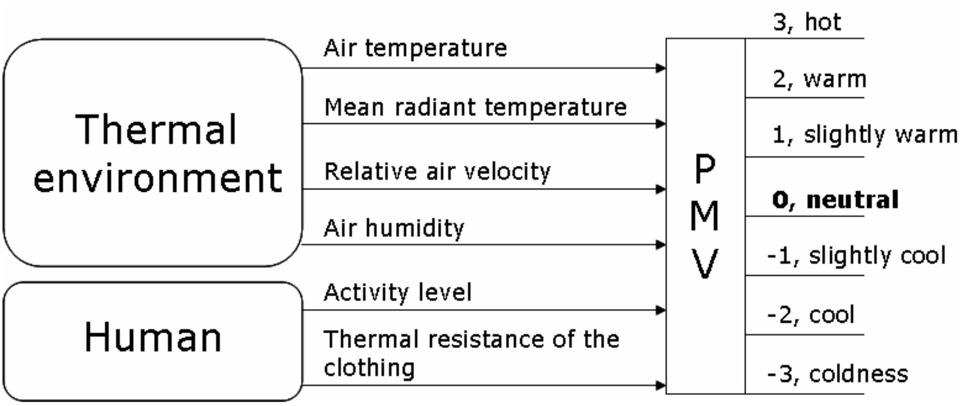

Fig. 3. Simplified illustration of the factors influencing thermal comfort according to the model by Fanger (1970). PMV = Predicted Mean Vote.

1.4.2 Adaptive approach to thermal comfort

The concept of adaptive approach to thermal comfort emerged from findings of surveys of thermal comfort conducted in the field. It was found that the heat balance models of thermal comfort fail to accurately predict thermal comfort in “real world” settings, i.e. in real buildings out of climate chambers (Brager and de Dear 1998; Nicol and Humphreys 2002).

While the heat balance models of thermal comfort view occupants as passive recipients of thermal environments and ignore cultural, climatic, social and contextual dimensions, the adaptive approach to thermal comfort pays attention to the interaction between people and their thermal environment (de Dear and Brager 2001). The occupants are not anymore seen as passive recipients of thermal environments. The adaptive approach is expressed by the adaptive principle: “if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” (Nicol and Humphreys 2002). Thermal comfort is restored by the occupants adapting to the building and by the occupants adapting the building to suit them.

There are many contextual factors influencing thermal comfort including the past thermal history and thermal expectations (Brager and de Dear 1998). There is no model available for handling all these factors. An adaptive model of thermal comfort (de Dear and Brager 2001) explains a correlation between comfortable indoor temperatures and mean outdoor temperatures. A new revision to ASHRAE Standard 55 (2004) and a new European standard EN 15251 (2007) include an adaptive thermal comfort criterion similar to de Dear and Brager (2001).

1.5 Thermal inertia

Thermal inertia refers to the delay in the room temperature change. It is not possible to switch from one thermal environment to another instantly as it is possible, for example, for lighting conditions. Because of the building materials and the heating/cooling system itself, the rate of room temperature change is slow. It may take even hours to reach a new temperature level in the heavy-weight buildings typical in Finland.

1.6 Summary

Because of individual differences in experiencing thermal environments, no thermal environment can satisfy everybody. In addition to thermal comfort, productivity and health reasons also support individual thermal control.

Nowadays the need for individual control of thermal environments is widely recognised and occupants typically have local temperature controls in modern offices. Thermal environments are still often unsatisfactory and the perceived control over room temperature is remarkably low – the individual temperature control seems not to fulfil the expectations. The reasons for that are unclear, although some usability problems with thermostats have been pointed out. There is a need for user studies, because surprisingly little is known on how temperature controls are used in real environments. Knowledge of usability approaches, for example, user-centred methods, is low in the field of building science and among practitioners in that field.

2. Introduction to user-centred design and usability

In this chapter, a short overview of user-centred design is presented and a definition of usability is provided. Additionally, several usability guidelines from various sources are presented with an overview of them. The chapter has two main purposes. It gives background information that is important especially for the readers from the field of building science. Secondly, the usability guidelines presented in the chapter will be cited later in the work, from Chapter 7.

2.1 User-centred design approach

The goal of user-centred design is to develop products that are of high value to users and highly usable. Making systems more usable contributes meeting user and organisational needs better. The benefits can be that the products or systems (ISO 13407 1999) are easier to understand and use, thus reducing training and support costs; improve user satisfaction and reduce discomfort and stress; improve the productivity of users and operational efficiency of organizations; and improve product quality, appeal to the users and can provide a competitive advantage.

There are several different processes available for user-centred design (Kujala 2002). No matter which design process is used, the incorporation of a user-centred approach is characterised by the following: the active involvement of users and a clear understanding of user and task requirements, an appropriate allocation of function between users and technology, the iteration of design solutions, and multi-disciplinary design (ISO 13407 1999). The Logical User-Centred Interactive Design Methodology (LUCID) (Kreitzberg 1996) is a framework that gives the background and tools needed to manage user-centred processes. LUCID identifies six stages: (1) envision (shared product vision), (2) discovery (user studies), (3) design foundation (conceptual design and its usability testing), (4) design detail, (5) build and (6) release.

There is a wide range of user-centred methods available in literature: different methods for different phases of product development, methods with and without user involvement, methods that require few resources, and methods that require many resources (Table 1). The methods used in this work are described in Chapter 4.

Table 1. Examples of user-centred methods (Gould et al. 1997; Shneiderman and Plaisant 2005; Courage and Baxter 2005).

Methods for focusing on users	Talking with users Visiting customer locations Videotaping users Learning about the work organization Trying it yourself Ethnographic observation Contextual inquiry Card sorting Focus groups Participatory design Use task analysis Use surveys and questionnaire Scenario development
Methods for usability testing	Early user manuals Mock-ups Simulations Early prototyping Early demonstrations Thinking aloud Hallway and storefront methodology (collecting user responses in public areas) Computer bulletin boards, forums, networks, and conferencing Formal prototype tests Field studies Follow-up studies Expert reviews
Methods for carrying out iterative design	Collect the requirements improvements during usability testing Organize the development work in a way that improvements can be made Have tools that allow you to make the needed improvements

2.2 Definition of usability

Several dimensions of usability can be identified. According to Keinonen (1998), usability can be seen as a design approach (usability engineering, user-centred design), as a product attribute (principles in usability guidelines), or as a measurement (Are the specified goals met? For example, Shackel 1986, Nielsen 1993 and ISO 9241-11 1998). Keinonen notes that in all of the dimensions, however, “usability deals with subjects trying to commit actions using artifacts”.

Bevan and Macleod (1994) state that “measures of overall usability can only be obtained by assessing the effectiveness, efficiency and satisfaction with which representative users carry out representative tasks in representative environments”. The relative importance of these three measures depends on the context of use and the objectives of the parties involved. Satisfaction may be a more important of criteria than effectiveness and efficiency when use is voluntary (Bevan and Macleod 1994), which is the case with room temperature controls.

Also Shackel (1986) and Nielsen (1993) include subjective satisfaction in their usability criteria: the tasks must be accomplished “so that satisfaction causes continued and enhanced usage of the system” (Shackel 1986); “the system should be pleasant to use, so that users are subjectively satisfied when using it; they like it” (Nielsen 1993).

In ISO 9241-11 (1998), usability refers to the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use (Fig.4).

- Effectiveness: the accuracy and completeness with which users achieve specified goals.
- Efficiency: the resources expended in relation to the accuracy and completeness with which users achieve goals.
- Satisfaction: freedom from discomfort, and positive attitudes to the use of the product.

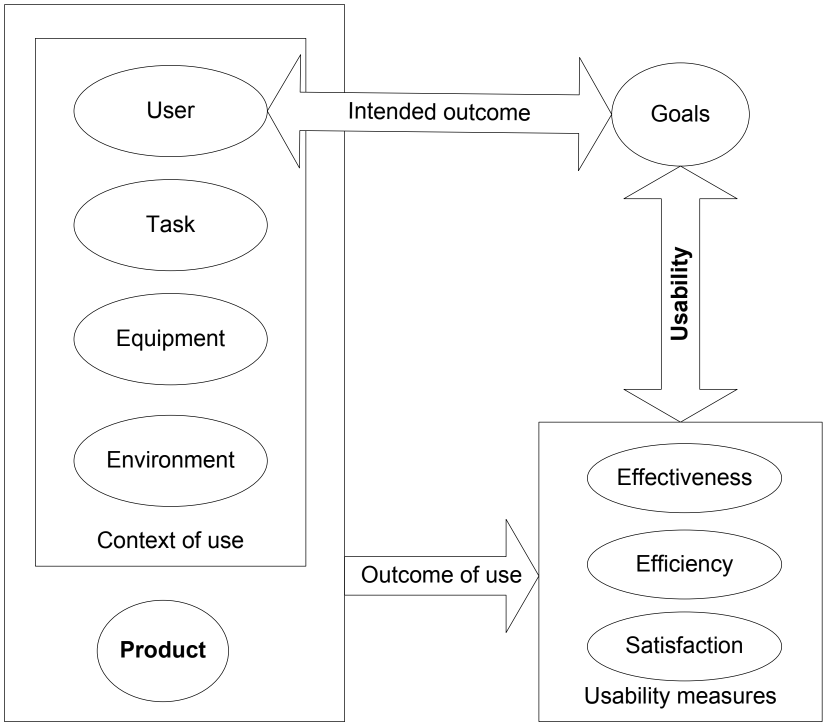

Fig. 4. Usability framework according to ISO 9241-11 (1998).

2.3 Usability guidelines

A common definition for the word guideline is "a rule or principle that provides guidance to appropriate behaviour". Usability guidelines are sets of rules and principles that give designers resources for developing interactive systems to ensure high usability. The most commonly used usability guidelines represent the relevant information in a short form, so that they can be easily used by designers as well as by non-experts of usability.

The usability guidelines presented here are mostly from the field of computer science, not from ergonomics science. Ergonomics guidelines give guidance on general office ergonomics, for example, computer workstation checklists. These guidelines may also give suggestions for room temperature levels, but are not useful in improving the usability of temperature controls.

Thermal comfort standards (ISO 7730 2005; ASHRAE Standard 55 2004) and guidelines (for example, FiSIAQ 2001) give guidance on room temperature levels and emphasize the importance of individual temperature control. They, however, do not give advice for designing interfaces for room temperature controls to ensure high usability.

In computer science, there are many usability guidelines (for example, Polson and Lewis 1990; Shneiderman and Plaisant 2005; Nielsen 2006; ISO 9241-10 1996). They are useful also in developing interactive systems for buildings, but, of course, they do not take into account the special characteristics of the systems in buildings and other issues specific to building environments. For example, the special qualities of room temperature control such as the thermal inertia (Section 1.5) and the characteristics of human thermal comfort (Section 1.4) are not taken into account.

Literature searches of scientific publications in the fields of HVAC and computer science (user interfaces, usability) were performed, but no specific usability guidelines for room temperature controls were found.

Usability guidelines from various sources are shown below. Most of the usability guidelines are primarily targeted for designers of software. The set of guidelines by Leaman and Bordass (Section 2.3.6) is the only one targeted for designers of interactive systems in buildings. None of the usability guidelines are specific for room temperature controls.

2.3.1 Norman: "Seven principles for transforming difficult tasks into simple ones"

In his book "The Design of Everyday Things", Norman (1988) advises designers to make sure that (1) the user can figure out what to do and (2) the user can tell what is going on. He states that design should:

- Make it easy to determine what actions are possible at any moment (make use of constraints).
- Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions.

- Make it easy to evaluate the current state of the system.
- Follow natural mappings between intentions and the required actions; between actions and the resulting effect; and between the information that is visible and the interpretation of the system state.

In the same book, Norman presents "Seven principles for transforming difficult tasks into simple ones". They are the following:

1. **Use both knowledge in the world and knowledge in the head.** The user acquires all knowledge of the system from the system image. The designer should develop a conceptual model that is appropriate for the user, that captures the important parts of the device, and that is understandable by the user.
2. **Simplify the structure of tasks.** Tasks should be simple in structure, minimising the amount of problem solving they require.
3. **Make mapping visible: bridge the gulfs of execution and evaluation.** Make things visible on the execution side of an action so that people know what is possible and how actions should be done. Make things visible on the evaluation side so that people can tell the effects of their actions. The system should provide actions that match intentions and make the outcomes of an action obvious.
4. **Get the mappings right.** Exploit natural mappings: between intentions and possible actions, between actions and their effects on the system, between actual system state and what is perceivable, between the perceived system state and the needs, intentions, and expectations of the user. The easiest way to make things understandable is to use graphics or pictures.
5. **Exploit the power of constraints, both natural and artificial.** Use constraints so the user feels there is only one possible thing to do – the right thing.
6. **Design for error.** Assume that any error that can be made will be made. Make it easy to reverse actions. Make it hard to perform irreversible actions.

7. **When all fails, standardise.** Standardised actions, outcomes, layout and displays only have to be learned once. Standardisation is essential only when all the necessary information cannot be placed in the world or when natural mappings cannot be exploited. When we have standardisation of our keyboard layouts, our operating systems, our text editors and word processors, and the basic means of operating any program, then suddenly we will see a major breakthrough in usability

2.3.2 Polson and Lewis: "Design for successful guessing"

Polson and Lewis (1990) addressed a problem of how to make walk-up-and-use applications. These kinds of applications require users be able to use them effectively with little or no training. Polson and Lewis provided a theoretical foundation for the design of such systems and created design guidelines. The guidelines, "Design for successful guessing", are the following:

1. **Make the repertoire of available actions salient.** For example, all menu choices should be visible.
2. **Use identity cues between actions and user goals as much as possible.** For example, if a chart utility requires users to select colours by numbers, not by name or choosing among colour patches, users will have problems.
3. **Use identity cues between system responses and user goals as much as possible.** Users must be able to gauge whether an action moved toward a goal or not.
4. **Provide an obvious way to undo actions.** If an action is seen to be a mistake, users must have a way to undo the action.
5. **Make available actions easy to discriminate.** For example, if there are many ways to delete that differ in the size of the unit deleted (e.g. character, worksheet, document), it will be difficult to determine which action best approached the goal.
6. **Offer few alternatives.** The chance of guessing the correct alternative goes down with the number of possibilities.

7. **Tolerate at most one hard-to-understand action in a repertoire.** Having no hard-to-understand choices is best, but if designers are not able to ensure this, the probability of error will be lower, if there is no more than one choice whose consequences cannot be protected.
8. **Require as few choices as possible.** A longer series of choices has less chance of being completed successfully.

2.3.3 Shneiderman and Plaisant: "Eight golden rules of interface design"

In the fourth edition of the book "Designing the User Interface", Shneiderman and Plaisant (2005) present "Eight golden rules of interface design":

1. **Strive for consistency.** Consistent sequences of actions should be required in similar situations. Also terminology, colour, capitalisation, fonts, and so on should consistent throughout.
2. **Cater for universal usability.** The needs of diverse users (novice vs. experts, age ranges, disabilities) should be recognised. For example, novices may need explanations while experts may need shortcuts.
3. **Offer informative feedback.** There should be system feedback for every user action. The response should be more substantial for infrequent and major actions than for frequent and minor actions.
4. **Design dialogue to yield closure.** Sequences of action should be organized into groups with a beginning, middle, and end.
5. **Prevent errors.** Users should not be able to make serious errors. In case of an error, the interface should detect the error and offer simple instructions for recovery.
6. **Permit easy reversal of actions.** Actions should be reversible. This relieves anxiety, since users know that errors can be undone.
7. **Support internal locus of control.** Make users the initiators of actions rather than the responders to actions.

8. **Reduce short-term memory load.** The limitation of human information processing in short-term memory requires that displays be kept simple, multiple page displays be consolidated, window-motion frequency be reduced, and sufficient training time be allotted for codes, mnemonics, and sequences of actions.

2.3.4 Nielsen: "Ten usability heuristics"

The usability guidelines by Nielsen are commonly used. He calls them "heuristics", because they are "more in the nature of rules of thumb than specific usability guidelines" (Nielsen 2006). The heuristics are used in heuristic evaluation but are useful also in design of interactive systems. The heuristics were originally published in 1990 (Molich and Nielsen 1990) and were later updated (Nielsen 2006). The revised version, "Ten usability heuristics", consists of the following:

1. **Visibility of system status.** Appropriate feedback should always keep users informed about what is going on.
2. **Match between system and the real world.** The system should speak the users' language rather than system-oriented terms and make information appear in a natural and logical order.
3. **User control and freedom.** Users need a clearly marked "emergency exit" to leave the unwanted state. Undo and redo should be supported.
4. **Consistency and standards.** Users should not have to wonder whether different words, situations, or actions mean the same thing. Platform conventions should be followed.
5. **Error prevention.** Even better than good error messages is a careful design which prevents a problem from occurring in the first place.
6. **Recognition rather than recall.** Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another.
7. **Flexibility and efficiency of use.** Systems should cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

8. **Aesthetic and minimalist design.** Dialogues should not contain information which is irrelevant or rarely needed.
9. **Help users recognize, diagnose, and recover from errors.** Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
10. **Help and documentation.** Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

2.3.5 ISO 9241-10: "Dialogue principles"

International standard ISO 9241-10 (1996) identifies seven principles to be important for the design of a visual display terminal dialogue[2].

The dialogue principles are:

1. **Suitability for the task.** A dialogue is suitable for a task when it supports the user in the effective and efficient completion of the task.
2. **Self-descriptiveness.** A dialogue is self-descriptive when each dialogue step is immediately comprehensible through feedback from the system or is explained to the user on request.
3. **Controllability.** A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until a point at which the goal has been met.
4. **Conformity with user expectations.** A dialogue conforms with user expectations when it is consistent and corresponds to the user characteristics, such as task knowledge, education and experience, and to commonly accepted conventions.

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[2] The term "dialogue" is defined as "interaction between a user and a system to achieve a goal" (ISO 9241-10: 1996).

5. **Error tolerance.** A dialogue is error-tolerant if, despite evident errors in input, the intended result may be achieved with either minimal or no corrective action by the user.
6. **Suitability for individualization.** A dialogue is capable of individualization when the software can be modified to suit the task needs, individual preferences and skills of the user.
7. **Suitability for learning.** A dialogue is suitable for learning when it supports and guides the user in learning to use the system.

2.3.6 Leaman and Bordass: "Three conditions for usability in buildings"

Occupant surveys examine how people perceive their indoor environment, and, for example, how people react to changes in their indoor environment. Based on findings from numerous occupant studies Leaman and Bordass (2001) state that usability is usually recognizable when all of the three following conditions are present:

1. **Predictable and reasonably acceptable 'default' states.**
2. **Opportunities to make interventions or corrections if requirements or conditions alter.**
3. **Ability to act quickly and to know immediately that an appropriate response has occurred.**

2.3.7 Overview

The usability guidelines presented above have major similarities with each other in accuracy level and content. The most commonly mentioned usability principles are appropriate presentation, consistency, user control and freedom, informative feedback, error prevention and recovery and memory load reduction (Table 2).

Table 2. Agreement between the usability guidelines on the principles, partly after Keinonen (1998).

	Norman (2.3.1)	**Polson and Lewis (2.3.2)**	**Shneiderman and Plaisant (2.3.3)**	**Nielsen (2.3.4)**	**ISO 9241-10 (2.3.5)**	**Leaman and Bordass (2.3.6)**
Appropriate presentation	X	X	X	X	X	
Consistency	X		X	X	X	
User control and freedom			X	X	X	X
Informative feedback	X	X	X	X		X
Error prevention and/or recovery	X	X	X	X	X	
Memory load reduction	X	X	X	X		
Suitability for individualization			X	X	X	
Help				X		
Aesthetics				X		

As distinct from the usability guidelines above, Smith and Mosier (1986) have created a very substantial collection of guidelines for designing user interface software. It gives very detailed guidance on six functional areas: data entry, data display, sequence control, user guidance, data transmission, and data protection. For practical purposes, guidelines presented in a short form are much more commonly used.

The usability guidelines are derived from empirical studies or practical experience. For example, the heuristics by Molich and Nielsen (1990) are based an analysis of a user interface and usability problems found. In creating the heuristics, the usability problems were classified and the principles by which the problems can be avoided were written.

It is clear that the origin of the guidelines, i.e. the work they are derived from, affects the quality of guidelines. Scapin et al. (2000) present some shortcomings of usability guidelines: (1) the confidence in applying guidelines depends on the source of the guidelines, (2) the more general guidelines are, the more their applicability domain is wide and the more their interpretation becomes abstract, and (3) specific vocabularies (for example, from cognitive modelling) may prevent designers from easily understanding and applying the guidelines correctly.

Domain-specific usability guidelines have some key advantages compared to general usability guidelines. First, domain-specific usability guidelines have a potential to address the most important issues affecting usability in the specific domain. Secondly, domain-specific guidelines have an audience that is smaller and may have a commonly shared and understood vocabulary. Thirdly, the use of usability guidelines in the design of interactive systems requires more or less interpretation, but the interpretation of domain-specific guidelines can be easier because there is no need to write guidelines in an abstract mode of presentation.

2.4 Usability of smart building environments

Not much research other than works by Leaman and Bordass (see Section 2.3.6 and Section 1.1)[3] has been conducted on building controls usability until recently. In the last five or ten years, however, an increasing amount of work has been performed under the concept of ubiquitous computing (originally by Weiser 1991) or the closely related concept of ambient intelligence. In addition, an increasing amount of work has lately been devoted to user needs or usability of smart homes (also known as intelligent or digital homes). In one of the first academic studies focusing on smart home users, Gann et al. (1999) identified two key areas for smart home applications: internal environmental control (permitting users to adjust the system to meet their own requirements, for example, regarding room temperature), and security and emergency aid. Recently published work on user needs or the usability of smart home environments includes Baillie and Schatz (2006), Harper (2003), Koskela and Väänänen-Vainio-Mattila (2004) and Leppänen (2004). For example, Koskela and Väänänen-Vainio-Mattila (2004) compared three alternative smart home user interfaces (PC, media terminal and mobile phone) in an ethnographic study.

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[3] In a very recently published paper Bordass et al. (2007) give examples of bad and good designs of user controls and provide guidance for good design and implementation of user controls. The guidance focuses on HVAC systems and lighting.

The scenarios of intelligent buildings and ubiquitous computing often present a scenario of a room that adjusts the room temperature according to individual preferences when a person enters a room (see, for example, Schmidt and Beigl (1998), Ito et al. (2003) and Mozer et al. (1995)). Challenges in human-technology interaction in such a system are discussed in Section 8.4.3.

2.5 Summary

The goal of user-centred design is to develop products that are of high value to users and highly usable, i.e. have high usability. In ISO 9241-11 (1998), usability refers to the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

Usability guidelines give designers resources for developing interactive systems to ensure high usability. The most commonly mentioned usability principles are appropriate presentation, consistency, user control and freedom, informative feedback, and error prevention and recovery. Domain-specific usability guidelines have advantages compared to general usability guidelines. However, no specific usability guidelines are available for room temperature controls in the scientific literature.

If usability guidelines are written in a short form in an understandable way, they can work as a very effective tool in delivering usability knowledge, also to new application areas. Designers not familiar with usability approaches and methods can profit from well-formulated usability guidelines.

3. Research setting and focus

The overall aim of the work is to improve office occupants' control over room temperature. The aim is targeted at improving the usability of interfaces of heating and cooling systems. The goal is to find out what kind of interfaces users are able to use with high effectiveness, high efficiency and high satisfaction.

A wide range of studies on thermal comfort and temperature control algorithms have been performed. However, only a small amount of scientific work has been done on user interfaces of user-adjustable temperature controls, and surprisingly little is known about how temperature controls are used in real environments. No specific usability guidelines for room temperature controls are available.

3.1 Research approach

The research approach of this dissertation involves several different methods by which it is targeted to find the usability characteristics, i.e. the essential elements of usable room temperature control.

The work was started with user research. Both qualitative and quantitative methods were used to study users and especially how the current systems are used. The principles of user-centred design (ISO 13407 1999) were adopted in the second stage when user interface prototypes were created and evaluated. The usability guidelines for room temperature controls were developed in the third stage based on what was learned in the first two stages. Fig. 5 shows the three stages in more detail. The research methods and materials are described in Chapter 4.

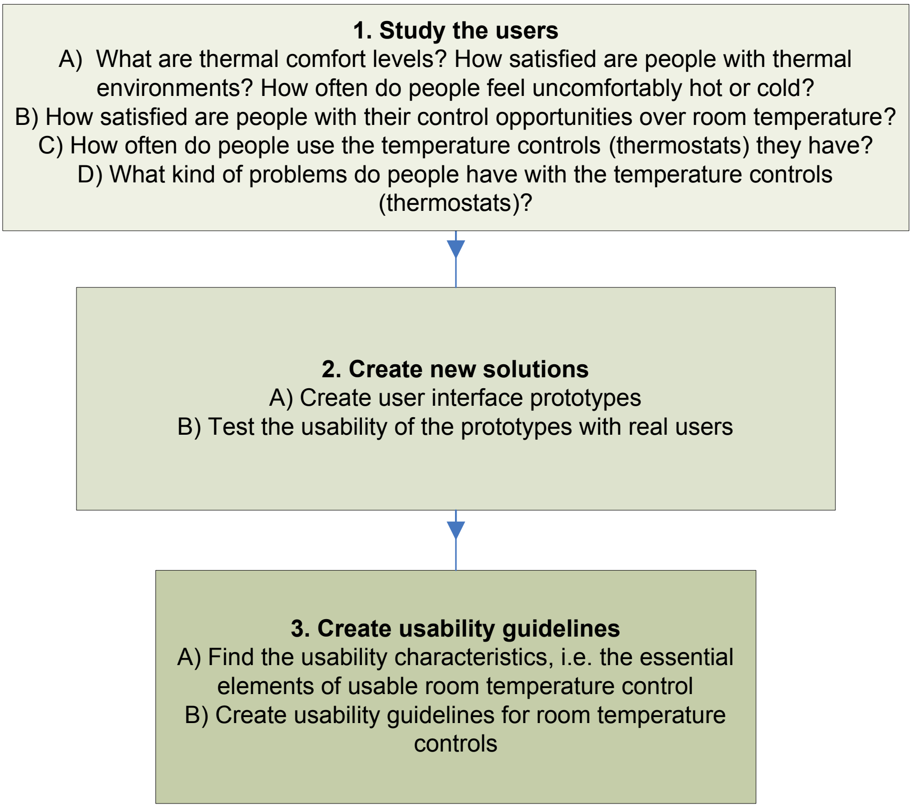

Fig. 5. The three stages of the work.

3.2 Scope of the work

The usability framework of ISO 9241-11 (1998) is applied to user control of room temperature in this thesis. Fig. 6 shows the most important contextual factors.

The specified users, context of use and goals – presenting the scope of the work – are:

> **Specified users:** office occupants in different professions.
>
> **Specified context of use:** office room, especially single-person office. Other types of rooms in office buildings, for example open-plan offices and meeting rooms are excluded.

Specified goals: set room temperature to desired direction with desired amount (when needed). It is very important that after the user adjustment the room temperature changes to the desired direction. A great accuracy between the desired and the "final" room temperature is not essentially important.

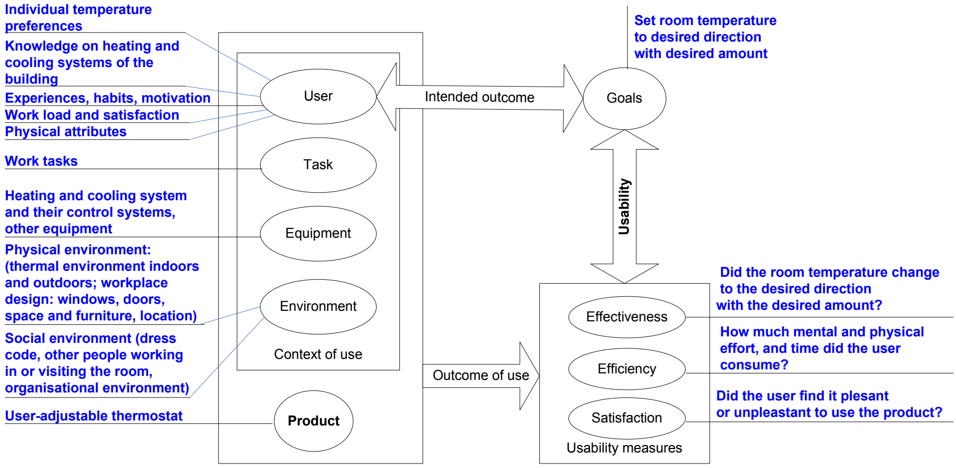

Fig. 6. The usability framework of ISO 9241-11 (1998) applied to user control of room temperature.

The user's primary goal is very simple: "to set room temperature to the desired direction". The user should be able to achieve the goal easily. Room temperature controls should be so easy to use that they can be used with high effectiveness and high efficiency by novice users as well by experts.

The secondary goal adds "with desired amount" to the primary goal. It is desirable that the desired room temperature would be achieved accurately and only one user adjustment would be needed. However, according to Leaman and Bordass (2001), most people are "satisfiers not optimisers", so a great accuracy between the desired and the "final" room temperature is not essentially important. It is also technically very demanding to create thermal environments with small tolerance margins in real buildings.

3.3 Research questions

The overall aim of the thesis is to improve office occupants' control over room temperature by improving the usability of interfaces of heating and cooling systems.

The main research question of the thesis is:

- **What are the characteristics of room temperature control that ensure high usability in offices?**

The supplementary research question that is answered *before* the main question is:

- **What usability problems do office occupants have with user-adjustable thermostats?**

3.4 Contribution of the thesis

The principal contribution of the thesis is the characteristics of room temperature control that ensure high usability in offices. The usability guidelines for room temperature controls (Chapter 7) represent the usability characteristics of room temperature control in a way they can be easily used also by non-experts of usability. The usability guidelines help designers to create user interfaces that enable office occupants to adjust the room temperature of their own office with high effectiveness, high efficiency and high satisfaction. Specific usability guidelines for room temperature controls have not earlier been available.

3.5 Outline of the thesis

The remaining chapters of this thesis are organised as follows.

Chapter 4 presents the materials and methods for both qualitative and quantitative studies of the thesis. Appendix A contains information about participants of the qualitative studies. Appendix B contains information about thermostats the participants have in their offices.

Results of the work are provided in Chapters 5–7. Chapter 5 summarises the results of extensive user research originally issued in Publications I–IV and also adds results not included in the publications. **Section 5.8 in Chapter 5 answers the supplementary research question.** Chapter 6 contains user interface prototypes and results of usability testing that were originally issued in Publication V.

With Chapters 5–6 and literature as a background, **Chapter 7 presents usability guidelines for room temperature controls and answers the main research question.** Discussions are presented in Chapter 8. Chapter 9, finally, contains general conclusions.

4. Methods and materials

Both qualitative and quantitative methods were employed to examine the research questions of the thesis. The work started with a qualitative interview survey taken in the offices of the participants. Later, a quantitative interview survey was performed to generalise the findings to the Finnish population. Additionally, to simulate the real use of thermostats, controlled experiments were taken. User interface development was based on the results of the preceding user studies. Overview on the methods and materials is presented in Fig. 7.

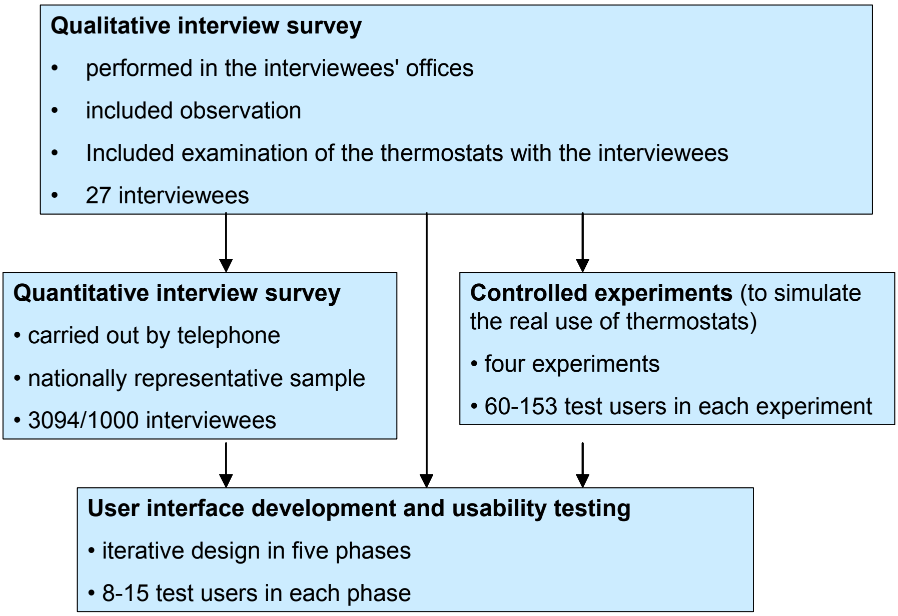

Fig. 7. Overview on the methods and materials of the thesis.

4.1 Qualitative interview survey

The goal of the qualitative interview survey was to study user needs, motivation, knowledge and behaviour regarding user control of indoor environment. The main purposes of the interviews were to understand the ways of using the controls and, more widely, how people act when they feel cold or hot, and to discover the problems users have with the controls.

The interviews were semi-structured: not all the questions were designed and phrased beforehand, but many questions were created during the interview, allowing flexible discussion. The questions were open-ended. A pilot interview was prepared, and the questions in the final interview were slightly modified after the experiences from the pilot. Appendix C shows a selection of the final interview questions.

The interviews were performed in actual context, in the interviewees' offices. We also asked interviewees to show and tell us how they use the temperature controls in their offices. The method was quite similar to contextual inquiry (Beyer and Holtzblatt 1998), but other techniques from contextual design by Beyer and Holtzblatt were not applied and the data analysis did not follow Beyer and Holtzblatt.

A total of 27 interviews were carried out. In the first part of the study we interviewed twelve persons. The results were analysed before the second part of the study, in which fifteen persons were interviewed. The length of each interview averaged one-and-a-half hours in the first part of the study. In the second part we concentrated on the most important issues and the length of each interview was about half an hour. All interviews were taped and the first twelve interviews were transcribed.

The interviewees were between 23 and 57 years of age. Fourteen women and thirteen men were interviewed. The educational level of the interviewees is high, which is typical for Finnish office workers. About half of the people have a university degree. Most of the interviewees do typical office work with a computer. We primarily interviewed people who work alone in an office, not in a shared working space, because they do not have to accommodate the thermal needs of others. Most of interviewees spend at least half of their working hours in their own room. The interviewees had been working in their present rooms from one-and-a-half months to more than ten years, so not all of them have experienced winter and summer conditions. Further details regarding the interviewees are shown in Appendix A.

The analysis of the interviewees consisted of systematic categorization of the interview responses. The categorizations were made for the central issues of the study, including thermal comfort levels, actions taken when feeling hot and cold, use of temperature controls, problems with thermostats, etc. (see Tables 4, 6 and

7 in Publication I). Because it was targeted to understand the motivations and strategy of the people and situations we investigated, all kinds of interesting observations were collected continuously during the interview and analysis process. Secondly, observations were collected to find ideas (and hypotheses) for the quantitative interview survey performed later.

4.2 Quantitative interview survey

In the quantitative interview survey, users were studied with a large and nationally representative sample. Some of the findings from the qualitative survey were treated as hypotheses and were tested – and generalised to the Finnish population – in the quantitative phase. Another important advantage of the quantitative study is that it is possible to examine the results by subgroups, for example, by age, sex or building type.

The interviews for the quantitative interview survey were carried out by telephone (computer-assisted telephone interview, CATI). The telephone interview is a quick and cost-efficient data acquisition method. The advantages of the telephone interview also include the fact that it allows accurate setting of quotas. Internet or postal surveys were not seriously considered in this work: non-response and frame undercoverage are major problems in internet surveys, and in postal surveys non-response increases quickly with the number of questions asked (Laiho and Hietaniemi 2002). In this work, face-to-face interviewing was the alternative for telephone interviewing. The interviews were chosen to be carried out by telephone, because no special advantage of more expensive face-to-face interviews was discovered.

In the same interviews material concerning both office and home environments was gathered. The first part of the interview concerned the home environment and the last part concerned the office environment. The latter part of the questionnaire was only asked of those who work in an office (a work environment away from the home). The sample size in question concerning the office environment was about one-third of the total: 3 094 people (1 556 females and 1 538 males) answered questions concerning the home environment and 1 000 people (520 females and 480 males) answered questions concerning the office environment.

A well-known Finnish data collection agency (Taloustutkimus Oy) was responsible for the practical realisation of the telephone interviews according to its quality system.

The interview questions were prepared by the author, because no standardised instrument suitable for the purpose exists. The goal was to create questions that are easy to understand and answer. The questions dealt mainly with opinions and attitudes, especially satisfaction with the present situation and attitudes towards future solutions. In addition, several questions on occupant behaviour, especially on the use of thermostats, were asked. Basic background information on the interviewees and the buildings in which they live and work were also gathered.

The final interview questions are the result of numerous iterations. Comments to the interview questions were obtained from experts of both VTT and the data collection agency. Furthermore, the interview questions were tested by performing test interviews by the author. Before the actual data acquisition a pilot interview with 100 interviewees was made by the data collection agency. Minor changes to the questions were made even in this stage. Appendix C shows a selection of the final interview questions.

Special attention was paid also to the answer alternatives of the structured interview. The respondents were mainly asked questions to which they responded on a linear scale from 1 to 5 or by selecting from alternatives. Some information such as age and living space was collected as number values.

The target group of the study was the population of Finland. A random sample of the Finnish population aged between 15 and 74 was selected with quotas set according to gender, age and province. In examining the results, rather small differences were noticed between the distribution of the population and the study sample. These distortions were corrected with weighting coefficients before statistical analysis.

The interviews were performed in early wintertime, in November and in December. This period is the most suitable because questions concerned both winter and summer season experiences of thermal environments. In November and in December the experiences from summer season are better remembered than later in the winter. The interviews were performed between the 22nd of

November and the 30th of December in 2004. In that period the mean outdoor temperature was 0 °C in the south and –7 °C in the north of Finland.

An attempt was made to keep the length of the interview moderate. The duration of the interviews dealing only with the home was 11 minutes on average. The interviews dealing both with the home and the office lasted 16 minutes on average.

4.3 Controlled experiments

The controlled experiments simulated real use of thermostats. The user interfaces, which were printed on paper, were similar to those of many room thermostats. Two kinds of paper user interfaces were distributed to users in each case, so each user received one of the two paper interfaces. Each user marked on the paper the change he or she wanted to make to the current room temperature. The scale was from –2 to +2 °C or from –3 to +3 °C (Fig. 8). In addition to temperature preference, the participants wrote their age and gender on the papers.

Depending on the case and a user group, the current room air temperature was shown or not shown on the paper interface (Fig. 8). The room air temperature was measured with a Fluke 52 digital thermometer just before the paper interfaces were distributed to the test group in all cases. No other measurements were taken because the idea was to simulate the normal use of thermostats.

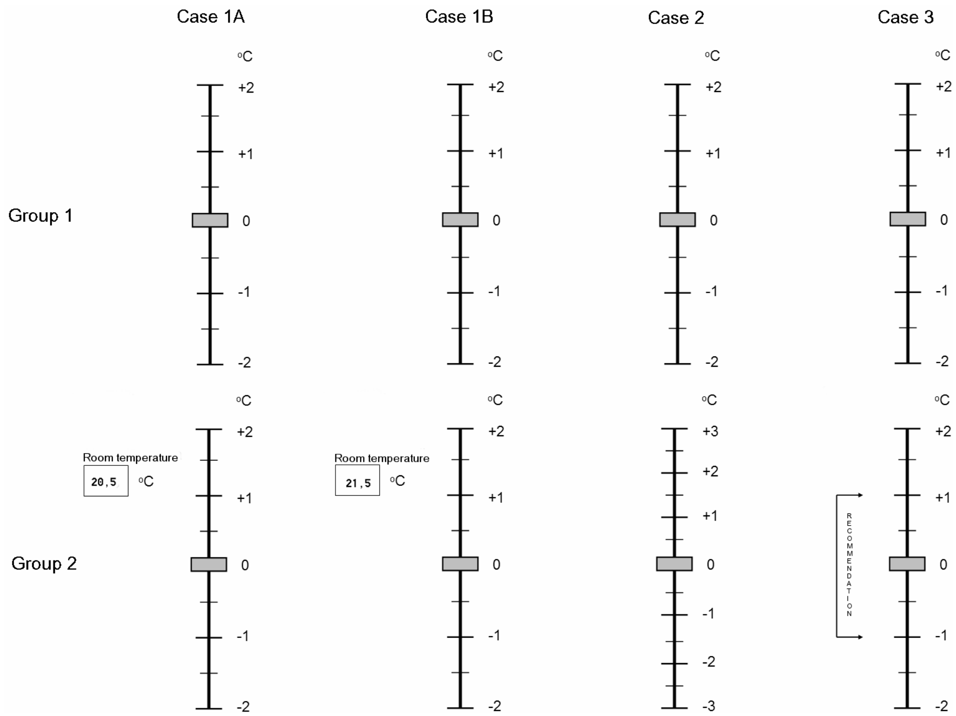

Fig. 8. User interfaces in the controlled experiments.

The participants in the tests were university students. Most were between 19 and 25 years of age. During the experiments they were seated in a large auditorium. Test Case 1a was performed ten minutes after the participants had arrived in the auditorium, but in the other tests the participants had been seated for about an hour before the test was taken. The participants were mostly the same persons for Case 1b, Case 2 and Case 3. The persons who participated in Case 1a were not involved in the other tests. Detailed information on the experiments is shown in Table 3.

The participants wore normal winter season clothes. Typical clothing was quite heavy: the students wore jeans or other trousers, sweaters with long sleeves (made of wool or cotton) and outdoor shoes in addition to underwear and socks. Skirts are not commonly used during the winter; long skirts are rare and short skirts are absent. Observations were made on clothing, and no gender difference in clothing insulation could be found. Males and females were not seated differently in the auditorium.

Table 3. Details on controlled experiments.

Research question	**How is user control action affected if the user knows the measured room air temperature?**		**How is user control action affected by the width of the temperature scale?**	**How is user control action affected if a recommendation for temperature is given?**
Case	**1a**	**1b**	**2**	**3**
Date and time	18th March 2004, 12 am	27th January 2005, 1 pm	3rd March 2005, 1 pm	14th April 2005, 1 pm
Description of test group	Students of usability in Helsinki University of Technology			
Mean age in test group	23.2 years	22.4 years	22.1 years	22.3 years
Number of persons in test group	68	152	80	60
Weather	+3 °C, cloudy	0 °C, cloudy	–5 °C, partly sunny	+12 °C, sunny
Room air temperature*	+20.5 °C	+21.5 °C	+20 °C	+18 °C

* In the centre of the auditorium at the height of a sitting person

There are windows on the right wall of the auditorium in which the experiments were conducted, but because curtains were in use, no direct radiation from the sun entered the room during the tests. The auditorium is heated by supply air. The supply air diffusers are located in the wall and under the seats. The exhaust air terminal devices are located in the ceiling. The building service systems were operating as usual and were not adjusted in any way because of the experiments.

The results from the controlled experiments are presented in Section 5.5, p. 65.

4.4 User interface design process

The work also included constructive research. In the work a user interface was developed for office occupants to use in controlling the temperature, ventilation and lighting of an office. It is targeted at people working in a single-person room, not for people sharing a room with others. The focus of the work is on individual control of room temperature; control of ventilation and lighting are not dealt with so profoundly.

The user interface prototypes were developed with a user-centred approach (see Section 2.1). The goal was not to create a commercial product but to study issues concerning individual control of the indoor environment. The target was to create a user interface that can be used with high effectiveness, high efficiency and high satisfaction (see the definition of usability in Section 2.2) by novice users.

4.4.1 Phases of user interface development

The user interface development was iterative. The results from each previous phase were analysed before the next phase, and a new version (or versions) of the user interface was developed for each phase.

The work was divided into five phases. In phases 1–4, the usability tests were performed in the offices of the participants. In these phases, user actions had no real effect on room conditions. In the last phase, the prototype was connected to a building and user actions had a real effect on room conditions. In each phase, eight to fifteen test users participated in usability tests. Overview on the phases of user interface development is shown in Table 4. The method of usability testing is described next.

Table 4. Phases of user interface development.

Phase	Paper prototypes	Working prototype(s) installed on a laptop	Working prototype connected to a building (real effects on room conditions)	Number of test users
1	X			12
2		X		15
3		X		11
4		X		8
5			X	8

4.4.2 Method for usability testing

The method for usability testing was an informal walkthrough (Riihiaho 2000). There are no pre-defined test tasks in an informal walkthrough, but the participant goes through the user interface at his or her own pace and preferred order. The idea is to simulate a real use situation. The participant is observed while using the system in the way he or she would do it alone. The participant is encouraged to think aloud and to comment on the system while exploring it.

The purpose of the informal walkthrough was to examine how easy the user interface is, and to gather user opinions. During the session the experimenter talked to the participant to clarify whether the participant understood the features of the user interface correctly, and whether he or she thought the features were necessary or not. The discussions were taped for later analysis. In phases 3–5, a short questionnaire was conducted before and after the usability test. Each test user only participated in a test once, and new participants were used for each phase.

The usability of the prototypes was analysed by three usability experts in phase 2. The heuristic analysis revealed software bugs and gave ideas for improvement. However, the most important information was gathered during the usability tests and interviews with office occupants. The results of the heuristic analysis are not presented in the thesis.

4.5 Climate and buildings in Finland

All materials of this thesis were collected in Finland. In this section, information about climate and buildings in Finland is presented.

The climate in Finland is marked by cold winters and warm summers. The mean annual outdoor temperature varies between +6 °C in the southwest and –2 °C in the northernmost part of the country. The warmest month is typically July, with mean temperature between +14 and +18 °C in most parts of the country. Daily maximum temperatures can reach +30 °C in July. The coldest months are January and February, with mean temperatures between –4 °C in the south and –15 °C in the north.

Buildings in Finland are well insulated and equipped with centralised heating systems. Room air temperatures are typically between +20 and +24 °C during the winter period. Heating systems are sized to be able to keep the room air temperature over +20 °C also on coldest winter days. The dimensioning outdoor temperatures are –26 °C in the south and –38 °C in the north. There is a fireplace in 43% of homes, but it is the primary heating system in only 4% of homes.

During the short summer, room air temperatures commonly rise to between +25 and +30 °C. Less than half of the offices, but most of the new ones, has a cooling system. There are no cooling systems in residential buildings, but heat pumps have become increasingly popular recently and they can be used as a cooling system in the summer season.

Residential buildings are typically equipped with a mechanical exhaust ventilation system, or are ventilated naturally. The most common ventilation system in office buildings is mechanical ventilation with supply and exhaust.

Fig. 1 (p. 18) shows examples of typical thermostats in Finland.

4.6 Statistical tests

Statistical tests were performed for the quantitative studies of this work, i.e. the quantitative interview survey and the controlled experiments. All statistical analyses were performed using SPSS (version 12.0.1 for Windows) software. Because the data did not meet the assumption for normality (Kolmogorov–Smirnov test), nonparametric tests, which make no assumptions about the frequency distributions of the variables being assessed, were used. Nonparametric tests have less statistical power than their parametric counterparts. Table 5 presents the statistical tests that were used. In addition, Spearman's correlation test was used in one case (in Section 5.1). The significance level of difference was set at 5% ($p < 0.05$).

Table 5. Statistical analysis tests used.

	For continuous data	**For categorical data**
Two independent samples tests[a]	Mann-Whitney U test[c]	Pearson's chi-square test
Two related samples tests[b]	Wilcoxon signed-rank test[c]	Marginal homogeneity test

[a] For example, for testing gender differences.
[b] For example, for testing differences between homes and offices.
[c] A nonparametric test, no assumption for normality.

5. Thermal comfort and use of thermostats

User interface development must start by understanding users. From the user interface development point of view important questions concerning users are:

- How satisfied are occupants with room temperatures and control opportunities over room temperature?
- How do occupants act in thermal discomfort? Do they use thermostats?
- Do occupants understand how heating and cooling systems work?
- What problems do occupants have with the thermostats?
- Are there any major differences between occupants?

Additionally, to deepen understanding of the meaning of context in use of thermostats, interviewees were also asked questions concerning home. The results concerning office and home environments are compared in this chapter.[4]

Users were studied with qualitative and quantitative methods in conjunction with each other. The work started with the qualitative interview survey taken in the office rooms of the participants. With this method, which included observation, rich information about office occupants as users of thermostats was collected. The main disadvantage of qualitative approaches is that the findings cannot be extended to wider populations (with the same degree of certainty that quantitative analyses can). The quantitative interview survey was performed to generalise the findings to the Finnish population. For example, a hypothesis of gender differences was developed in the qualitative phase and was later tested with the quantitative study.

Results from both the qualitative and the quantitative user studies are presented in this chapter. If respondents were asked similar questions in both the qualitative and quantitative phase, only statistically reliable information is presented here. In these cases, the statistical results are enriched by information from the qualitative study.

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[4] The home population is different from the office population, because only one third of people work in offices. In this chapter only the results concerning the office population are presented.

5.1 Thermal comfort and perceived control over room temperature

Thermal comfort and perceived control were examined in the quantitative interview survey using the following questions and answer choices.

- How satisfied are you with room temperature in [winter/summer] in [office room/home]? (Very dissatisfied = 1, ..., very satisfied = 5).
- How often do you feel uncomfortably [cold/hot] in [winter/summer] in [office room/home]? (Continuously, daily, weekly, monthly, less frequently, not at all).
- How well do you feel you can personally control room temperature in [winter/summer] in [office room/home]? (Very badly = 1, ..., very well = 5).

The results show that thermal comfort levels are lower in office rooms than in homes. The mean values for satisfaction with room temperature are between 3.0 and 3.2 for office and between 3.7 and 4.0 for home (very dissatisfied = 1, ..., very satisfied = 5). Satisfaction is higher during the winter season than during the summer season. The results are presented in Fig. 9. The differences between office and home are statistically significant (Wilcoxon signed-rank test, 2-tailed: winter season: $Z = –15.586$, $p = 0.000$, significant; summer season: $Z = –13.209$, $p = 0.000$, significant).

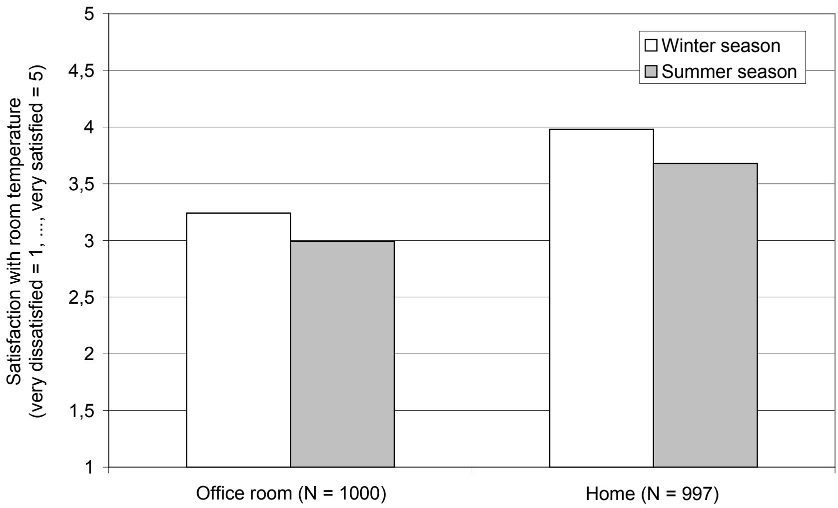

Fig. 9. Satisfaction with room temperature in the office and at home. Mean values are shown.

There are differences in satisfaction between different types of offices and between different types of homes. In offices people are most satisfied in single-person rooms (Fig. 10). These differences are, however, smaller than the differences between offices and homes: even the least satisfied group in homes is more satisfied than the most satisfied group in offices.

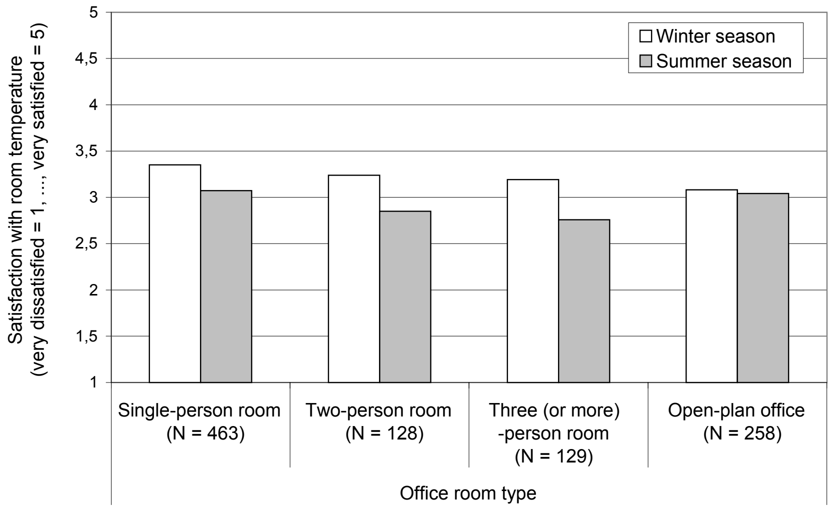

Fig. 10. Satisfaction with room temperature in different types of offices. Mean values are shown.

The main problems are coldness during the winter season and heat during the summer season (Fig. 11). During the winter period, 28% of the respondents feel uncomfortably cold weekly or more often (weekly, daily, or continuously) in the office. During the summer period, 42% of the respondents feel uncomfortably hot in the office weekly or more often. People feel cold and hot more often in offices than in homes during both the winter and the summer seasons. Statistical significances for the differences between the office and home environments were calculated, and the differences were found to be statistically significant (marginal homogeneity test: feeling cold in the winter season: Std. MH = 10.809, p = 0.000, significant; feeling cold in the summer season: Std. MH = 8.238, p = 0.000, significant; feeling hot in the winter season: Std. MH = 3.728, p = 0.000, significant; feeling hot in the summer season: Std. MH = 7.274, p = 0.000, significant).

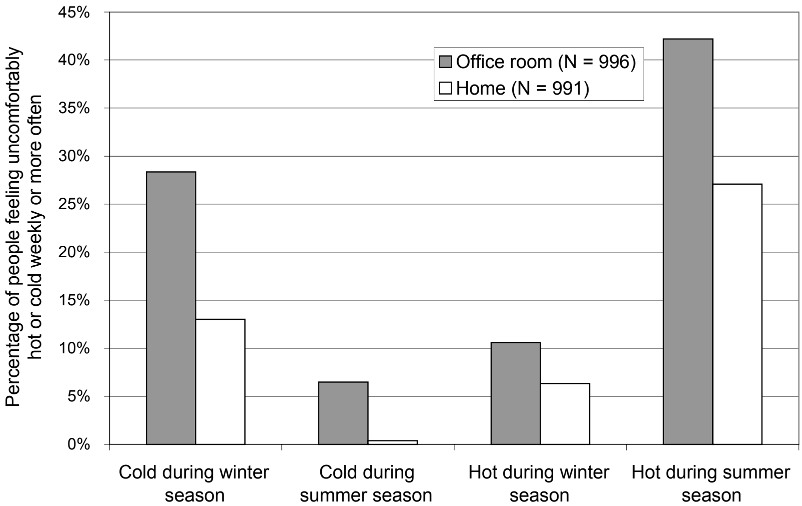

Fig. 11. Percentage of people feeling uncomfortably cold or hot weekly or more often in the office and at home.

The respondents were asked to rate their perceived control over room temperature with a scale from 1 to 5 (very badly = 1, ..., very well = 5). The values given are much lower for the office than for the home: the mean values are between 2.1 and 2.3 for office and between 3.3 and 3.9 for the home (Fig. 12). The differences between office and home are statistically significant (Wilcoxon signed-rank test, 2-tailed: winter season: $Z = -23.163$, $p = 0.000$, significant; summer season: $Z = -19.331$, $p = 0.000$, significant).

Satisfaction with room temperature and perceived control over room temperature are related statistically significantly both in offices and homes (Spearman correlations: office/winter: $p = 0.000$; office/summer: $p = 0.000$; home/winter: $p = 0.000$; home/summer: $p = 0.000$).

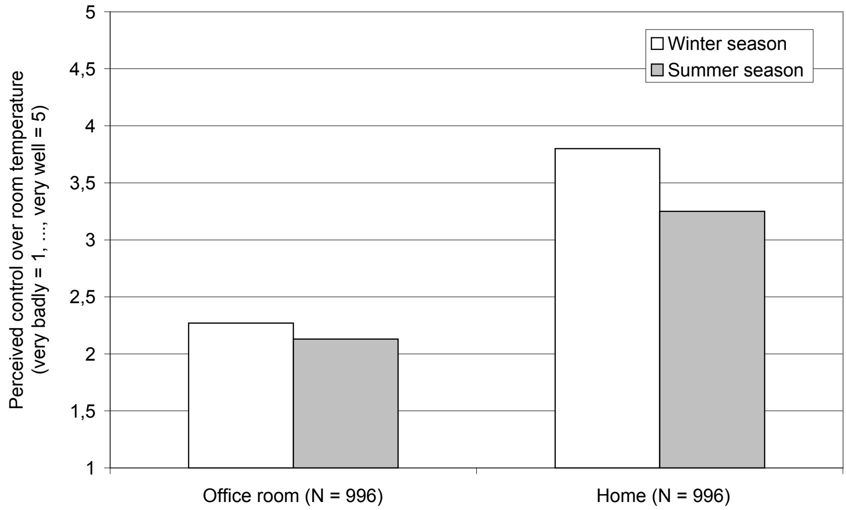

Fig. 12. Perceived control over room temperature in the office and at home. Mean values are shown.

There are differences in perceived control between different types of offices and between different types of homes, but the differences are distinctly smaller than the general difference between offices and homes. In offices the perceived control is higher in single-person and two-person rooms than in the other kind of offices (Fig. 13).

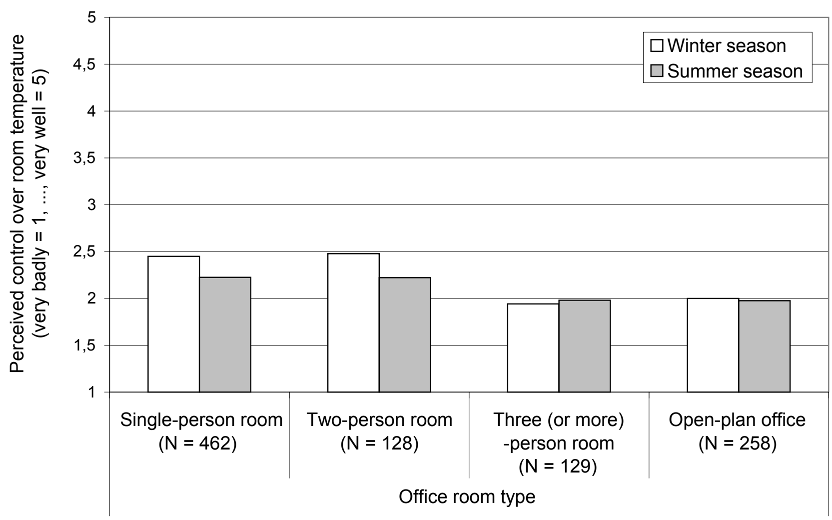

Fig. 13. Perceived control over room temperature in different types of offices. Mean values are shown.

The results show that there is absolutely more dissatisfaction and more need for improvement in offices than at homes. The problems in offices are not restricted only to open-plan offices, but also people that are working in single-person rooms are dissatisfied with their degree of control over room temperature.

5.2 User actions in thermal discomfort

It is typical that thermal discomfort leads to not just one but several responses (Heerwagen and Diamond 1992). That was found also in the qualitative interviews of the work. In the quantitative interview survey, the respondents were asked what their *principal* action is when feeling uncomfortably cold and hot.

When feeling cold, 58% of the people in the office and 51% at home put more clothes on as their principal action (Fig. 14); 17% of the respondents in the office and 25% at home adjust the heating or cooling system thermostat or use an extra heater.

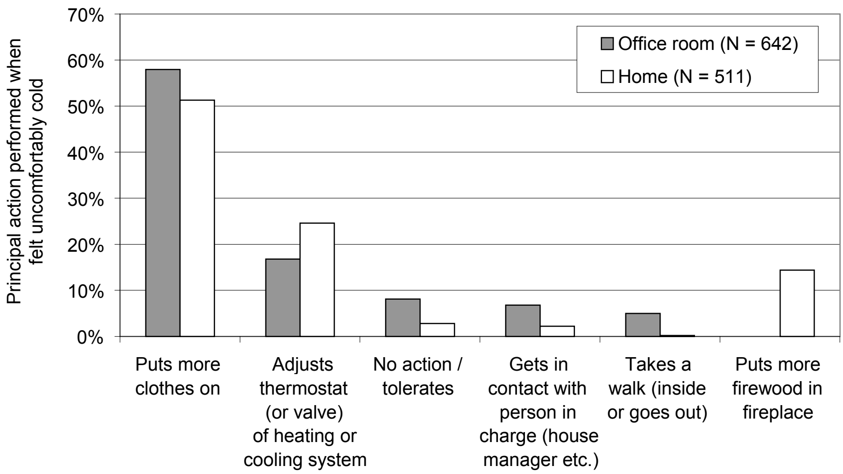

Fig. 14. Principal action performed when feeling uncomfortably cold in the office and at home. The question was open-ended and all the actions with a proportion of 5% or more are included. Use of extra heaters is included in use of thermostats.

When feeling hot, opening a window is the most common action performed (Fig. 15). Windows are opened by 47% at home and by 34% in the office as their principal action; windows are often not able to be opened in offices. 19% of office occupants do not take any action when feeling uncomfortably hot, they just tolerate it.

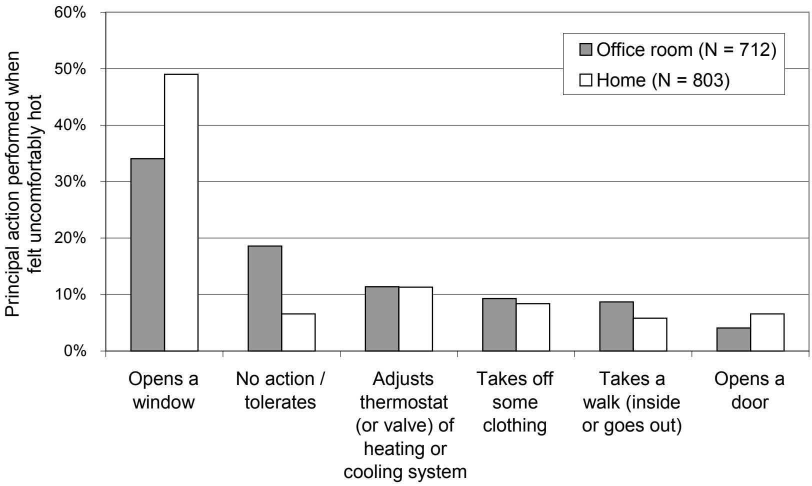

Fig. 15. Principal action performed when feeling uncomfortably hot in the office and at home. The question was open-ended and all the actions with a proportion of 5% or more are included.

The differences between office and home are statistically significant in both cases (marginal homogeneity test: actions performed when feeling uncomfortably cold: Std. MH Statistic = –2.914, $p = 0.004$, significant; actions performed when feeling uncomfortably hot: Std. MH Statistic = –5.183, $p = 0.000$, significant).

5.3 Availability and use frequency of thermostats

Most people have a user-adjustable thermostat (or an adjustable non-thermostatic valve) for room temperature control. Only 12% of the respondents stated that they do not have an adjustable thermostat (or valve) in their living room at home, but in the office the corresponding percentage is higher at 38%. The qualitative interviews showed that not everyone is aware of thermostats in their own office, so it is clear that thermostats are more common in offices than Fig. 16 indicates.

Thermostats installed in radiators or electric heaters are more common than room thermostats (Fig. 16).

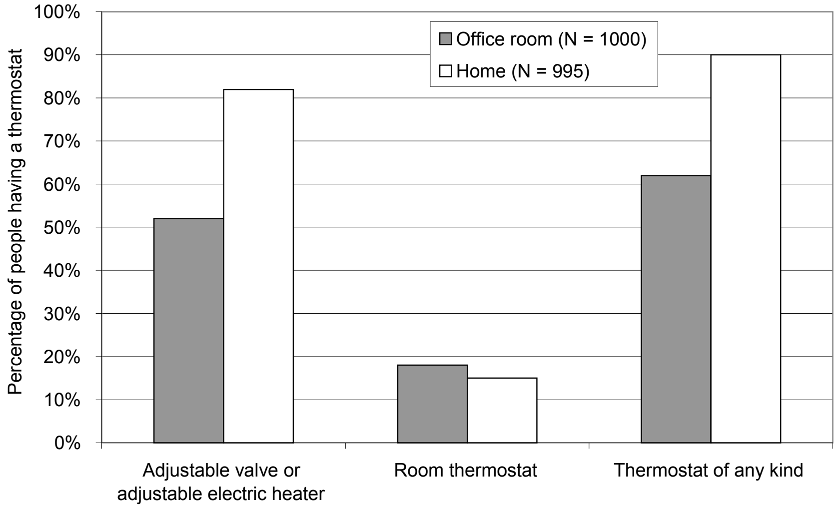

Fig. 16. Percentage of people having a thermostat and in their office and in their living room at home. (Most of adjustable valves and adjustable electric heaters are thermostatic. For simplicity, they are called thermostats. Room thermostats are non-programmable in offices and mostly non-programmable at homes, and typically installed on walls.)

Thermostats (of any kind) are statistically more common in living rooms in homes than in office rooms (marginal homogeneity test: Std. MH = –16.329, p = 0.000, significant).

Thermostats are not used frequently even if they are available. Less than 20% of the respondents use a thermostat weekly or more often (Fig. 17). About 60% do not use a thermostat at all, or use it less than once a month. The actual value is even higher because not everyone is aware of the thermostats they have (This lack if awareness was found in the qualitative interviews, see Table 8). Thermostats are used less frequently in offices than in homes (marginal homogeneity test: Std. MH = –3.460, p = 0.001, significant).

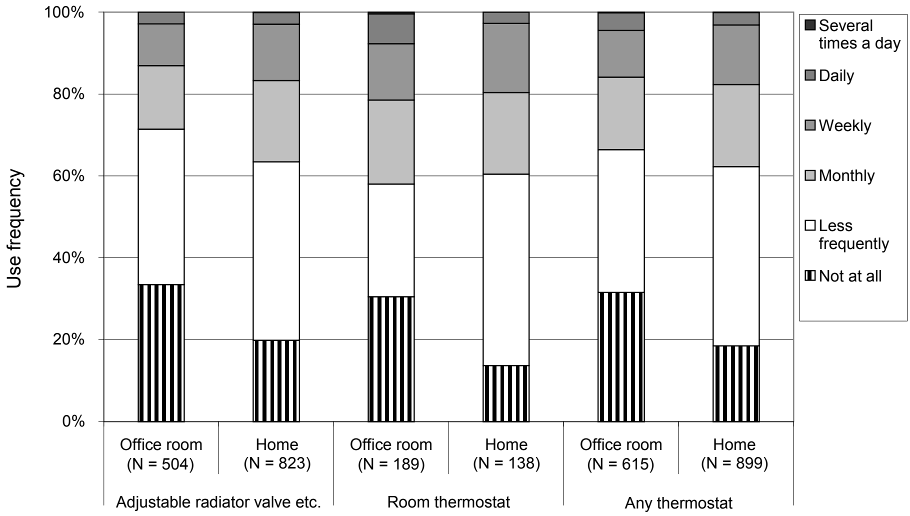

Fig. 17. Frequency of use of thermostats in the living room at home and in the office. The questions were only asked of those who reported having a thermostat of that kind. Note that the proportion of those who use thermostats several times a day is very small, and not seen in the figure.

5.4 Use experiences of thermostats

Thermostats are easier to reach in the living room at home than in the office (Wilcoxon signed-rank test, 2-tailed: adjustable radiator valve or adjustable electric heater: $Z = -11.354$, $p = 0.000$, significant; room thermostat: $Z = -3.012$, $p = 0.003$, significant) (Fig. 18), and it is easier to choose an appropriate thermostat position at home than in the office (Wilcoxon signed-rank test, 2-tailed: adjustable radiator valve or adjustable electric heater: $Z = -7.890$, $p = 0.000$, significant; room thermostat: $Z = -3.638$, $p = 0.000$, significant) (Fig. 18).

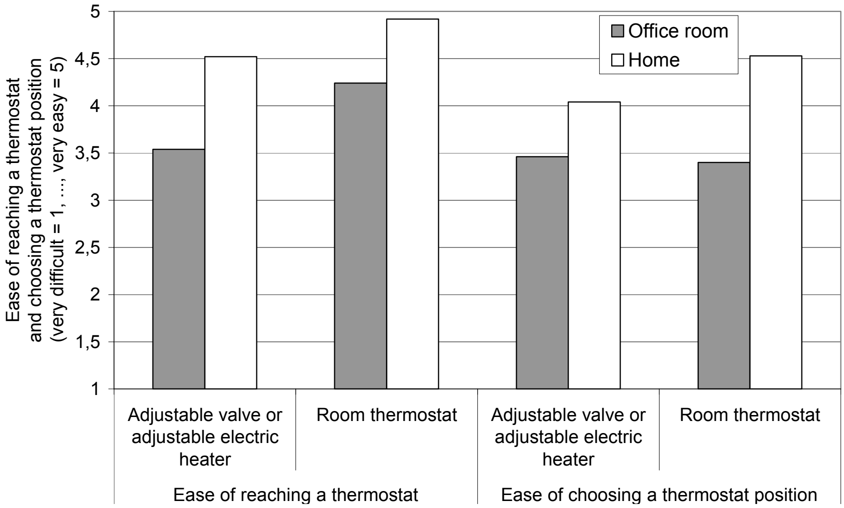

Fig. 18. Ease of reaching a thermostat and choosing a thermostat position in a living room at home and in an office. Mean values are shown.

After a user adjustment, it is felt that the change in room temperature is faster at home than in the office (marginal homogeneity test: adjustable radiator valve or adjustable electric heater: Std. MH = 4.811, p = 0.000, significant; room thermostat: Std. MH = 2.769, p = 0.006, significant) (Fig. 19).

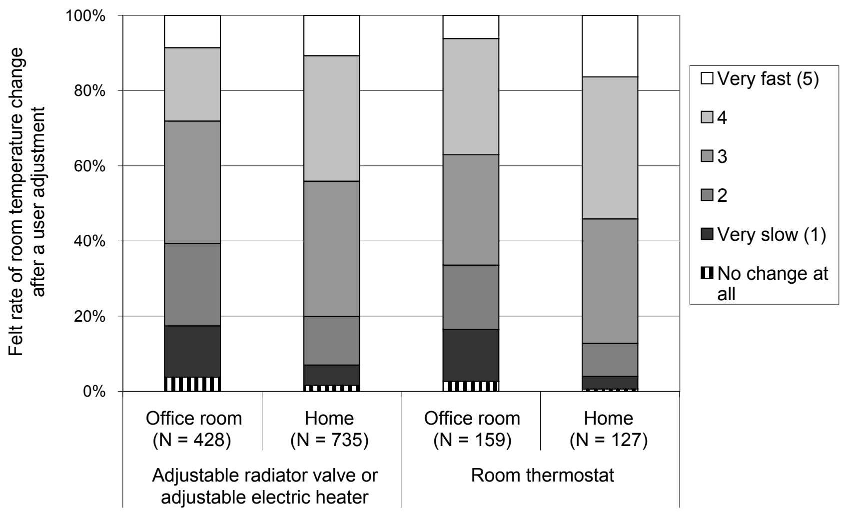

Fig. 19. Felt rate of change in room temperature after a user adjustment in the living room at home and in the office.

5.5 Experiments on use of thermostats

In the controlled experiments, each person in the auditorium received a paper user interface to simulate the use of a thermostat. Each user made a single control action by marking on the paper how he or she would adjust the room temperature to fulfil his or her current temperature preference. For a more detailed description of the method, see Section 4.3, p. 48.

The purpose of the experiments was to study what kind difference is made in user control action if (1) the measured room air temperature is shown (Cases 1a and 1b in Fig. 8), (2) the temperature scale is wider (Case 2), and (3) a recommendation for temperature is shown (Case 3).

Four experiments were performed, and the results were similar in all of them: no statistical significance was found between group 1 and group 2 in each case (Table 6). The results show that it does not have any significant effect on user control actions if the user knows the measured room air temperature, or if the temperature scale is wider, or if a recommendation for temperature is given.

Mean user control actions in each case are shown in Table 6. All the single control actions in each case are shown in Fig. 20.

Table 6. Mean user control actions in group 1 and group 2.

Mean user control action	**Case 1a**	**Case 1b**	**Case 2**	**Case 3**
Group 1	0.33 °C (n = 34)	0.64 °C (n = 78)	0.58 °C (n = 48)	0.91 °C (n = 38)
Group 2	0.29 °C (n = 34)	0.50 °C (n = 74)	0.61 °C (n = 32)	0.81 °C (n = 22)
Statistical significance (Mann-Whitney U test, 2-tailed)	U = 548 p = 0.709 Not significant	U = 2573 p = 0.244 Not significant	U = 736 p = 0.739 Not significant	U = 386 p = 0.621 Not significant

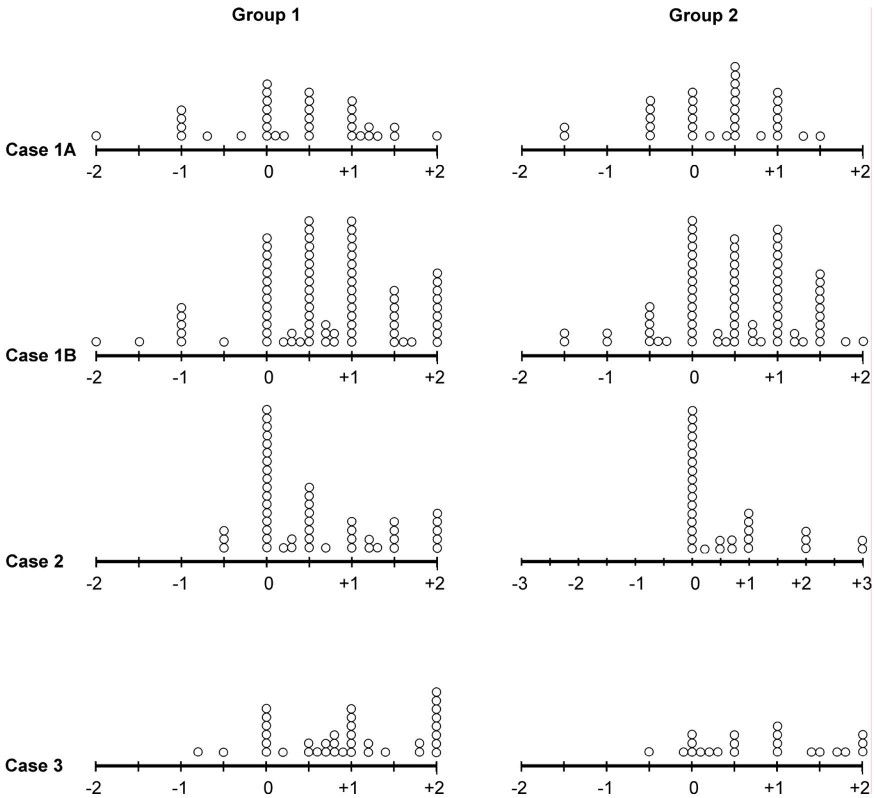

Fig. 20. User control actions in the controlled experiments in group 1 and group 2. X axes present the change wanted to the current room temperature (°C).

Age and gender data were collected as background information. Age had no effect on the results, but it was found that gender had a statistical significance on user control actions, even though clearly fewer females than males participated in the tests (Table 7). In each test there was a gender difference in temperature preference: females used the control to achieve higher room temperatures than males.

Mean user control actions in each case are shown in Table 7. All the single control actions in each case are shown in Fig. 21.

Table 7. Mean user control actions by males and females.

Mean user control action	Case 1a	Case 1b	Case 2	Case 3
Males	0.20 °C (n = 51)	0.50 °C (n = 131)	0.71 °C (n = 68)	0.77 °C (n = 52)
Females	0.71 °C (n = 14)	1.03 °C (n = 21)	0.96 °C (n = 12)	1.42 °C (n = 6)
Statistical significance (Mann-Whitney U test, 2-tailed)	U = 215 p = 0.021 Significant	U = 845 p = 0.004 Significant	U = 223 p = 0.009 Significant	U = 75 p = 0.037 Significant

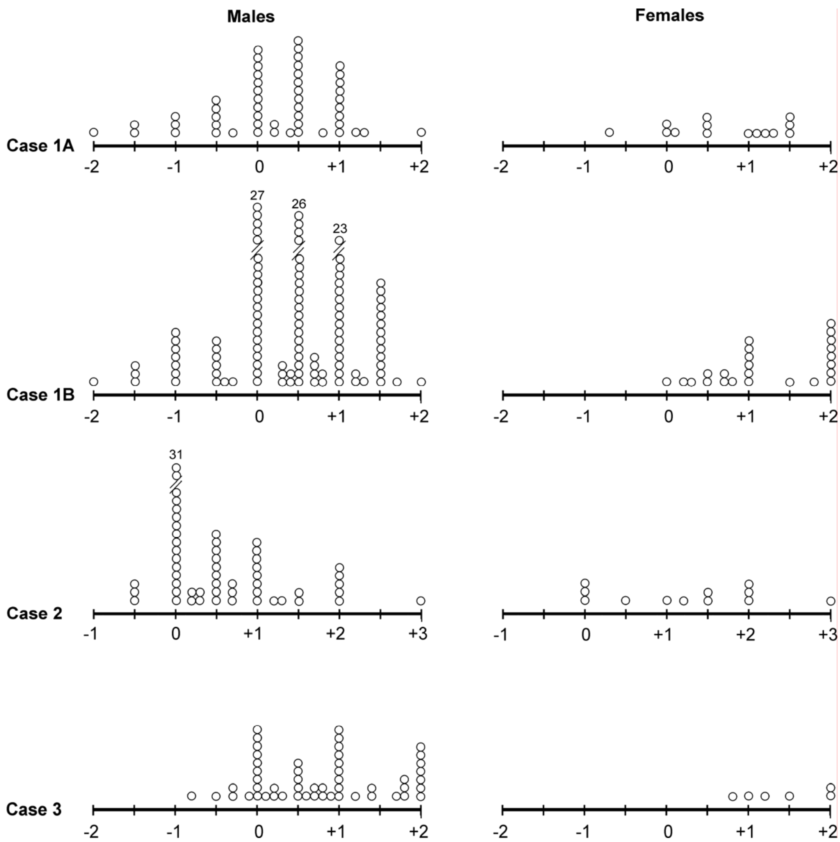

Fig. 21. User control actions in the controlled experiments by males and females. X axes present the change wanted to the current room temperature (°C).

In the controlled experiments, females and males were dressed similarly, and there was no gender difference in clothing insulation (discussed in Section 4.3), so the gender difference in temperature preference cannot be explained by clothing.

5.6 Differences between the genders

The individual differences in thermal comfort responses are well known, but the differences between male and female subjects are considered to be minor (Fanger 1970; Parsons 2003). Usually, the differences, if they have been found, have been explained in terms of clothing differences.

In the controlled experiments (Section 5.5) females adjusted room temperature higher than males to fulfil their current temperature preferences although females and males were dressed similarly, and there was no gender difference in the clothing insulation. This difference in how users adjust room temperature was not the only statistically significant difference between the genders that was found in this work. In this chapter, the most important gender differences are shortly presented.

In the quantitative interview survey it was found that males are more satisfied with room temperatures than females. Males are more satisfied with room temperatures in offices both in the winter and summer seasons. The differences between males and females are more remarkable in the office environment than the home environment. As an exception, females give better values for summer season temperatures at home than males. The results are presented in Fig. 22. Statistical analysis showed statistically significant differences between the genders (Mann–Whitney U test, 2-tailed: office/winter: $U = 116028$, $p = 0.000$, significant; office/summer: $U = 114745$, $p = 0.000$, significant; home/winter: $U = 1695006$, $p = 0.029$, significant; home/summer: $U = 1535735$, $p = 0.001$, significant).

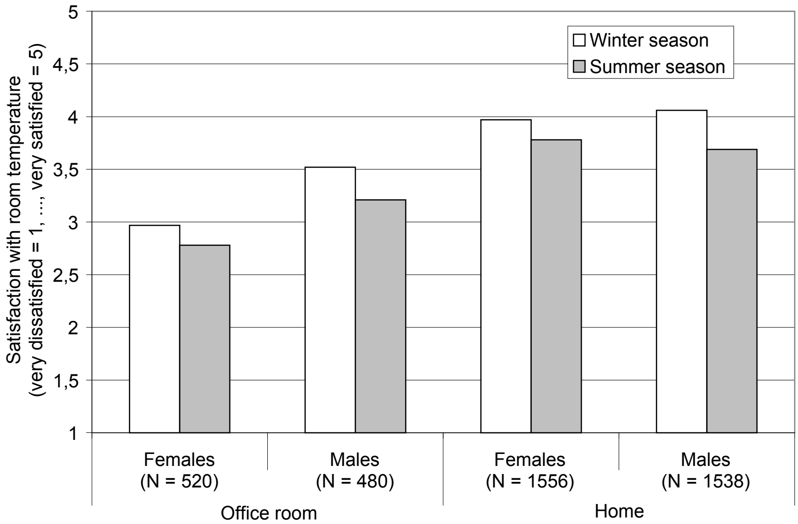

Fig. 22. Satisfaction with room temperature in the office and at home by gender. Mean values are shown.

Females feel uncomfortably cold and uncomfortably hot more often than males (Fig. 23); During the winter season, 40% of females feel uncomfortably cold weekly or more often (weekly, daily, or continuously) in offices. Coldness is felt less often at homes: 18% of females reported that they feel uncomfortably cold weekly or more often. The same values for males are significantly lower: 16% of males feel uncomfortably cold in offices and 8% weekly or more often at homes. Females also feel hot and cold more often than males during the summer season. In offices, 48% of females and 37% of males feel hot weekly or more often. During the summer season, coldness is felt in offices weekly or more often by 10% of females and by 3% of males. The differences between the genders are statistically significant in feeling cold in the winter and summer seasons, and feeling hot during the summer season, but not in feeling hot during the winter season (Pearson's chi-square test: office/cold/winter: $\chi 2$ = 78.792, p = 0.000, significant; office/cold/summer: $\chi 2$ = 19.806, p = 0.000, significant; office/hot/winter: $\chi 2$ = 2.491, p = 0.114; office/hot/summer: $\chi 2$ = 13.823, p = 0.000, significant; home/cold/winter: $\chi 2$ = 75.238, p = 0.000, significant; home/cold/summer: $\chi 2$ = 14.657, p = 0.000, significant; home/hot/winter: $\chi 2$ = 1.744, p = 0.187; home/hot/summer: $\chi 2$ = 9.388, p = 0.002, significant).

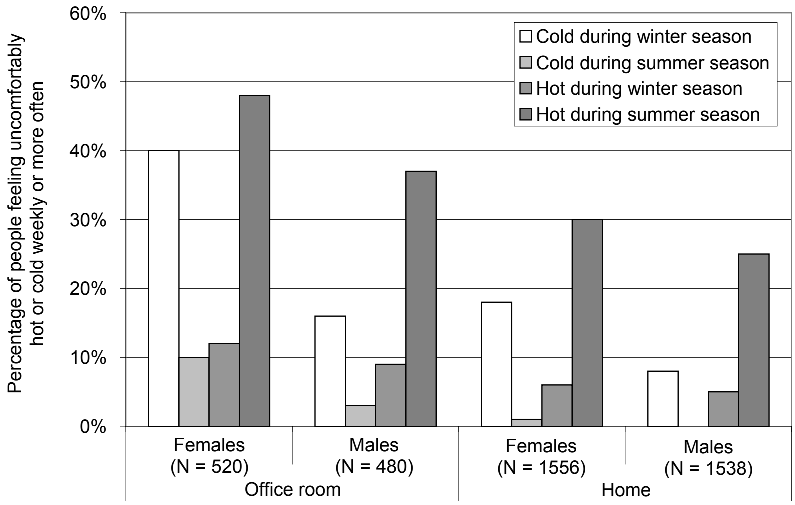

Fig. 23. Percentage of people feeling uncomfortably cold or hot weekly or more often in the office and at home by gender.

A gender difference was found again in perceived control over room temperature: women are less happy with their control options (except in the summer season at home), see Fig. 24. The differences between the genders are statistically significant (Mann–Whitney U test, 2-tailed: office/winter: $U = 132740$, $p = 0.000$, significant; office/summer: $U = 131629$, $p = 0.000$, significant;home/winter: $U = 1646289$, $p = 0.001$, significant; home/summer: $U = 1585450$, $p = 0.030$, significant).

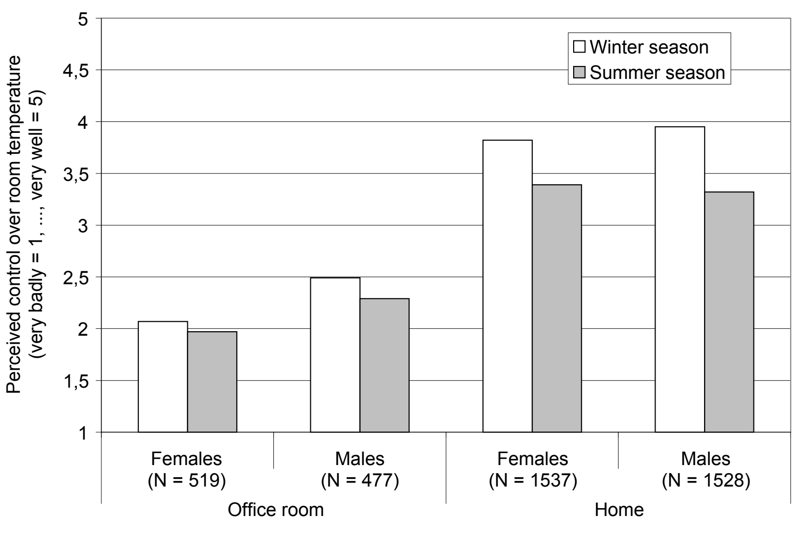

Fig. 24. Perceived control over room temperature in the office and at home by gender. Mean values are shown.

According to the quantitative interview survey, 36% of those who live with a spouse stated that there are different preferences for room temperatures in their household. They were asked the following question: "Is the one who wants a higher room temperature a male or a female?" 65% of them said that it is a female who wants higher room temperature and 31% of them said it is a male (Fig. 25). An interesting difference was found when the answers were compared by gender: 76% of males and only 53% of females said that it is a female who wants higher temperatures.

The respondents who reported that they have different preferences for room temperatures in the household were asked the following question: ''Is it a male or a female who uses thermostats more actively in your household?'' The results in Fig. 25 show that males use thermostats more actively: 51% of the respondents said that the more active thermostat user is a male and 35% said it is a female. Females and males share the view that males are more active users of thermostats.

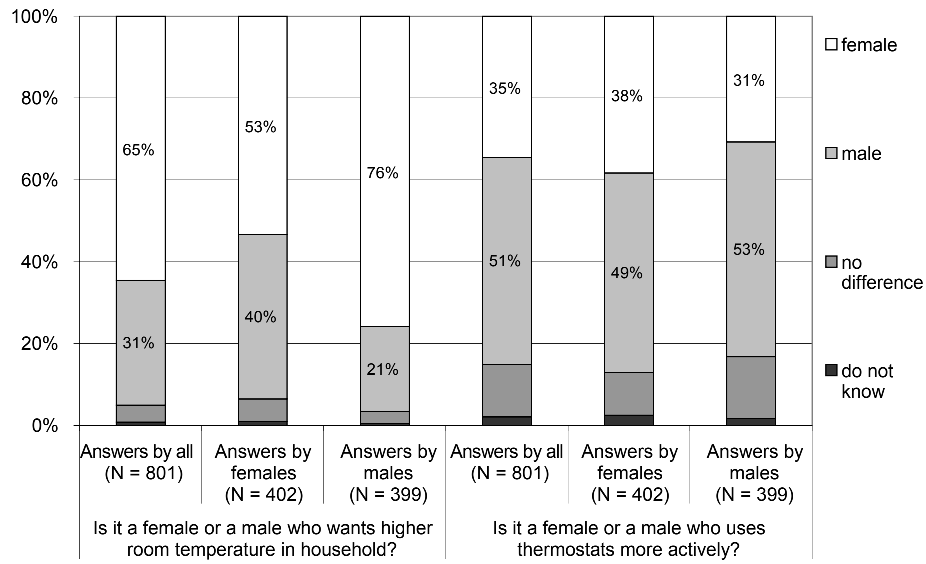

Fig. 25. Temperature preference and use of thermostats in households by gender.

Several statistically significant gender differences were found in this study. In the office, compared with males, females were found to

- be less satisfied with room temperatures during the winter and summer seasons (Fig. 22);

- feel cold more often during the winter and summer seasons (Fig. 23);
- feel hot more often during the summer season (Fig. 23);
- feel they have less control over room temperatures during the winter and summer seasons (Fig. 24).

At home, compared with males, females were found to

- be less satisfied with room temperatures during the winter season (Fig. 22) (statistically significant but practically a minor difference);
- be more satisfied with room temperatures during the summer season (Fig. 22) (statistically significant but practically a minor difference);
- feel cold more often during the winter season (Fig. 23);
- feel cold more often during the summer season (Fig. 23) (statistically significant but practically a minor difference);
- feel hot more often during the summer season (Fig. 23);
- feel they have less control over room temperatures during the winter season and more control during the summer season (Fig. 24) (statistically significant but practically minor differences);
- prefer higher room temperatures (Fig. 25);
- use thermostats less often (Fig. 25).

5.7 Other characteristics of occupants as users of thermostats

The qualitative interviews revealed characteristics of office occupants as users of temperature controls. The general findings are briefly summarised as:

- Most of occupants have very little knowledge of the heating, cooling and ventilation systems of the office building they work in. Occupants know that the radiators are full of water and emit heat, and the air terminal devices are part of the ventilation system, but otherwise their knowledge is very restricted.

- Most of occupants have little motivation to save energy in offices, because they do not pay for the energy themselves and because they consider their own energy use to be negligible.
- Most of the occupants have a false idea of the Celsius values of comfortable room temperatures. Occupants typically think that in the summer season room temperatures should be lower than in winter season. Their thinking goes that the warm outdoor temperature should be compensated by cool room temperature: "If it is hot outside, I don't like it hot inside". Occupants do not typically have thermometers in their offices. In reality they would feel very cold if room temperatures would be lower than in the winter season[5].

These findings from the qualitative interviews were further examined with the quantitative interview survey. The results from the quantitative interview survey are presented next.

The respondents were asked to rate their own knowledge of the heating and ventilation systems of homes and office buildings. Reported knowledge of the systems of office buildings is low. The mean value for offices is 2.03 and for homes 3.46 with a scale from 1 to 5 (very bad = 1, ..., very good = 5). The results are shown in Fig. 26. The difference between office and home is statistically significant (Wilcoxon signed-rank test, 2-tailed: $Z = -22.286$, $p = 0.000$, significant).

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[5] Thermal comfort studies (Fanger 1970) and standards (ASHRAE Standard 55 2004; ISO 7730 2005) show that room temperatures should be higher in the warmer season than in the colder season. This difference comes from two main reasons: the changes in clothing insulation related to the outdoor temperature (de Dear and Brager 2001), and the adaptive relationship of comfortable room temperature with the mean monthly outdoor air temperature (Humphreys 1978; Humphreys and Nicol 1998; de Dear and Brager 2001; McCartney and Nicol 2002).

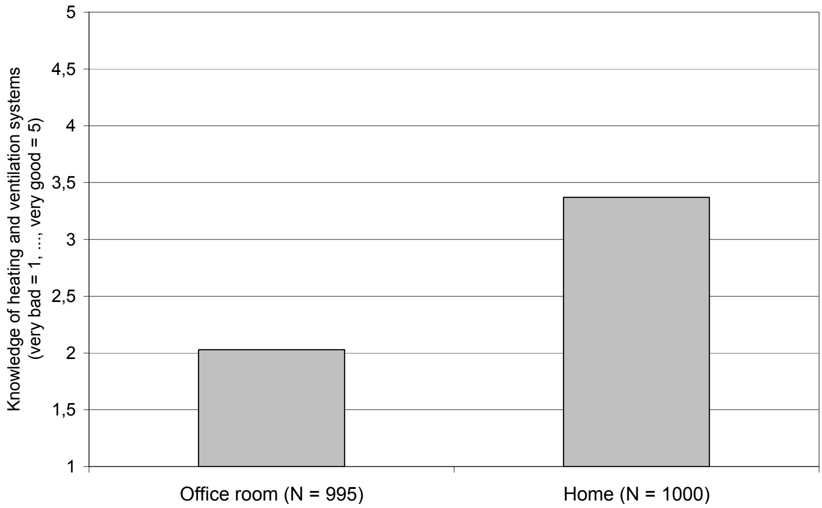

Fig. 26. Knowledge of heating and ventilation systems of home and office buildings rated by the respondents themselves. Mean values are shown.

The respondents were asked to describe their own efforts to save energy in the office and at home with a five step scale (very little = 1, ..., very much = 5). The results in Fig. 27 show that people are much more interested in saving energy at their own homes. The difference between office and home is statistically significant (Wilcoxon signed-rank test, 2-tailed: $Z = -18.910$, $p = 0.000$, significant).

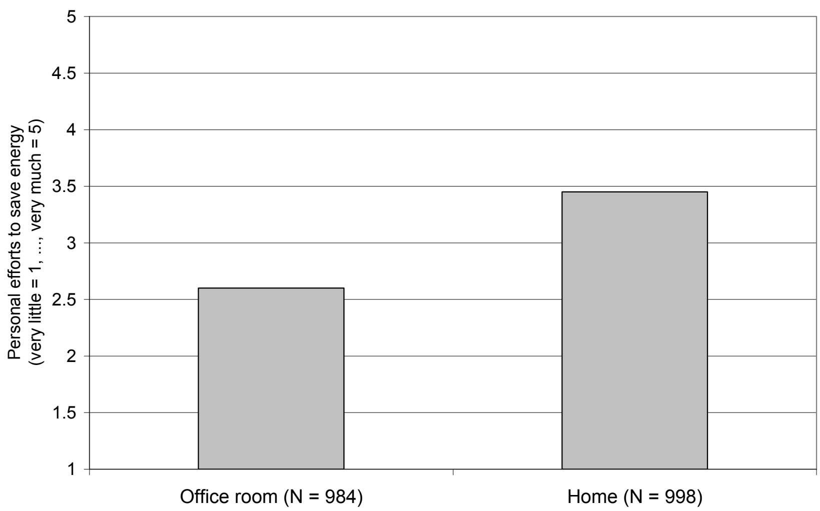

Fig. 27. Personal efforts to save energy in the office and at home. Mean values are shown.

In the quantitative interview survey, the respondents were asked to state the Celsius values of the room temperatures they prefer in the winter and summer seasons in their living room at home. The results are shown in Fig. 28. 89% of the respondents say they prefer a temperature between 19.5 and 23 °C in the winter season. There is more deviation in the summer season temperatures: 22% think that room temperature should be 19 °C or below. A mean value for the preferred winter season temperature is 21.2 °C and for the preferred summer season temperature it is 20.5 °C.

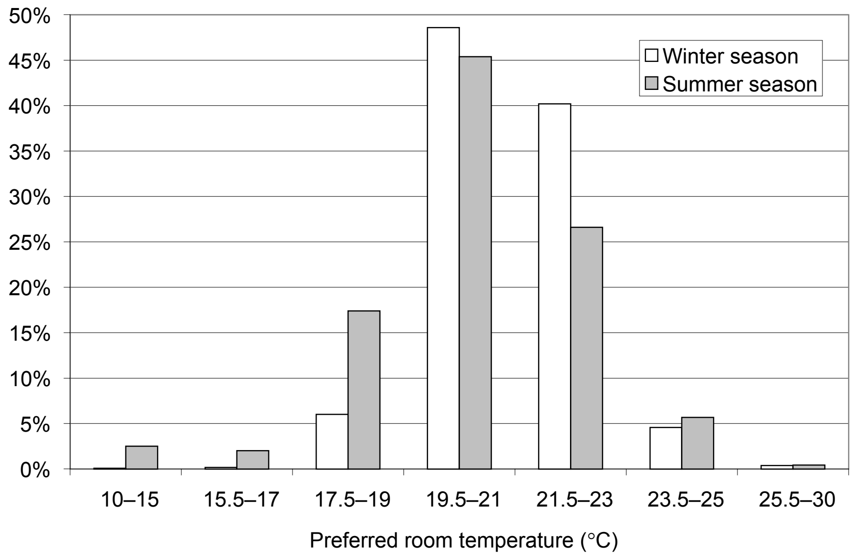

Fig. 28. Preferred room temperatures in the winter and summer seasons in living room at home. N = 3064.

41% of the respondents think that room temperature should be lower in the summer season than in the winter season (Fig. 29). Only 15% of people have the correct idea: comfortable room temperature is higher in the summer season than in the winter season.

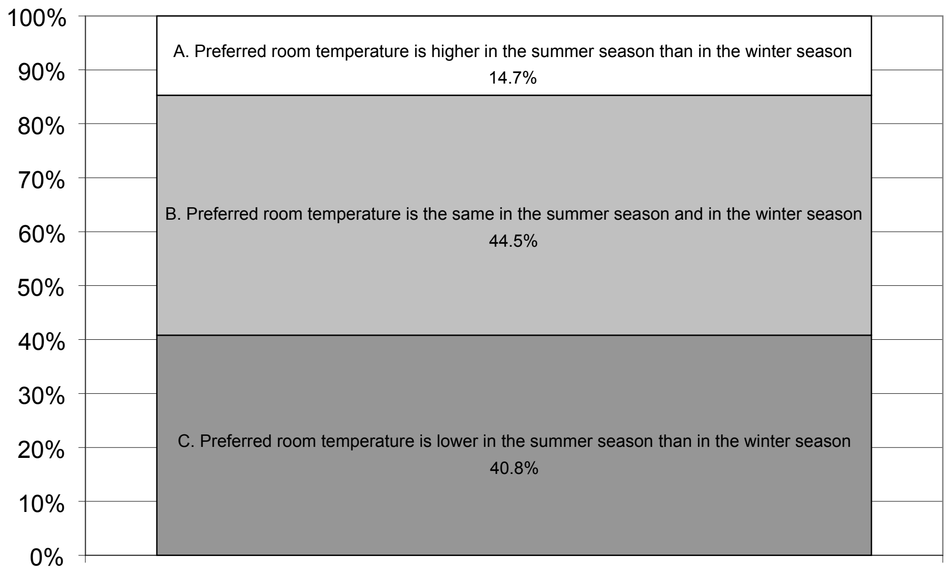

Fig. 29. Influence of season on preferred room temperatures in living room at home. N = 3000.

The results show that people have a false idea of the absolute values of comfortable temperatures. People would feel very cold in the summer season if room temperatures would be at the level most of them suggested.

The respondents of the present study were occupants in residential buildings in Finland. The results are consistent with an office occupant study by Vastamäki et al. (2005) performed in five European countries.

5.8 Usability problems with thermostats in offices

As shown earlier, many people do not use the room thermostats and thermostatic valves they have in their offices. The reasons behind this lack of usage were studied by interviewing 27 participants and by examining the thermostats with them. The interviews were performed in actual context, in the interviewees' offices. An important part of the interviews was observation. The participants were also asked to show us how they use the thermostats. The research method and materials are described in Section 4.1.

The problems with the user controls were found to be fundamental and diverse. Office occupants do not always even know they have individual temperature control in a room, because the purpose of the device remains unclear or the device is not recognised at all. If the temperature controls are inappropriately located, they are not always found, and they are impossible or awkward to use. Occupants may think that they are for service personnel only.

There are also problems with the use of temperature controls. It is not always known if the temperature control is operating or not. Although the room thermostats our interviewees have in their rooms are simple, the lights and other symbols on the user interface were often not understood correctly.

Because of the thermal inertia of the building materials and the heating (or cooling) system itself, the rate of room temperature change is slow. Users are not satisfied with the feedback they get from their control actions because they do not know whether the system is working to fulfil the request. Users also found that it is not easy to know how much to turn the dial to get the desired effect.

The list of detected problems is presented in Table 8. The problems from number 1 to 6 are all serious and common.

Table 8. Problems users have with temperature controls in offices. See Appendix A for information on the participants and Appendix B for description of thermostats they have in their offices.

No		Description of problem (partici-pants with the specific problem[a])	Note
1	A	It is not known that there is an adjustable thermostatic valve in a room (P1-4, P1-7, P1-9, P1-10). The room thermostat is located behind a panel so that it is not found (P1-11).	After many years working years in the office, everyone is still not aware of the thermostats and possibilities to control thermal environment of the office.
	B	The purpose of the room thermostat remains unclear. It is not recognised as being for temperature control (P1-3, P2-8, P2-15).	There is often a lot of equipment installed in walls of offices. It is not easy to know what the purpose of each of them is. Appearance of many of the room thermostats do not relate to temperature in any way (for example, there are no symbols that users understand to be temperature related). Instead, the purpose of one of the room thermostats (Type D in Appendix B) was clear as the red and blue colours in the thermostat were understood to refer to temperature.
2	A	The room thermostat is located too high on the wall or behind furniture so that it is impossible or awkward to use it (P1-12, P2-6, P2-7, P2-8, P2-9, P2-10, P2-12, P2-13, P2-14, P2-15).	Room thermostats are commonly located high on the wall. Because they are awkward to use, it may be assumed that they are for service personnel only, see no 3.
	B	The thermostatic valve is located behind furniture so that it is impossible or awkward to use it (P1-1, P1-2, P1-5, P1-7, P1-9).	The problem is partly related to the small size of offices.
3	A	Does not dare to touch thermostat because it is thought to be for service personnel only (P1-1, P1-5, P1-8, P2-7).	There is often a lot of equipment installed in walls of offices. It is not easy to know which of them office occupants are allowed to touch. The problem is related to office occupants' low knowledge of the heating and cooling systems (Fig. 26).

No		Description of problem (partici-pants with the specific problem[a])	Note
	B	Does not dare to touch the room thermostat because its effect is not known (P1-12).	Related to no 6.
4	A	It is not known that the room thermostat is for control of the heating or cooling system, or for both of them (most of the participants).	Most of office occupants have very little knowledge of the heating and cooling systems of the office building they work in (see Fig. 26). It is far too difficult for office occupants to know to which system a room thermostat is connected – and if the system active or not at the moment.
	B	If there is both a room thermostat and a thermostatic valve in a room, the room thermostat is considered to be the only one (P1-4, P1-7, P1-9).	After finding a room thermostat many of the users suppose that it is the only thermostat in the office. In several cases this led to long-term coldness in winter season as users were adjusting the room thermostat that was passive (connected to the cooling system) while the thermostatic valve of the heating system was fully closed.
5	A	Room thermostat does not give any feedback, or the feedback is not understood by users (P1-1, P1-3, P1-4, P1-7, P1-8, P1-9, P2-4, P2-12, P2-14)	It is not easy to see whether the room thermostat is operating or not. And after a user control action, it is not easy to know whether the room temperature is changing or not. In one of the buildings where we interviewed occupants, the control actions are followed by instant feedback as the fan convector starts to make a noise. That makes it easy to notice that the system is operating.
	B	The meaning of lights and symbols in the room thermostat are misunderstood (P1-1, P1-3, P1-4, P1-7, P1-8, P1-9, P2-1, P2-4, P2-15).	In many of the room thermostats there are light symbols that inform about the status of the equipment, but the meaning of the light symbols is typically not understood. There are also problems in understanding the other symbols on room thermostats.
	C	The dial on the room thermostat which is to be turned to set the temperature is not found (P1-7)	If the interface of a room thermostat looks complex or has a lot of elements, users may not discover the knob, dial, etc. that is to be used.

No		Description of problem (partici-pants with the specific problem[a])	Note
6	A	Users do not know how much the dial should be turned to get the desired effect on room temperature (most of the participants).	By examining thermostats users typically do not get a clear idea of how to get the desired effect on room temperature. Previous experience may help. Users typically choose the minimum or maximum setting as they don't know how to achieve the desired room temperature (and because they want as fast an effect as possible).
7	A	The thermostatic valve is stiff and the user does not have enough physical power to turn it (P1-1).	If a thermostat is stiff, it may be misinterpret that it is not meant for use. Related to no 3.

[a] The list of persons in brackets does not necessarily include all people with the specific problem because the thermostats located too high on the wall or behind furniture could not be studied closely.

5.9 Summary

This chapter provided results from the extensive user research of the thesis. The results are summarised next.

There is absolutely more dissatisfaction and more need for improvement in offices than at homes. People feel cold and hot more often in offices than in homes during both the winter and the summer seasons. Most of occupants have very little knowledge of the heating, cooling and ventilation systems of the office building they work in. Thermostats are quite similar in offices and homes but are found to be easier to use and are used more actively at home. When feeling hot, opening a window is the most common action performed. When feeling cold, the most common action is to put more clothes on. Thermostats are not used frequently even if they are available.

The perceived control over room temperature is remarkably low in offices. The key reasons for lower thermal comfort levels in offices compared to homes are that people have fewer opportunities to control the thermal environment, do not deal with thermostats so well, and people have fewer opportunities to adapt to different thermal environments (for a discussion of adaptive opportunities, see Section 8.4.1). The perceived control over room temperature could be improved by greater availability and usability of user-adjustable thermostats.

The problems with user controls in offices were found to be fundamental and diverse. Room thermostats and thermostatic valves in offices are often not used at all by office occupants, and the significance of individual temperature control on thermal comfort is low. It is often not known that there is individual temperature control in a room. Lights and other symbols on the user interface are often not understood correctly, and it is not always known whether the temperature control is operating or not. In general, users are not satisfied with the feedback they get from the systems. Room thermostats were not found to be well designed in any of the buildings we studied. The main reason for the many of the problems is that the systems are planned and constructed without a realistic view of their users, i.e. occupants are supposed to have knowledge they do not have.

Significant differences were found between the genders, especially in office environments. Females are less satisfied with room temperatures than males, and feel both uncomfortably cold and uncomfortably hot more often. In households, the inhabitants have already discovered that females prefer higher temperatures than males. In addition to the interview survey, controlled experiments were conducted to simulate the real use of a thermostat, and it was found that females preferred significantly higher room temperatures than males. The results suggest that females tend to be more critical of their thermal environments, and are more sensitive to both cold and hot room temperatures. In households, however, males use thermostats more often than females.

Because females are more critical of thermal environments in real-life situations than males, female subjects should primarily be used in field studies on thermal comfort. In the product development phase, for example, females are more suitable as test persons. If the females are satisfied, it is most likely that males will also be satisfied.

Comfortable room temperature is higher in the summer season than in the winter season. Most of occupants have a false idea of the absolute Celsius values of comfortable room temperatures. Many of them think that in the summer season room temperatures should be lower than in the winter season. Occupants would feel very cold in the summer season if room temperatures would be at the level most of them suggested.

6. User interface prototypes for individual control of temperature in offices

The overall aim of the work is to improve office occupants' control over room temperature. The goal of this chapter is to find out what kind of interfaces users are able to use with high effectiveness, high efficiency and high satisfaction. The user interface prototypes presented here were developed with a user-centred approach (see Section 2.1). Overview of the phases of user interface development and description of the method for usability testing are provided in Section 4.4. In this chapter, the user interface prototypes are presented with the results from their usability tests. This chapter is based closely on Publication V.

The user interfaces were originally in Finnish, but were translated into English for publications. For that reason, issues of terminology are not dealt with in detail.

6.1 Phase 1

Working prototypes had not yet been developed in the first phase, but the twelve participants evaluated paper prototypes of different kinds of temperature scales. The goals of this phase were to examine user preference and understandability of the different temperature scales.

Fig. 30 shows the different temperature scales for adjusting room temperature. A room temperature set point is given by the user as an absolute value in one of them. The temperature scale is relative (numerical or verbal) in three of them. One of the temperature scales has no numerical or verbal scale, only the symbols "+" and "–".

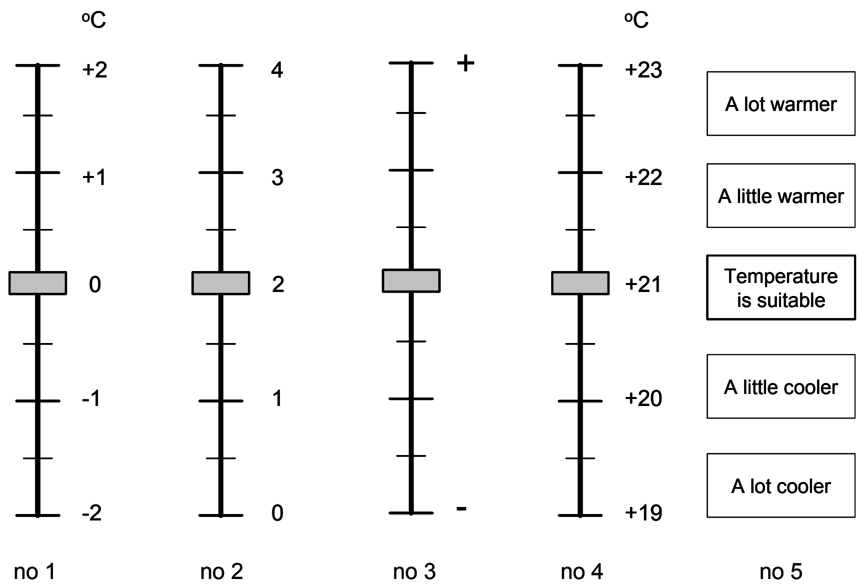

Fig. 30. Temperature scales for adjusting room temperature in the paper prototypes of phase 1.

The participants were asked to rate the temperature scales in order of preference, or choose the one that was preferred the most. Clearly, the most preferred temperature scale was the one that shows absolute temperature values (no 4 in Fig. 30). Nine participants out of twelve preferred it. The other three participants chose the verbal scale (no 5 in Fig. 30).

The absolute temperature scale was seen to be easy to understand, familiar and concrete. One of the respondents suggested developing a version otherwise similar but showing the optimum range for energy and comfort.

The verbal scale (no 5) was found to be clear but indeterminate. The three other alternatives (no 1–3 in Fig. 30) were not favoured. None of the participants preferred any of them. This is remarkable as these kinds of temperature scales are currently the most commonly used.

The participants seemed to understand all the temperature scales. It is clear, however, that understandability was affected by the fact that the evaluated temperature scales were quite similar to each other and that they were shown at the same time.

In addition, the participants were asked to describe what other features should be included in a system that enables the user to adjust the room temperature from a personal computer. The respondents were given alternatives and they commented on their interest in them. All the twelve respondents were interested in getting information on room temperature and outdoor temperature. An opportunity to notice defects in a room (burned out light bulbs, for example) was also found to be important. Information on energy consumption or energy consumption history, or the temperature history, was only thought useful by a few of the respondents.

6.2 Phase 2

Based on the results from the first phase and on the findings from the previous steps of the work six user interface prototypes were developed in the second phase (Fig. 31). In phase 2, fifteen participants tested working prototypes (programmed in Visual Basic 6.0) with a laptop (operating system Windows). The prototypes were not connected to the building and so had no real effect on room temperature.

There are several reasons why software user interface prototypes for a laptop were developed. Firstly, office occupants are more interested in adjusting a room temperature with a computer than with speech, gestures, remote control or a mobile phone[6]. Secondly, a laptop is easy to carry around, so the usability tests could be performed in the offices of the participants. Thirdly, it was cost-effective to create software user interface prototypes (I was able to do the programming by myself).

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[6] Interest in different interaction modes of room temperature control was studied in the quantitative interview survey (Section 4.2). The respondents were asked to evaluate their own interest in the control systems on a scale of five steps (1 = not interested at all, ..., 5 = very interested). The respondents did not receive any other information on the systems, but evaluated their interest in the control systems just by a short verbal description. 994 people answered questions concerning the office environment. The possibility to adjust room temperature with gestures or speech received little interest (mean values: 1.70 and 1.90); neither were the respondents interested in adjusting room temperature with a mobile phone (mean value: 1.87). Remote control was seen to be more suitable for temperature control (mean value: 2.42). The user-adaptive room temperature control ("system that learns the personal preferences of room temperature and controls room temperature accordingly") received a mean value of 2.59. The respondents were most interested in adjusting the room temperature with a computer (mean value: 3.11). 48.3% of the respondents were very interested (5) or interested (4) in adjusting the room temperature with a computer.

The design decisions were based on the following issues. In phase 1, it was learned that people prefer either a temperature scale with absolute temperature values or a verbal scale. It was also learned that people are interested in getting information on room temperature and outdoor temperature. No specific energy saving option was included in the prototypes, because most of occupants have little motivation to save energy in offices (Section 5.7). Nor did we include information on energy consumption history or temperature history in the prototypes, because interest in these features was low in phase 1. Because the purpose of a room thermostat may remain unclear (Section 5.8, problem 1B in Table 8), the user interfaces elements were labelled on the prototypes. Because of the thermal inertia (Section 1.5), the prototypes were designed to give instant feedback. For the purpose of comparison, the design of one of the prototypes (no 6) was based on a prototype developed by one of our industry partners.

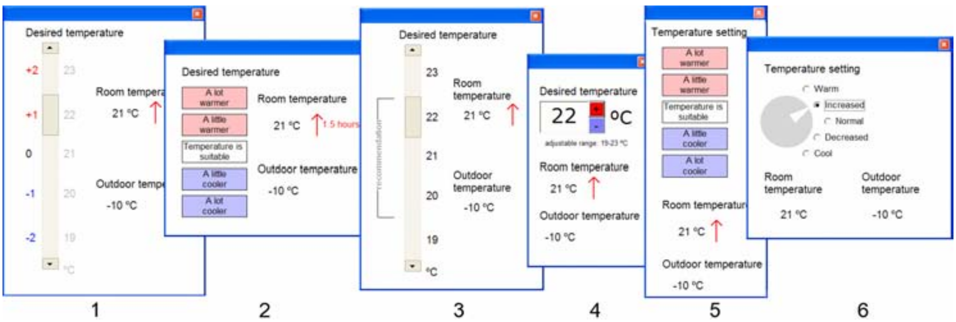

Fig. 31. Six user interface prototypes of phase 2.

The functions in all the prototypes are close to each other, but otherwise the prototypes differ remarkably from each other. Each of the user interface prototype has the same functions: opportunity to adjust room temperature, opportunity to see the current room temperature, and opportunity to see the current outdoor temperature. Five of the prototypes include an arrow to denote the direction of the room temperature change. The arrow is red and directed upwards when the room temperature is increasing, or blue and directed downwards when the room temperature is decreasing. Three of the prototypes also give information about the time it takes the room temperature to change to the adjusted level.

The room temperature set point is adjusted differently in the different prototypes. Five different temperature scales were used in the prototypes:

- Prototype 1. Combined relative (±2 ºC) and absolute scale. The idea of the two scales is that the relative scale remains the same, but the values in the absolute scale can depend on the outdoor temperature or the set point of the building. Slider.
- Prototypes 2 and 5. Verbal scale. Buttons.
- Prototype 3. Absolute scale. Slider.
- Prototype 4. Absolute scale. Numerical value. Written information on the minimum and maximum values (adjustable range) of the room temperature set point. The numerical value can be changed with "+" (red) and "–" (blue) buttons or by typing in a new value.
- Prototype 6. Verbal scale. Rotatable with radio buttons.

Other differences between the user interface prototypes are shown in Table 9. In addition, some terminological differences existed between the prototypes.

Table 9. Comparison of feedback and temperature recommendation in the user interface prototypes of phase 2.

Number of prototype	The arrow that shows the direction of the temperature change	Information about the time it takes the room temperature to change to the adjusted level	Recommendation for the room temperature set point
1	X		
2	X	X	
3	X	X[a]	X
4	X		
5	X	X[a]	
6			

[a] In a separate dialog that opens when the temperature is adjusted.

The goal of the usability tests was to compare the prototypes and find the pros and cons of each. The prototypes were shown to the different participants in a different order.

The results showed that users prefer to adjust room temperature setting by giving an absolute temperature value. The verbal scale was not preferred. That was explained by an idea that users have an insight on what a room temperature change of a degree or two means in practice. A verbal description was found to be indeterminate and to have different meanings for different persons. The absolute scale was the most liked and gained less resistance (Fig. 32). All the respondents said that they understood the influence of the absolute scale.

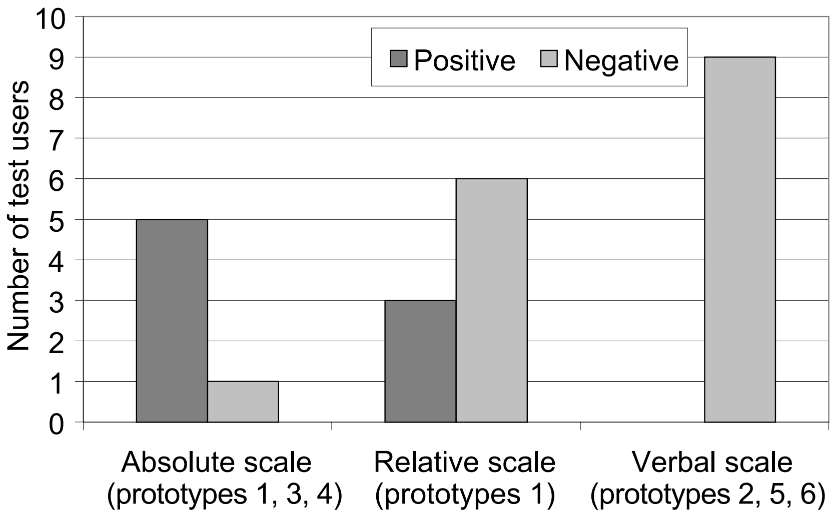

Fig. 32. User attitudes to the different temperature scales in phase 2 prototypes.

In designing the user interface prototypes, special attention was given to the feedback user interfaces give. Several variations of the feedback were developed (Table 9). The arrow shows that the room temperature is changing and denotes the direction of change. Three of the prototypes give information about the time it takes the room temperature to change to the adjusted level. That information is either shown on the right side of the arrow or in a separate dialog that opens when the temperature set point is adjusted. If the time is shown in a dialog, it is clarified with a text: “The room is getting warmer, and it will take [1 hour] before the adjusted temperature is reached”.

The usability tests showed that the arrow was informative: the red arrow up was understood to denote an increase and the blue arrow down a decrease in temperature. Information about the time it takes the room temperature to change was also found to be important. Only one of the participants would omit that information. The users preferred to see the time near the arrow, and the separate dialog and the text in the dialog were found to be unnecessary by most respondents. User attitudes to feedback in the prototypes are shown in Fig. 33. According to the results, both the arrow and the time should be included in the user interface.

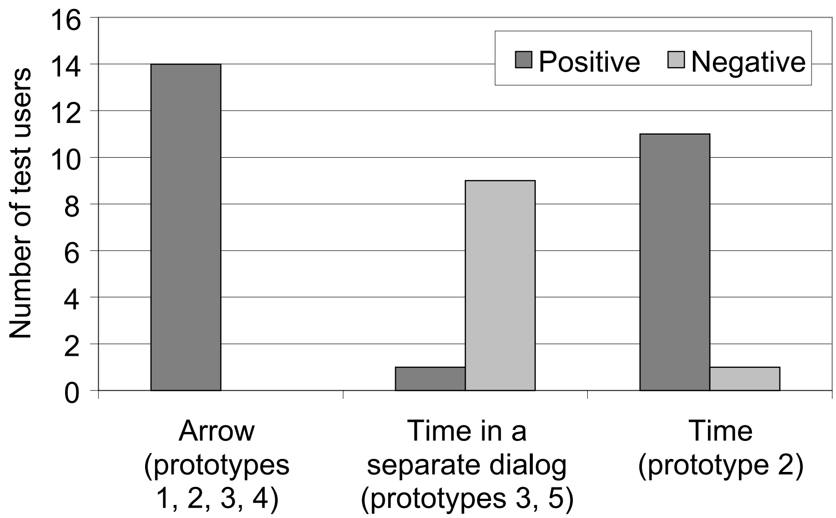

Fig. 33. User attitudes to the feedback in phase 2 prototypes.

The user interface prototype 3 showed a recommendation for the room temperature set point. It was possible to adjust the set point between +19 and +23 ºC but a temperature between +20 and +22 ºC was recommended. User feedback on this feature was diverse. The recommendation was seen as paternalistic, or as a good way to promote ecological behaviour and healthy temperatures. According to the results, a recommendation on the room temperature set point is liked by many users, but if a recommendation is given, the purpose and description of the recommendation should be included.

An adjustable range of room temperature was shown in prototype 4. The meaning was well understood. Ten of the test users thought that the user interface should show that information. None of the test users considered the feature unfavourable.

The outdoor temperature was shown in all of the prototypes. In general, the feature was liked; such information was needed, especially for dressing when going out. A few respondents wondered if the outdoor temperature could be adjusted, but then noticed the impossibility. One of the test users examined how the room temperature and outdoor temperature are related, because they are shown close to each other. These examples make clear that the secondary features should not be as visible in the user interface as the primary features; the outdoor temperature should be presented in the user interface, but not in the central part of it.

The user interface prototype 4 (Fig. 31) received very positive feedback from the test users. All the test users liked its clarity and compactness. The current temperature set point is presented clearly, and it was easy to adjust the set point with the red (+) and blue (–) buttons.

At the end of each usability test each test user was asked to choose the prototype he or she preferred the most. In addition, they were asked to give suggestions on how to improve the prototype. Without doubt, the most popular of the prototypes was number 4, with 12 votes, while prototypes 2, 3, and 6 received one vote each; none of the other prototypes were chosen by any test user. The only criticism of prototype 4 was that it lacked the time information (how long it takes the room temperature to change). A few test users wished to include a recommendation for the temperature set point.

Prior to the usability tests, some participants were critical of the idea that room temperature could be adjusted with a personal computer, but after they had seen the prototypes and had had an opportunity to try them, all 15 test users would like to have that kind of user interface for their own use.

6.3 Phase 3

Based on the results from the second phase one user interface prototype was developed in phase 3 (Fig. 34). The prototype was based on the prototype 4 of the previous phase with some modifications. It now includes the time information (how long it takes the room temperature to change) because the feature was liked in phase 2.

Control of ventilation and lighting (with limited features) were also included in phase 3. The user interface allows the user to boost ventilation for a chosen time, and to dim general lighting, or turn it on and off. This dissertation concentrates on the temperature control, and the results concerning ventilation and lighting are not presented in any detail.

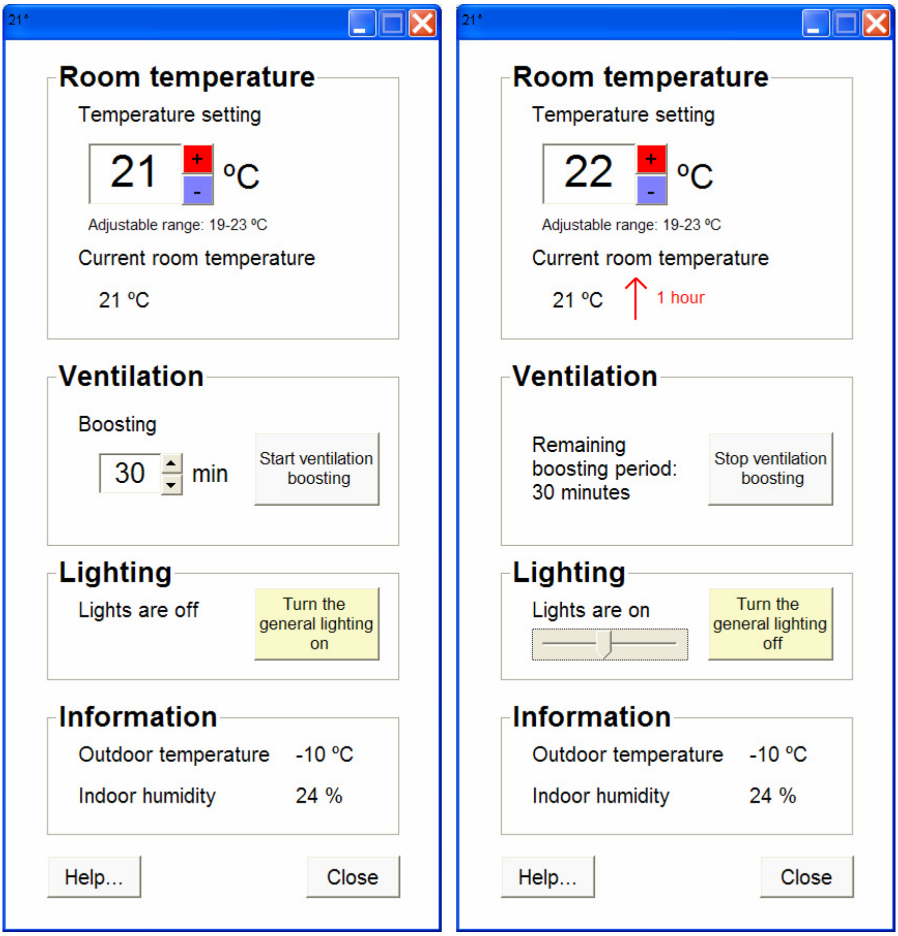

Fig. 34. User interface prototype in phase 3. The figure shows the user interface before and after user adjustments.

As in phase 2, the user can adjust the room temperature, and see the adjustable range of the room temperature, the current room temperature, and the current outdoor temperature. The user can also see the current room air humidity (%).

The arrow and the time information are shown when the temperature is adjusted (Fig. 34).

The goal of the third phase was to find usability problems with the prototype and to gather user opinions. How accurately users want to adjust the temperature set point was also studied, asking if an accuracy of 1 ºC enough, or if users want to adjust the temperature more accurately.

In general, the user interface prototype received very positive comments from the test users. All eleven test users would like to have the user interface for their own use (Table 10, p. 94). Room temperature was found to be easier to adjust with this user interface than with the systems currently in their offices. The room temperature control was found to be a more important feature than the other two main features, boosting ventilation and controlling lighting[7].

All the test users succeeded in adjusting the temperature, boosting the ventilation and controlling the lighting, but some usability problems were found. The meaning of the arrow and the related time was not understood by all the test users. The time was incorrectly understood to mean the period during which the adjustment was effective (as in boosting ventilation). Two of the test users did not understand the meaning of the adjustable range (note, the text was in Finnish on the user interface). None of the test users wanted to adjust the room temperature more accurately than 1 ºC. The results are shown in Table 11 (p. 95).

6.4 Phase 4

The prototype for phase 4 (Fig. 35) was based on the results of the previous phase. The modifications are rather small:

- The time was labelled with the text “Time it still takes to reach the temperature setting”. A progress bar was added to visualise the time.

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[7] Also the participants of phase 4 and 5 think that the room temperature control is the most important feature.

- The terminology was slightly modified. For example, the text ”Adjustable range” was replaced with the text ”Temperature can be adjusted between”. The text was placed differently because it was longer than before (especially in Finnish).
- A help file was written. Additional contextual help messages (pop-ups) were included. The contextual help messages are opened from the question marks, see Fig. 35.
- Several modifications concerning ventilation and lighting were made.

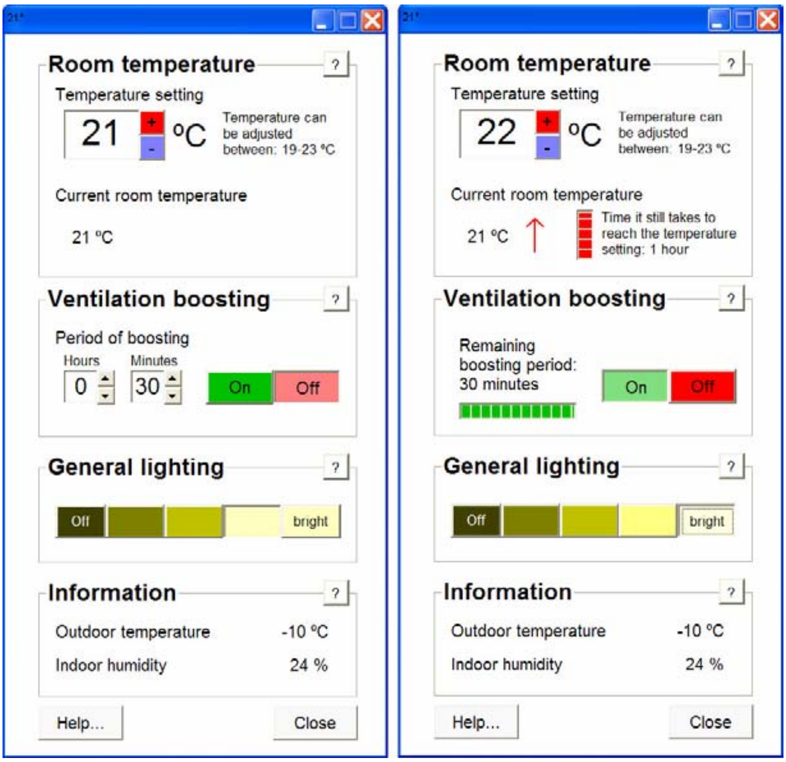

Fig. 35. User interface prototype in phase 4. The figure shows the user interface before and after user adjustments.

The goal was to study how the differences affect the usability of the prototype. The results show that the arrow and the time were well understood and that the information was found to be important, but there were problems in understanding the meaning of the progress bar that was added to visualise the time.

The contextual help messages were found to be useful and short enough. The shared help file was long and hard to read, and it was not liked that it opened in a browser and covered the prototype. In addition, there were still some terminology problems concerning ventilation.

Overall, the results were similar to the previous phase. All the test users were novices but were able to adjust the temperature, boost the ventilation and control the lighting. All of the eight test users would like to have the user interface for their own use. The results are shown in Table 10 (p. 94) and Table 11 (p. 95) as in phase 3.

6.5 Phase 5

In phase 5 the user interface was connected to a building, so the user actions had a real effect on the temperature, ventilation and lighting of a room. The control system was built with LabVIEW. The user interface was re-designed with LabVIEW, but was similar to the previous phase with some minor changes: the progress bar visualising the time and the shared help file were removed (contextual help was still in use). The system was built in one room.

The results of the usability tests in phase 5 confirmed the results of the previous phases. Novice users were able to use the user interface with high effectiveness, high efficiency and high satisfaction. Many of the test users were delighted when they noticed that they really can adjust room conditions with a personal computer. The effect on temperature could not be perceived because of the delay, but the lighting changed instantly, and increased noise informed the user when ventilation was boosted.

The arrow denoting the direction of the room temperature change was not found necessary by everyone, because they got the information without recognizing the arrow. However, there is no reason to remove the arrow from the user interface. The opinions concerning dimming were diverse; respondents were either satisfied with it or wanted to have more or less steps than five, or stepless control.

All of the eight users would like to have the user interface for their own use. There was a lot of interest in using that kind of system also at home. The results are shown in Table 10 and Table 11 as in phases 3 and 4.

Table 10. Results of the questionnaire which was filled in after testing the user interface prototype of phases 3, 4 and 5. Depending on the question, the respondents were presented with either two alternative answers or five alternative answers. The format: phase 3/phase 4/phase 5. Percentages are given for sums of phases 3–5.

Question	**Results**						
Would you like to have that kind of user interface for your own use? (It is supposed that the systems in the building enable the functions.)	yes	11/8/8 100%			0/0/0 0%		no
How easy is it to use the user interface?	very easy	6/5/5 59%	4/2/3 33%	1/1/0 7%	0/0/0 0%	0/0/0 0%	very hard
Is it easier or harder to adjust the room temperature with the user interface than with the current office system?	a lot easier	10/5/7 81%	1/1/1 11%	0/2/0 7%	0/0/0 0%	0/0/0 0%	a lot harder
Are there any terms that are hard to understand?	a lot	0/0/0 0%	0/0/1 4%	1/2/0 11%	3/3/2 30%	7/3/5 56%	not at all
How important is it to improve the layout of the user interface?	very neces sary	0/0/0 0%	1/1/2 15%	1/1/1 11%	5/3/3 41%	4/3/2 33%	not necessary at all

Table 11. Results of the usability tests in phases 3, 4 and 5. The format: phase 3/phase 4/phase 5. Percentages are given for sums of phases 3–5.

	Yes (+)	**Between yes and no (+/–)[a]**	**No (–)**
Did the test user understand the meaning of the arrow correctly?	8/7/6 78%	3/0/2 19%	0/1/0 4%
Did the test user think the arrow is necessary?	8/5/5 67%	1/2/2 19%	2/1/1 15%
Did the test user understand the meaning of the time correctly? (In the phase 4 and 5 prototypes the time was labelled with the text "Time it still takes to reach the temperature setting".)	6/8/8 81%	3/0/0 11%	2/0/0 7%
Did the test user think the time is necessary?	10/7/8 93%	0/1/0 4%	1/0/0 4%
Did the test user understand the meaning of the adjustable range correctly? (In the phase 4 and 5 prototypes the text "Adjustable range" was replaced with the text "Temperature can be adjusted between".)	9/8/8 93%	0/0/0 0%	2/0/0 7%
Did the test user think the information on the adjustable range is necessary?	11/7/8 96%	0/1/0 4%	0/0/0 0%
Did the test user think an accuracy of 1 ºC is enough for adjusting the temperature (no need to adjust the temperature more accurately)?	11/7/7 93%	0/0/1 4%	0/1/0 4%

[a] Between yes and no (+/–) means that the test user understood the meaning of a feature almost correctly, or the test user thought that feature is quite important.

6.6 Summary

A user-centred approach was applied in developing user interfaces for office occupants for controlling the temperature, ventilation and lighting of an office. The focus of the work was on individual control of room temperature. The user interface development was iterative, and the usability tests were conducted several times during the development process. The results show that novice users are able to use the user interface prototypes with high effectiveness, high efficiency and high satisfaction. This is a remarkable improvement as users have serious problems with the thermostats currently in offices. All 42 participants in the usability tests would like to have that kind of new user interface for their own use. It was also found that users prefer absolute temperature scales in the interface and many users like temperature recommendations. The arrow denoting the current direction of the room temperature change and short contextual help messages were found to be useful.

7. Usability guidelines for room temperature controls

Usability guidelines give designers resources in developing interactive systems. There are many usability guidelines available in the literature (Section 2.3), but none takes into account the special qualities of room temperature control such as the thermal inertia (Section 1.5), the characteristics of human thermal comfort (Section 1.4), occupants' low knowledge of heating and cooling systems (Section 5.7), occupants' false idea of comfortable temperatures (Section 5.7), and characteristics of heating and cooling systems.

Usability guidelines developed in this work are presented in this chapter. A preliminary version was issued in Publication V (in a form of user requirements). The principal goal of the guidelines is to help designers to create temperature controls that enable office occupants to adjust the room temperature of their own office. Novice users should also be able to use the temperature controls with high effectiveness, high efficiency and high satisfaction without a learning period.

Although the usability guidelines are targeted for designing user controls in offices, they can be largely applied in designing room temperature controls for other spaces also. The usability guidelines are useful in designing both hardware ("solid" user interfaces, for example, a room thermostat) and software (for example, graphical user interfaces for PC). The applicability of the usability guidelines is discussed in Section 8.4.4.

The usability guidelines developed in this work are based on (1) the problems office occupants have with temperature controls (Section 5.8), (2) the experiences gained from the user interface development and usability testing (Chapter 6), (3) other user research performed in this work (Chapter 5), and (4) literature.

The usability characteristics, i.e. the essential elements of usable room temperature control, are included in the usability guidelines. Guidelines from 2 to 12 present the characteristics of usable room temperature control. They are related to the characteristics of user interface or the characteristics of the system behind the user interface. The first guideline (no 1) refers to the general principle of the system. The last guideline (no 13) is not related to product characteristics but to the development process of room temperature controls.

7.1 Keep occupants in the loop

Keep occupants in the loop: occupants should have temperature controls available for adjusting room temperatures.

Justification

Individual control of thermal environments is needed from the standpoint of thermal comfort and satisfaction (Section 1.1). In offices, productivity and health reasons also support individual thermal control (Section 1.1). Currently, the perceived control over room temperature is remarkably low in offices (Section 5.1).

Users must also be kept in the loop in user-adaptive systems, because thermal comfort depends on one's psychological state and the systems are not able to predict how individuals are feeling at any particular time (see discussion in Section 8.4.3).

7.2 Visibility, identification and reachability of temperature controls

A temperature control should be visibly located in the room it affects and its purpose should be easily identifiable. Identifiably is enhanced by symbols that refer to temperature, e.g. a thermometer, a degree sign, or red and blue colours (denoting warm and cool); text can also be used to clarify the purpose of temperature controls.

Office occupants should be advised that the temperature controls are for their use, not for service personnel.

Temperature controls should be placed in an easily reachable position, for example, not high up on the wall.

Justification

Currently office occupants do not always know they have a temperature control (thermostat) in a room, because the device is not recognised at all or the purpose of the device remains unclear (problem 1 in Table 8, p. 78).

If office occupants have noticed the existence of temperature controls, they often have not used them. Many of the occupants do not know that they are allowed to touch temperature controls but think that they are for service personnel only (problem 3A in Table 8, p. 78). Temperature controls (thermostats) are often inappropriately located and impossible or awkward to use (problem 2 in Table 8, p. 78).

7.3 Shared temperature controls with heating and cooling systems

In a room, there should not be separate temperature controls for heating and cooling systems. If a room is heated and cooled by separate (building-level) systems, the temperature controls should be shared.

Justification

If there are separate controls for the systems, users do not find them all and may adjust a passive system (problem 4 in Table 8, p. 79).

7.4 Acceptable default settings

With the default settings, the average person should be satisfied with the room temperature.

Justification

It is desirable that most occupants do not have to adjust temperature controls (thermostats) to be comfortable since Paciuk (1990) has noted that there is a cost involved in the exercise of temperature control. Also Leaman and Bordass (2001) (Section 2.3.6) suggest that default states should be predictable and reasonably acceptable.

7.5 Simplicity of interface

The user interface should be simple. The features should be limited to the most important. Secondary features should not add unnecessary complexity.

Justification

The rule of simplicity is included in almost all the guidelines for usability, for example, Polson and Lewis (1990) (Section 2.3.2) suggest offering few alternatives and Nielsen (2006) (Section 2.3.4) suggests minimalist design. For example, the problem 5C in Table 8 (p. 79) may have been avoided with simpler design. If outdoor temperature is presented in the user interface (which is suggested) it should not be in the central part of it (Section 6.2).

7.6 Clear way to adjust room temperature

The user interface should very clearly represent how to increase and decrease the room temperature set point.

One should consider showing temperature set point values in the user interface, because it makes it easier to choose a temperature setting and reduces the possibility to adjust the temperature in the wrong direction.

Justification

Users had problems in understanding the meanings of lights and symbols and in understanding how to use temperature controls (problem 5B and problem 6 in Table 8, p. 79) when the thermostats in offices were examined. The prototypes developed in this work were understood much better and it was found to be easy to adjust the room temperature (Table 10, p. 94). The understandability of the prototypes was supported especially by two characteristics of the interface: temperature value is shown, and red and blue colours are used to denote warmer and cooler temperatures.

Some symbols are easy to misunderstand. A sun and a snowflake can be understood to mean the summer and winter period, or an increase and decrease in temperature, so these symbols are not recommended. Similarly, "+" and "–" can be understood to mean either an increase and decrease in temperature or in cooling power.

Phases 1 and 2 (Sections 6.1 and 6.2) of user interface development revealed that users prefer absolute temperature scales in interface, i.e. they want to set an exact temperature value. Similarly Nielsen (2006) (Section 2.3.4) suggests to "match between system and the real world", a match which is realised best with absolute temperature scale.

When adjusting temperature settings users have a goal of setting room temperature to the desired direction by the desired amount (Section 3.2). If temperature set point values are shown on the interface, it makes it easier to choose a setting by which the desired change in room temperature will be achieved.

In general, if a control system requires formal training, it is too complex. It is unrealistic to suppose that office occupants would be motivated to spend much of their valuable time on learning the way in which building works.

7.7 Advice on comfortable room temperatures

Temperature controls should advise occupants on comfortable room temperatures, for example, by denoting thermal comfort zones. A recommendation should be given together with information on its purpose.

Justification

Occupants have a false idea of absolute values of comfortable room temperatures, especially in the summer season (Section 5.7). Many users like a room temperature recommendation (Section 6.2).

7.8 Clear and sufficient feedback after adjustment

The temperature control should give clear feedback to the user. The user should be given two kinds of feedback because the rate of temperature change is slow.

The user should instantly receive feedback after the adjustment to know that the system is working to fulfil the request. Later the user should receive feedback which informs him or her that the requested change to the room temperature has been realised in total.

The feedback can be natural (for example, noise from the system) or artificial (such as the arrow, time, and temperature values in the user interface prototypes in Sections 6.2–6.5).

If it is not possible to reach the adjusted room temperature, the user should be informed (and given an explanation).

Justification

The rule of clear and understandable feedback is included in almost all the guidelines for usability: for example, Shneiderman and Plaisant (2005) (Section 2.3.3) suggest offering informative feedback and Nielsen (2006) (Section 2.3.4) argues for the visibility of system status. Leaman and Bordass (2001) (Section 2.3.6) state that user should "know immediately that an appropriate response has occurred".

Because of the thermal inertia (Section 1.5), it is particularly important that room temperature controls give clear and sufficient feedback.

Currently temperature controls (thermostats) often do not give any feedback, or if they do give it, the feedback is typically not understood by users (problem 5 in Table 8, p. 79).

In usability tests with elderly persons, Baillie and Schatz (2006) recognized that without immediate understandable feedback users do not know when they have accomplished the task of adjusting "heating temperature" by using a PDA (personal digital assistant).

7.9 Fast effect on room temperature

It is desirable that the room temperature changes rapidly after user adjustment. So, from the user's point of view, the systems should be chosen and dimensioned to have a fast effect on the room temperature.

Justification

Occupants may become quite uncomfortable before acting, but when they take an action, they want to get a fast response (Bordass et al. 1994). If room temperature changes are fast, users will have less need for other responses, such as opening a window, or adding or taking off clothing.

7.10 Adequate effect on room temperature

The necessary range of individual temperature control is 4 ºC (±2 ºC).

However, users have no need to adjust the temperature set point with great accuracy; an accuracy of 1 ºC is sufficient.

Justification

If users have only very limited possibilities to adjust the room temperature, the idea of individual temperature control is not realised. On the other hand, high differences between room temperatures cannot be achieved because of heat transfer between rooms. For energy efficiency, it is not reasonable to give users a very large range of individual temperature control (see discussion, Section 8.3).

According to Wyon (1996) individual control equivalent to 4 ºC (±2 ºC) satisfies more than 90% of building occupants. If the room temperature could be adjusted over a range of 6 ºC (±3 ºC), 99% of occupants would be thermally comfortable.

The usability tests showed that users think that an accuracy of 1 ºC is enough for adjusting the room temperature (Table 11, p. 95).

7.11 Informative help

Occupants should be given information on the effect the system gives (i.e. adjustable range of room temperature) and how to use the system. This information should be presented in a short form.

Justification

According to Nielsen (2006) (Section 2.3.4) it may be necessary to provide help and documentation, even though it is better if the system can be used without documentation. Because most of occupants have very little knowledge of the HVAC systems of the office building they work in (Section 5.7), occupants should be given some basic information. In the usability tests, the short contextual help messages were found to be useful (Section 6.4), and the information concerning the adjustable range was found to be necessary (Table 11). A long help file that opened in a browser and covered the prototype was not liked by the test users (Section 6.4).

7.12 Aesthetic design

The temperature controls should be aesthetic[8, 9].

Justification

There is no reason for temperature controls to be ugly, but there are reasons for aesthetic design. One of the three criteria for usability is satisfaction, i.e. positive attitudes to the use of the product (Section 2.2). According to Norman (2002) "attractive things work better". He states that positive affect can even make it easier to do difficult tasks and that in positive situations people are more likely to be tolerant of minor difficulties. Also Tractinsky et al. (2000) stress the importance of the aesthetic aspects on usability.

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[8] Note that the user interface prototypes developed in this work (Sections 6.2–6.5) should not be considered as examples of an aesthetic look. The prototypes presented in this work are tools for research, not final products, and were not designed by a graphic artist. The aesthetics of the prototypes could be improved considerably.

[9] Because there are individual differences in aesthetic preferences, it is recommended that a user could choose the aesthetic appearance he or she prefers.

7.13 Females as test users in real-life situations

Female subjects should primarily be used as test persons in field studies of thermal comfort, for example, in the product development phase of temperature controls.

Justification

Females are more critical of indoor thermal environments in real-life situations than males (Section 5.6)[10,11]. If the females are satisfied, it is most likely that males will also be satisfied.

7.14 Overview

The goal of the usability guidelines presented in Chapter 7 is to help designers to create usable room temperature controls. Because knowledge of general usability guidelines (Section 2.3) is low in the field of building science and among practitioners in that field, the most important general type of usability guidelines for the purpose were included in the usability guidelines. By including guidelines specific to room temperature control as well as ones for general usability, it is targeted that the designers of room temperature controls do not have to use other usability guidelines in parallel with these guidelines. Table 12 shows an overview of how the usability guidelines are related to special qualities of room temperature control and denotes the general type of usability guidelines.

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[10] In a study performed in Sweden, Hartig et al. (2007) found that cold summer weather affects mental health of females more than males.

[11] Sick building symptoms are more common among females than males (Burge et al. 1987; Lenvik 1992; Brasche et al. 2001).

Table 12. The relationship of the usability guidelines to special qualities of room temperature control. The general type of usability guidelines are marked with an asterisk (*) in the column on the right.

	The thermal inertia (Section 1.5)	**The characteristics of human thermal comfort** (Section 1.4)	**Occupants' low knowledge of heating and cooling systems and comfortable temperatures** (Section 5.7)	**Characteristics of heating and cooling systems**	**General usability guideline**
Keep occupants in the loop		X			*
Visibility, identification and reachability of temperature controls			X	X	
Shared temperature controls with heating and cooling systems			X	X	
Acceptable default settings	X				*
Simplicity of interface			X		*
Clear way to adjust room temperature			X		
Advice on comfortable room temperatures			X		
Clear and sufficient feedback after adjustment	X		X		*
Fast effect on room temperature	X	X			
Adequate effect on room temperature		X			
Informative help			X		*
Aesthetic design					*
Females as test users in real-life situations		X			

8. Discussion

8.1 Methodological considerations

The research methods of the thesis are described in Chapter 4. Fig. 7 (p. 44) shows an overview on the methods and materials. Next the methods are critically evaluated.

8.1.1 Qualitative interview survey

With the qualitative interview survey which included observation, rich information about office occupants as users of thermostats was collected. The interviews were performed in actual context, in the interviewees' offices. The method and materials are described in Section 4.1.

With the method, it was possible to gather data that revealed a lot of usability problems and many reasons for them. It was essentially important to have a direct contact with users, and it was a good decision to perform the interviews in the field, in the interviewees' offices. It is clear that, for example, telephone interviews or questionnaires could not have revealed all the usability problems that were discovered with the contextual interviews.

A total of 27 interviews were carried out. In the first part of the study twelve persons were interviewed. The results were analysed before the second part of the study, in which 15 persons were interviewed. The most important findings were made in the first part of the study. In the second part, only minor new findings were made, so it was clear that there was no reason to continue with more interviews, because saturation was reached.

Many of the findings originally made in the qualitative interview survey were later proved to be proper with the quantitative interview survey (e.g. gender differences and false idea of comfortable room temperatures), which shows that the results of the qualitative survey were reliable.

8.1.2 Quantitative interview survey

In the quantitative interview survey, users were studied with a large and nationally representative sample. The interviews were carried out by telephone. The method and materials are described in Section 4.2.

The method was evaluated during the whole work process. This section was basically written after the compilation of the interview questions but before the interviews. That was a good moment for a critical evaluation since it was still possible to edit the interview questions and the data acquisition procedure. In the thesis, the evaluation is presented only in a short form.

Size and representativeness of the sample

The goal of the survey was to obtain nationally representative data. Representativeness means that there are the same properties in the sample as in the population. Generally speaking, non-response is not random. It is easiest to get old people (pensioners) to the interviews as interviewees. In this study, the sample was collected with quotas set according to gender, age and province (demographic factors). This means that there is only a corresponding number of old people in the final sample. Instead it is more difficult to control the internal differences of each group (psychographic factors). For example, do the people who answered to the interview questions have a more positive attitude to technology than those who did not answer? That is not known, but they may have a more positive attitude since they agreed to answer interview questions dealing with technology[12]. However, it is not probable that there are differences between interviewees and non-interviewees in experiencing thermal environments.

The respondents of the study were between 15 and 74 years old. This age delimitation is based on international practices. I think that it is questionable to mark off the oldest people since now the voice of this age group is not heard. On the other hand, the study is directed at the future. Because the time span of the development work is many years and because the oldest respondents are not the

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[12] In the introduction to the interviews, the interviewee candidates were told that the interview deals with satisfaction with room temperature, lighting, and ventilation, and interest in future solutions.

most potential users of new applications, the delimitation of the people can be considered justified. And it is, of course, notable that the oldest people are not office workers.

Generally speaking, the results concerning homes can be kept more reliable than the results concerning offices, because the sample size was bigger. The questions concerning offices were answered by 1,000 persons, which is also a good number and gives reliable results. The margin of error is 1–3% in a sample of thousand people (at a level of confidence of 95%).

Effect of interview questions on the results

The possible problems related to the interview questions of the study are dealt with next.

Do the interviewees understand the questions correctly?

In preparing the interview questions an attempt was made to use as clear language as possible, unambiguous expressions and neutral form. The interview questions were tested several times before the realisation (see Section 4.2), which improved the quality of the questions considerably.

Can the interviewees answer the questions?

The majority of the questions treat opinions, attitudes and behaviour. The topics covered are close to everyday life. For example, everybody has experienced thermal environments which are too warm or too cool. No special knowledge is needed for answering most of the interview questions.

Certain questions are more difficult to answer. The question concerning the year of building construction is not easy to answer for everyone and was chosen to be asked only with an accuracy of a decade. No detailed questions on HVAC systems were asked because with the limited knowledge the occupants have they can not answer questions like this.

Many answer one question wrong. In the qualitative interview survey it was found that many office occupants are not aware of thermostats in offices (problem 1 in Table 8). So a part of those who say they do not have a thermostat in the office do actually have one.

Do the interviewees answer honestly?

The majority of the questions deal with opinions, attitudes and behaviour. There were no sensitive questions asked in the interview. Generally speaking, the interviewees have no reason to intentionally answer the questions incorrectly.

The interviewees may exaggerate their interest in energy saving because energy saving is generally considered important. Because the results show that the personal effort to save energy is quite low in offices (Fig. 27), it is clear that the interviewees have not (largely) exaggerated their interest in energy saving.

Do the interviewees have the endurance to concentrate on the long interview?

The duration of a telephone interview should not exceed 30 minutes (Laiho and Hietaniemi 2002). The average length of the interviews concerning home and office was 16 minutes. The interviews concerning only home were five minutes shorter. Although the interviews were fairly long, the average is not even near the suitable maximum length.

A problem with telephone interviews can be that the interviewees do something else simultaneously. If concentration is not decent, it will affect the answers. Because the topics in this study are close to everyday life, there is no reason to suppose that the interviewees have answered with poorer concentration than they normally do in surveys.

Effect of the time period when the interviews were performed

The interviews were performed in early in the winter, in November and in December. In the same interviews material concerning both the summer and winter seasons was gathered. This period was chosen because the experiences from the summer season are better remembered than later in the winter. However, the results would have been more reliable if two separate interviews had been performed, one in the summer season and another in the winter season, and if the respondents had been asked only questions concerning the current season.

The interviewers' effect on the results

The interviewers' education and supervision affect the quality of the results. In the data collection agency which was responsible for the practical realisation of the interviews, the interviewers have project-specific education in addition to the basic education. The supervision is made at many separate levels. The quality system of the data collection agency includes the piloting, real-time supervision of the telephone interviews and random post-control of the performed interviews.

The interviewers' personality and the way they ask the questions also influence the results. There were a total of 117 interviewers in this study so the characteristics of an individual interviewer do not affect the results remarkably.

8.1.3 Controlled experiments

The controlled experiments simulated real use of thermostats. For a more detailed description of the method, see Section 4.3. The results show that females adjusted room temperature higher than males to fulfil their current temperature preferences. There was no gender difference in clothing insulation, and males and females were not seated differently in the auditorium (discussed in Section 4.3).

Are there any other research-design related reasons that would explain the gender difference? Do females have a different idea of what temperature values (for example, 2 °C) mean in practice? Because all the subjects were university students of technology (see Table 3), i.e. both the females and the males are mathematically oriented in nature, it is not presumable that the gender difference which was discovered results from a different idea of temperature values.

8.1.4 Usability testing

The method for usability testing was an informal walkthrough, so there were no pre-defined test tasks, but the participant went through the user interface at his or her own pace and in his/her preferred order. For a more detailed description of the method and materials, see Sections 4.4.2 and 4.4.1.

The informal walkthrough is suitable for testing how easily the system can be learned, but not for measuring efficiency (Riihiaho 2000). For example, it is not possible to measure task completion time with the informal walkthrough. Because the user's goal (set room temperature in the desired direction by the desired amount, see Section 3.2) is very simple and can be achieved just by pressing one button, it is clear that a system that is easy to learn is also efficient to use.

All the test users were novices but were able to adjust the temperature in the desired direction. However, it was not possible to determine whether the secondary goal "by the desired amount" was met, because of the artificial nature of the tests, i.e. in phases 1–4, user actions had no real effect on room temperature, and not all of the participants had a real need to set room temperature. It is clear, however, that it is easier to achieve the desired effect on room temperature with the absolute temperature scale (which was used in the prototypes in phases 3–5) than with no scale or with a relative scale which has no temperature values.

In a review of usability measures in research practice Hornbæk (2006) emphasizes the importance of studying both objective and subjective measures of usability. He gives examples of studies where diverging results were gained with objective and subjective measures (objective time vs. subjective experience of duration, objective workload vs. subjective workload). In the present work, the usability measures were mostly subjective (see Table 10 and Table 11). The objective measures of the tests included task completion (Were the test users able to adjust the temperature?) and measures of the understandability of the interface elements. An important question is the following: are any essential usability measures missing? Bevan and Macleod (1994) see that subjective satisfaction may be the most important criteria when use is voluntary, which is the case with room temperature controls. In this study, it was assumed that the key features of temperature control interfaces are related to the understandability of the interfaces and subjective satisfaction with the interfaces.

According to Nielsen, 85% of usability problems can be discovered with only five test users and all the usability problems can be found with fifteen test users (Nielsen and Landauer 1993; Nielsen 2000). In this work, usability tests were performed in five phases and in each phase 8–15 test users participated in the tests. The amount of the test users was sufficient to find all of the most important usability problems. The usability tests also gave information on user preferences and improved our understanding of user requirements.

Long-term implications of the use of the prototypes could not be studied in the short usability tests. The real effect of improved user interface design on perceived control, thermal comfort, occupant satisfaction, productivity and energy consumption was not studied. To study these important issues, a prototype should be installed in a real building and the real-use situation over a longer period of time should be investigated.

8.2 Applicability of the usability guidelines

The purpose of the usability guidelines (Chapter 7, summarized below in Table 13) is to help designers create room temperature controls which enable office occupants to adjust the room temperature of their own office.

The usability guidelines are based on (1) the problems office occupants have with temperature controls (Section 5.8), (2) the experiences gained from the user interface development and usability testing (Chapter 6), (3) other user research performed in this work (Chapter 5), and (4) literature.

Table 13. Usability guidelines for room temperature controls.

Keep occupants in the loop
Visibility, identification and reachability of temperature controls
Shared temperature controls with heating and cooling systems
Acceptable default settings
Simplicity of interface
Clear way to adjust room temperature
Advice on comfortable room temperatures
Clear and sufficient feedback after adjustment
Fast effect on room temperature
Adequate effect on room temperature
Informative help
Aesthetic design
Females as test users in real-life situations

The set of usability guidelines is specific for room temperature controls but quite general in the way it handles different kinds of room temperature controls (see Table 13). For example, every kind of room temperature control should have a "simple interface", give a "clear and sufficient feedback after adjustment" and have a "fast effect on room temperature".

Although the usability guidelines are targeted for designing user controls for offices, they can be largely applied in designing room temperature controls for other spaces also. The usability guidelines are useful in developing room temperature controls for homes and for meeting rooms, for example. An important difference between homes and offices is that people are much more interested in saving energy at home, which should be taken into account in designing interfaces for use at homes.

If occupants in an open-plan office share a user interface (for example, a room thermostat on a wall), it can be developed following the usability guidelines.

The user interface prototypes developed in this work were graphical user interfaces for PC. The usability guidelines are, however, also based on the problems office occupants have with room thermostats and other thermostats in offices (Section 5.8). The applicability of the usability guidelines is not restricted to software interfaces only, but the usability guidelines can also be applied to the design of room thermostats (i.e. hardware).

Although the user interface characteristics of mobile phones were not taken into account, the usability guidelines are also *useful* for developing user interfaces for mobile phones, but the guidelines should not be considered as all-inclusive for the purpose.

8.3 Influence on energy consumption

The principal aim of the work is to improve office occupants' control over room temperature by improving the usability of interfaces. Energy conservation is not primarily targeted in the work, but the issues influencing energy consumption are also considered.

Individual temperature control may increase energy consumption. Still, even a minor improvement in productivity or health has a higher monetary value than the possible increase in energy consumption (for estimates of improved productivity and health from better indoor environments, see Fisk and Rosenfeld 1997 and Clements-Croome 2000). It is, however, not reasonable to give users a very large range of individual temperature control. For example, users should not be able adjust the room temperature to +16 ºC in the summer. Users should have the possibility to adjust the room temperature to fulfil their individual needs, but not to make inappropriate adjustments.

Office occupants have low motivation to save energy in offices (see Section 5.7) and it is not easy to motivate them to save energy. The goal should be that the systems and their user interfaces should be designed so that the normal way of use leads to energy conservation.

How does usability of temperature controls affect energy consumption? I suppose that improving the usability of temperature controls leads to energy conservation since Bordass et al. (1994) note that “when discomfort arises, what gets operated first is what comes easiest, not what is desirable technically”. Nowadays windows are commonly opened to cool room air during the heating period (Fig. 15), although the most appropriate action would be to reduce the heating. If room temperature controls were usable and quickly affected room temperature, occupants would be more likely to adjust thermostats, instead of opening windows. This would lead to energy savings. In this work, impact on energy consumption was not studied. Future work should test the hypothesis that usability of temperature controls leads to energy conservation.

8.4 Other considerations

Next, several different issues on room temperature control are discussed.

8.4.1 Adaptive opportunities in offices and homes

A very distinctive difference in perceived control over room temperature at home and in the office was found (Fig. 12). In offices occupants are strongly dissatisfied with their control opportunities over room temperature.

There are several reasons why control over room temperature is felt to be better at home than in offices. User-adjustable thermostats are more common in homes (Fig. 16). Thermostats in homes are easier to reach (Fig. 18); in offices they are often located inappropriately (problem 2 in Table 8). Although thermostats are similar in homes and offices, thermostats are found to be easier to use at home (Fig. 18). That finding is supported by the fact that knowledge of heating and ventilation systems is better at home (Fig. 26). Thermostats are used more actively at home (Fig. 17); people often do not dare to touch thermostats in offices because thermostats are thought to be for service personnel only (problem 3A in Table 8), or because they do not know how a thermostat affects the environment (problem 3B in Table 8), or because their own temperature preferences may conflict with the preferences of others. It is clear that there are also problems in the use of thermostats at home, but these problems seem not to be as widespread and serious as in offices.

People have better adaptive opportunities at home than in offices also for several other reasons. Clothing can be chosen more freely at home because dress codes are more strict in offices than in homes. The possibility of moving from one room to another with a more satisfying thermal environment is better at home. At home, if feeling cold, one can get under a blanket. At home, one can take a warm or cold shower or bath, and in Finland we often go to the sauna.

Another important difference between the two environments is that most of the occupants can open a window at home, but less than half have an openable window or are allowed to open a window in offices. An immediate effect on the thermal environment can be achieved by opening a window. At home, 43% have a fireplace, which can be used to increase the room temperature. This is one of the many reasons for better control over room temperature at home than in the office.

A comparison between home and office makes clear that thermal comfort is affected by the adaptive opportunities. The key reasons for lower thermal comfort levels in offices (Fig. 9) are that people have fewer opportunities to control the thermal environment, do not deal with thermostats so well, and have fewer opportunities to adapt to different thermal environments.

8.4.2 Placebo effect with thermostats

The goal of designing environments should be to enhance the occupants' perceived freedom and perceived control (Barnes 1981). It may not be necessary that occupants actually have control over the relevant events but to perceive this control (Burger 1989). The availability of temperature controls may improve thermal comfort by the mechanism that works like this: an occupant has access to a temperature control and feels that he or she has control over temperature. He/she may not actually use the temperature control, but knows that he or she is able to use it if needed. Several papers (Humphreys and Nicol 1998; Leaman and Bordass 2000; Brager et al. 2004) note that people are more tolerant if they have control over their own thermal environment.

This is, however, not a real placebo effect. The placebo effect is, in the context of thermostats, a phenomenon that a user adjusts a thermostat and believes that it works and feels a change in room temperature, although there is no actual effect on the temperature.

The placebo effect is more likely with room thermostats than with thermostatic valves. Users of thermostatic valves often touch radiators and notice if there is no change in the radiator surface temperature. Users of room thermostats do not generally have that kind of possibility (but that depends on the system the room thermostat is connected to).

A newspaper article (Sandberg 2003) claimed that a lot of office thermostats (room thermostats) are “dummies”. According to the article, HVAC technicians have installed dummy thermostats to give workers the illusion of control and to reduce complaints about temperature. Another article (Arabe 2003) continued the story by conducting an informal survey on its web site, asking, “Have you installed dummy thermostats?” Most of the 70 respondents said that they have. Although the reliability of the study is low, it is presumable that there are dummy thermostats in offices. Some HVAC experts (in the United States) say that 90% of office thermostats are dummies and others say it’s below 2% (Sandberg 2003).

No scientific study on the placebo effect with thermostats was found in the literature. The possible existence of the placebo effect could be studied by collecting two comparable data sets: one with thermostats that have a real effect on temperature and the other with dummy thermostats.

The placebo effect was not studied in this work. However, the possible existence of the placebo effect is next examined by discussing the results of this work.

The actual change in the room temperature is slow, because of the thermal inertia (Section 1.5). If a fast change in room temperature is felt after a user adjustment of a room thermostat, it may be psychological in nature. The results of the quantitative interview survey show that more than one-third of the occupants feels that the rate of change in the room temperature is “very fast” or “fast” (Fig. 19). However, it is not exactly known what the respondents mean with “very fast”. Do they mean that they feel an (almost) instant change in temperature? Or, do they just say that they are happy with the speed? To study the placebo effect, respondents should be asked to state the time it takes the room temperature to change to the satisfied level after a user adjustment.

Fig. 19 shows also that more than one-third of the occupants think that there is no change in the room temperature or the change is “very slow” or “slow”, which suggests that the possible placebo effect does not work on all the occupants.

The qualitative interviews showed that it is frequently the case that a user adjusts a system which is not currently active and gets frustrated when the thermal environment does not improve. This frustration does not suggest a placebo effect. Instead, if there were users of passive thermostats that feel to profit from adjusting a passive thermostat, it would suggest a placebo effect. However, no clear evidence of that was discovered in the qualitative interviews.

In summary, it is apparent that there are psychological factors affecting thermal comfort (Parsons 2003; Fountain et al. 1996; Brager and de Dear 1998; Muhic and Butala 2004). The placebo effect may work on a portion of the occupants. A placebo test could be performed by collecting two comparable data sets.

8.4.3 Challenges in human-technology interaction in user-adaptive temperature control

It would be ideal that the thermal environment of a room adjusts according to individual preferences when a person enters a room. That kind of feature is common in the scenarios of intelligent buildings and ubiquitous computing (see, for example, Schmidt and Beigl (1998), Ito et al. (2003) and Mozer et al. (1995)). The ideal system would learn preferences gradually from actual use, and no user programming would be needed. A person can be identified if, for example, he or she is carrying an active badge (Weiser 1991; Want et al. 1992) or by a smart floor that identifies users from footsteps (Orr and Abowd 2000). In Bill Gates’ house (Gates 1995), occupants and visitors wear small electronic pins that let the computers know who and where they are.

Learning individual preferences from actual use

If thermal environments are to be controlled individually and automatically, individual preferences must be known by the systems[13]. Learning is typically

[13] Also information concerning time and place (for example, working hours) would be useful for a system that aims to improve comfort and save energy.

done in situations where the user overrides automatic control. Override is seen as a motion of dissatisfaction used to teach the system a user preference. The main problem here lies in the fact that the system knows the action the user took but does not know *why* the action was taken. The system knows, for example, that the user wants a higher room temperature, but it does not know why. Did he or she take the control action because he or she has always been feeling cold in that room? Or is he or she wearing lighter clothing today? Or is he or she becoming ill? Or is he or she feeling cold because of an (indefinable) emotional reason?

When the system learns from user action, how does it do it? Does a user action teach a new room temperature level, which is utilised continuously from now on, or should the system learn the user's week profile – or day profile – because he or she may want a higher temperature in the morning than at night? Should the new temperature level only be utilised in one room or all the rooms the person uses?

As seen, user actions can be used in learning in many different ways. It is, however, very important that the system works in an expected manner from the user's point of view. If the user feels that he or she has lost control of the system, he or she will be unsatisfied. The user will not accept a system that works oddly.

Whatever the method, the learning processes may be difficult to convey to the users. However, it is important that the users get an explanation of why the system is behaving like it is (Birnbaum et al. 1997). Otherwise, behaviour that was meant to be intelligent may lead to more harm than good. Jameson (2003) uses the concept of predictability to refer to the extent to which a user can predict the effects of his or her own actions and the concept of transparency to refer to the extent to which a user can understand how the system works.

Other challenges

Clothing and activity level also influence thermal comfort (Fanger 1970). To work optimally, automatic control systems should adjust the thermal environment taking account of the current activity level and clothing, which is only possible in futuristic scenarios.

Because thermal comfort also depends on one's psychological state[14] (Parsons 2003; Fountain et al. 1996; Brager and de Dear 1998; Muhic and Butala 2004), it is not possible to predict how an individual is going to regard the thermal environment at any particular time. This means that feedback from users will always be needed, because systems are not able to predict how individuals are feeling at any particular time (assuming that we are not talking about very futuristic solutions).

8.4.4 Directions for future research

In this work, a diversity of usability problems with office thermostats was found (Section 5.8). An important reason for the usability problems is that a substantial amount of information is needed to use the thermostats but office occupants do not have that information. Other issues affecting the use and disuse of the thermostats were not thoroughly studied in this work. Future studies should improve our understanding on user behaviour.

Factors influencing user behaviour include the social environment, for example, the organizational environment and one's own responsibilities in the organization: for example, even if occupants know they are allowed to touch the temperature controls, they may avoid using them if they feel that it is not a part of their responsibilities. Open-plan offices need a study of their own because the social environment is very different from single-person offices, and it is clear that it affects the use of temperature controls. Mental models related to room temperature control should also be studied more thoroughly, because they affect the use of controls significantly.

As the definitive result of the thesis usability guidelines for control of room temperature were developed. The next step for research would be to install a new kind of user-adjustable temperature control (designed following the usability guidelines) in a few real buildings and to investigate the real-use situation over a longer period of time. With this approach, the real effect of improved user interface design on perceived control, thermal comfort, occupant satisfaction, productivity and energy consumption could be studied.

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[14] Thermal comfort is defined as "the condition of mind that expresses satisfaction with the thermal environment" (ISO 7730 2005).

9. Conclusion

Studies performed mainly in the late 1980's and early 1990's emphasised the importance of individual control of thermal environments. Nowadays the need for individual control of room temperature is widely recognised and local user controls of temperature are commonly available in modern office buildings, for example in Finland. However, the perceived control over room temperature is still remarkably low in offices.

The success of individual temperature control depends on the user controls (i.e. thermostats), the heating and cooling system and the control strategy. In this thesis, it was found that office occupants have fundamental problems with thermostats. Office occupants do not always even know they have a possibility to individually control the room temperature, because the device is not recognised at all or the purpose of the device remains unclear. If temperature controls are inappropriately located, they are not always found, and they are impossible or awkward to use. Occupants may think that they are for service personnel only. There are also problems with the use of temperature controls. It is not always known whether the temperature control is operating or not. Although the room thermostats our interviewees have in their rooms are simple, the lights and other symbols in the user interface were often not understood correctly. Users are not satisfied with the feedback they get from their control actions because it is not clear whether anything is happening. Users also found that it is not easy to know how to use the thermostat to get the desired effect on the room temperature. The main reason for the many of the problems is that the systems are planned and constructed without a realistic view of their users, i.e. occupants are supposed to have knowledge they do not have.

In this work, new user interface prototypes for room temperature control were developed. The prototypes were developed iteratively with a user-centred approach. The results of the usability tests show that novice users are able to use the user interface prototypes with high effectiveness, high efficiency and high satisfaction, and all 42 participants in the usability tests would like to have a similar kind of user interface for their own use.

As the definitive result of the work usability guidelines for control of room temperature were developed. The usability characteristics, i.e. the essential elements of usable room temperature control, are included in the usability guidelines. The usability guidelines are based on the user research performed in this work and the experiences gained from the user interface development. The usability guidelines are: (1) keep occupants in the loop, (2) visibility, identification and reachability of temperature controls, (3) shared temperature controls with heating and cooling systems, (4) acceptable default settings, (5) simplicity of interface, (6) a clear way to adjust room temperature, (7) advice on comfortable room temperatures, (8) clear and sufficient feedback after adjustment, (9) fast effect on room temperature, (10) adequate effect on room temperature, (11) informative help, (12) aesthetic design and (13) females as test users in real-life situations. The usability guidelines help designers to create user interfaces that enable office occupants to adjust the room temperature of their own office with high effectiveness, high efficiency and high satisfaction.

The next step for research would be to install a new kind of user-adjustable temperature control (designed following the usability guidelines) in a few real buildings and to investigate the real-use situation over a longer period of time. With the approach, the real effect of improved user interface design on perceived control, thermal comfort, occupant satisfaction, productivity and energy consumption could be studied.

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Appendix A: Participants in the qualitative interviews and usability tests

Table A1. The participants in each phase of the work. For example, P1-2 refers to participant 2 in phase 1. Participants of phases 1 and 2 participated in qualitative interview survey.

Code	Gender	Age	Occupation
P1-1	Female	54	Study advisor
P1-2	Male	52	Researcher
P1-3	Male	25	Researcher
P1-4	Female	45	Researcher
P1-5	Female	56	Dentist
P1-6	Female	28	Janitor/cleaner
P1-7	Male	36	Managing editor
P1-8	Female	25	Project co-ordinator
P1-9	Female	23	Office secretary
P1-10	Male	53	News editor
P1-11	Male	47	Development manager
P1-12	Male	49	Communications manager
P2-1	Female	28	Social worker
P2-2	Female	39	Social worker
P2-3	Female	33	Social worker
P2-4	Female	50	Social worker
P2-5	Female	43	Leading social worker
P2-6	Female	24	Accountant
P2-7	Female	47	Assistant accountant
P2-8	Male	57	Transportation chief
P2-9	Male	36	Financial manager
P2-10	Male	56	Cost accountant
P2-11	Male	31	System specialist
P2-12	Male	57	Group leader
P2-13	Male	32	Innovation consultant
P2-14	Female	27	Planner
P2-15	Male	40	IT developer
P3-1	Female	49	Taxation official
P3-2	Female	38	Taxation official
P3-3	Female	50	Taxation official
P3-4	Male	37	Taxation official
P3-5	Female	56	Clerical worker
P3-6	Male	44	Internal service provider
P3-7	Female	50	Publication secretary
P3-8	Female	53	Office manager
P3-9	Male	57	Office manager

Code	Gender	Age	Occupation
P3-10	Male	50	Librarian
P3-11	Female	51	Design engineer
P4-1	Male	67	Docent
P4-2	Female	60+	Teacher
P4-3	Male	39	Youth worker
P4-4	Female	41	Library assistant
P4-5	Female	43	Specially trained nurse
P4-6	Male	36	Head design engineer
P4-7	Male	59	Contact person
P4-8	Male	35	Buyer
P5-1	Female	33	Researcher
P5-2	Female	56	Personnel administration assistant
P5-3	Female	52	Secretary
P5-4	Female	42	Payroll secretary
P5-5	Male	47	Senior researcher
P5-6	Female	27	Researcher
P5-7	Male	28	Research trainee
P5-8	Female	45	Secretary

Appendix B: Thermostats the participants have in their offices

Table B1. Thermostats the participants of phases 1 and 2 have in their offices.

Code	Room thermostat[a]	Radiator with adjustable thermostatic valve
P1-1	Type A	Yes
P1-2	No	Yes
P1-3	Type A	No
P1-4	Type B	Yes (3 valves)
P1-5	No	Yes
P1-6	No	No
P1-7	Type B	Yes
P1-8	Type B	Yes (2 valves)
P1-9	Type A	Yes
P1-10	No	Yes
P1-11	Type C	No
P1-12	Type A	No
P2-1	Type D	Yes
P2-2	Type D	Yes
P2-3	Type D	Yes
P2-4	Type D	Yes
P2-5	Type D	Yes
P2-6	Type E	No
P2-7	Type E, but it was not working	No
P2-8	Type E	No
P2-9	Type E	No
P2-10	Type E	No
P2-11	Type B	No
P2-12	Type B	No
P2-13	Type B	No
P2-14	Type B	No
P2-15	Type B	No

[a] Type A is shown in Fig. 1 (p. 18) at right of the first row. To increase room temperature the dial should be turned upwards (+) and to decrease, downwards (–). The light symbol in the upper right corner is green when the room temperature is increasing and red when it is decreasing. In type B (Fig. 1, at left of the first row) the temperature dial is coloured with red and blue, which refer to warmer and colder. In this thermostat there are texts "comfort", "economy" and "off", and a light symbol that denotes the active mode. The mode cannot be chosen by the user. Type C has a similar temperature dial to type A, and, additionally, a dial to control the fan speed of the fan convector. Type D has a similar temperature dial to type B, and a dial to control the fan speed of the fan convector. Type E has two push buttons, one for increasing and one for decreasing temperature. It has a line of lights for indicating the user's choice.

Appendix C: Interview questions

This appendix gives an overview of the interview questions of the qualitative and quantitative interview surveys. Only a selection of the most important interview questions is shown to keep the appendix short. Interview questions concerning the home are mostly not included in this appendix, because the questions were basically similar to the questions concerning the office environment. Basic background information on the interviewees and the buildings they live and work in was collected in both the qualitative and quantitative survey, but the questions are not shown here. In the qualitative interviews, information on the office environment was also collected by observation.

The interview questions of the qualitative survey were semi-structured and open-ended: not all the questions were designed and phrased beforehand, but many questions were created during the interview, allowing flexible discussion. The interview questions of the quantitative survey were structured and the respondents were mainly asked questions to which they responded on a scale from 1 to 5 or by selecting from alternatives. The answer alternatives are partly suppressed in this appendix.

The reader should also note that the interview questions were originally in Finnish, but were translated into English for this publication.

Qualitative interview survey

- What do you like most/least in your office?
- How satisfied are you with room temperature / indoor air quality / lighting?
- What kind of problems have you had related to office indoor conditions?
- How important are comfortable room temperature / good indoor air quality / good lighting conditions for you? What is the most important of them for you?
- How do you react if you feel the room temperature is too high/low? Please, tell and show. How fast is the effect?
- What user controls do you have in your office? Please, present them us. How do they work?

- What kind of problems have you had with the user controls? Are they understandable? Are you able to use them?
- How familiar are you with the heating / cooling / ventilation system in the office? Could you explain how they work?
- What is your preferred room temperature? Is it related to the season? Do you think you need a higher or lower temperature than people on average?
- What is the room temperature now?
- Are you satisfied with your possibilities to adjust the room temperature / ventilation / lighting / humidity? Would you like to have improved control over the room temperature / ventilation / lighting / humidity?
- How important do you think it is to save energy? Is it important to save energy in the office? Would you accept temporary discomfort if energy could be saved?
- In which way do you think you could control room temperature / ventilation / lighting? With a computer? With a mobile phone? With speech? With gestures? With traditional devices?
- If you had a computer program by which you could control room temperature, what other functions or information would you like to have included in the system?

Quantitative interview survey

- How satisfied are you with the office? (1–5, very dissatisfied = 1, ..., very satisfied = 5)
- How satisfied are you with ventilation? (1–5)
- How satisfied are you with lighting? (1–5)
- How satisfied are you with room temperature in winter/summer? (1–5)
- How well do you feel you can personally control lighting? (1–5, very badly = 1, ..., very well = 5)
- How well do you feel you can personally control ventilation? (1–5)
- How well do you feel you can personally control room temperature in winter/summer? (1–5)

- How often do you feel uncomfortably cold/hot in the office in winter / summer? (alternatives)
- What is your principal action when feeling uncomfortably cold/hot? (an open-ended question)
- Do you have a user-adjustable heating device (radiator / convector / electronic heater) in the office? (yes/no)
- Do you have a room thermostat installed on a wall? (yes/no)
- How easy is it to reach the thermostat? (1–5, very difficult = 1, ..., very easy = 5)
- How often do you use the thermostat? (alternatives)
- How easy is it to choose a thermostat position? (1–5, very difficult = 1, ..., very easy = 5)
- What is the rate of room temperature change after a thermostat adjustment? (0–5, 0= no change at all, very slow = 1, ..., very fast = 5)
- How important do you think it is to save energy in an office? (1–5, not important at all = 1, ..., very important = 5)
- How much do you think office occupants influence the energy consumption? (1–5, very little = 1, ..., very much = 5)
- How much personal efforts do you make to save energy in the office? (1–5, very little = 1, ..., very much = 5)
- How important is it to improve the possibilities to monitor energy consumption of the office? (1–5, not important at all = 1, ..., very important = 5)
- How good is your knowledge of heating and ventilation systems of the office building? (1–5, very bad = 1, ..., very good = 5)
- What is your interest in the following? The possibility to adjust room temperature with a computer / a remote controller / a mobile phone / speech / gestures. What is your interest in a system that learns the personal preferences of room temperature and controls room temperature accordingly? (1 = not interested at all, ..., 5 = very interested)
- What is your preferred room temperature in living room at home in winter/summer? (an open-ended question)

- Do your family members have different preferences over room temperature? (yes/no)
- Is the one who wants a higher room temperature a male or a female? (male / female / no difference)
- Is it a male or a female who uses thermostats more actively in your household? (male / female / no difference)

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Title

The characteristics of usable room temperature control

Abstract

The overall aim of the work is to improve office occupants' control over room temperature by improving the usability of user interfaces of heating and cooling systems. Both qualitative and quantitative methods were employed to study office occupants as users of room temperature controls. The work started with qualitative interviews taken in actual context, in the offices of the participants. The problems with thermostats were found to be diverse and fundamental. Next, in a quantitative interview survey, users were studied with a large and nationally representative sample: 1 000 Finnish office occupants answered questions concerning the office environment. Additionally, to simulate the real use of thermostats, controlled experiments were taken. Based on the results of the preceding user studies, user interface prototypes for room temperature control were next developed with a user-centred approach. As the definitive result of the work, usability guidelines for room temperature controls were developed. The usability guidelines are based on the user research performed in this work and the experiences gained from the user interface development. The usability guidelines are: (1) keep occupants in the loop, (2) visibility, identification and reachability of temperature controls, (3) shared temperature controls with heating and cooling systems, (4) acceptable default settings, (5) simplicity of interface, (6) clear way to adjust room temperature, (7) advice on comfortable room temperatures, (8) clear and sufficient feedback after adjustment, (9) fast effect on room temperature, (10) adequate effect on room temperature, (11) informative help, (12) aesthetic design and (13) females as test users in real-life situations.

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Huonelämpötilan hallinnan käyttöliittymät
Käytettävyyden tarkasteluja toimistoympäristössä

Tiivistelmä

Työn kokonaisvaltaisena tavoitteena on parantaa toimistotyöntekijöiden mahdollisuutta vaikuttaa huoneensa lämpötilaan parantamalla lämmitys- ja jäähdytysjärjestelmien käyttöliittymien käytettävyyttä. Työssä tutkittiin toimistotyöntekijöitä huonelämpötilan hallintalaitteiden käyttäjinä sekä laadullisilla että määrällisillä menetelmillä. Ensin tehtiin laadullisia haastatteluja toimistotyöntekijöiden työhuoneissa, jolloin käyttäjillä havaittiin olevan monenlaisia ja perustavanlaatuisia ongelmia termostaattien kanssa. Käyttäjiä tutkittiin seuraavassa vaiheessa määrällisellä haastattelututkimuksella, jonka otos oli laaja ja suomalaisia edustava: 1 000 suomalaista toimistotyöntekijää vastasi toimistoa koskeviin kysymyksiin. Lisäksi järjestettiin kontrolloituja kokeita termostaattien käytön simuloimiseksi. Edeltävään käyttäjätutkimukseen pohjautuen ja käyttäjäkeskeistä lähestymistapaa soveltaen työssä kehitettiin käyttöliittymäprototyyppejä huonelämpötilan hallintaan. Lopullisena tuloksena luotiin käytettävyysohjeisto huonelämpötilan hallinnan käyttöliittymille. Käyttävyysohjeisto pohjautuu työssä tehtyyn käyttäjätutkimukseen ja käyttöliittymäkehitykseen. Käytettävyysohjeisto on seuraava: (1) anna mahdollisuus vaikuttaa huonelämpötilaan, (2) helposti tunnistettava laite näkyvässä ja helposti ulotuttavassa paikassa, (3) yhteinen käyttöliittymä lämmitys- ja jäähdytysjärjestelmän hallintaan, (4) hyväksyttävät oletusasetukset, (5) yksinkertainen käyttöliittymärakenne, (6) selkeä tapa muuttaa huonelämpötilan asetusta, (7) tieto miellyttävästä huonelämpötilan tasosta, (8) selkeä ja riittävä palaute käytön jälkeen, (9) nopea vaikutus huonelämpötilaan, (10) riittävä vaikutus huonelämpötilaan, (11) informatiivinen opastus, (12) esteettinen ulkoasu ja (13) naiset testikäyttäjinä todellisissa kohteissa.

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VTT PUBLICATIONS 662 The characteristics of usable room temperature control Sami Karjalainen

The importance of individual temperature control in offices was established in the 1980s and 1990s. Unfortunately, the advantages of individual temperature control have not been realized well in practice, largely because of problems in the usability of thermostats. The research approach of this dissertation involves several different methods by which it is targeted to find the usability characteristics, i.e. the essential elements of usable room temperature control. As the definitive result of the work, usability guidelines for room temperature controls are presented.

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