User requirements and user interface solutions for individual control of temperature in offices

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Abstract

Individual thermal control is important for handling personal differences in thermal preference. Several studies have shown that comfort, health and productivity in offices can be improved by individual thermal control. However, usability of the current solutions is low. Room thermostats and thermostatic valves are not often used by office workers. In this work new user interfaces were developed for controlling temperature, ventilation and lighting in office rooms. The focus of the work was on individual control of room temperature. Prototypes were developed iteratively with user-centred methods, and 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 effectiveness and satisfaction, and all the 42 participants in the usability tests would like to have that kind of user interface for their own use. The paper represents general user requirements for control of room temperature.

Keywords: Thermal comfort; Individual control; Office; User interface; Usability; Thermostat.

1. Introduction

1.1. The need for individual control of temperature

According to a well-known study by Fanger [1], there are individual differences in experiencing thermal environments, and no thermal environment can satisfy everybody. The need for individual control of thermal environments is widely recognised. It is agreed that individual control of local thermal environments is needed from the standpoint of comfort and satisfaction [2]. In addition to comfort, health and productivity reasons also

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support individual thermal control. According to studies [3–7], it is one of the central issues in improving working conditions and productivity. It has also been found that individual control of room temperature in office buildings reduces sick building syndrome (SBS) symptoms [8] and sick leave days [9].

Humphreys & Nicol [10] 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 [7,10]. According to Leaman and Bordass [11], most people are satisfiers not optimisers: people want conditions that are "good enough", and tolerate offsets if they have opportunities to make interventions. Nicol & Humphreys [12] state that discomfort increases if control is not provided, or if the controls are ineffective, inappropriate or unusable.

Wyon [5] 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.

1.2. User problems with temperature controls

Local temperature controls are often available in modern offices; adjustable thermostatic valves and room thermostats (Figure 1) are both common. Thermal environments are still often unsatisfactory, and several studies [13–15] have shown that the perceived level of control is low. Room thermostats and thermostatic valves are not often used by office workers, and the significance of individual temperature control on thermal comfort is low [16]. User problems with thermostats include the following [16]:

- The purpose of the room thermostat remains unclear. It is not recognised as being for temperature control.
- If both a room thermostat and a thermostatic valve exist in a room, the room thermostat is considered to be the only one and the thermostatic valve is not found.
- The thermostat is located behind furniture, or the room thermostat is located too high up on the wall, so that it is impossible or awkward to use it.
- Users do not dare to touch the thermostat because it is thought to be for service personnel only, or because its effect is not known.
- The thermostat does not give any feedback, or users do not understand the feedback (lights and

symbols, for example).

- Users don't know how to use the thermostat to get the desired effect on room temperature.

The main reason for many of the problems is that systems are planned and constructed without a realistic view of their users, and end users are presumed to have knowledge they don't have [16].

Fig. 1. Examples of typical room thermostats and thermostatic valves in Finnish offices.

1.3. User-centred design and usability

The goal of user-centred design is to develop products that are of high value to users and highly usable. There are several different processes available for user-centred design [17]. Whatever the design process is used, the incorporation of a user-centred approach is characterized by the following [18]: 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.

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 user [19].

2. Methods and material

In this work user interface prototypes were developed for office workers to use in controlling the temperature, ventilation and lighting of an office. They are 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 user-centred methods. The goal was not to create a commercial product but to study issues concerning individual control of the indoor environment. The prototypes are tools for research, but still give ready-to-use solutions for commercial products.

Initially, the work concentrated on user needs, motivation, knowledge and behaviour. The problems in using the current systems were studied and a separate paper [16] was written. In later phases the work concentrated on user interface solutions. The target was to create a user interface that can be used with effectiveness and satisfaction by novice users.

2.1. Phases of the work

The user interface development was iterative. The results from each previous phase were analyzed before the next phase, and a new user interface prototype (or prototypes) was developed for each phase. The first version of the user requirements (Section 4) was written after the first phase, but the user requirements were later updated. The work was divided into five phases:

Phase 1. Long interviews (one and half hours on average) and observation in the offices of the participants. Usability testing of paper prototypes. The participants: twelve occupants working in ten buildings.

Phase 2. Shorter interviews (emphasis on the most important issues, half an hour on average) and observation in the offices of the participants. Usability testing of six prototypes installed in a laptop. The participants: fifteen occupants working in three buildings. Additionally, the usability of the prototypes was analyzed by three usability experts.

Phase 3. Usability testing of a prototype installed in a laptop. The usability tests were performed in the offices of the participants. A short questionnaire was conducted before and after the usability test. The participants: eleven occupants working in two buildings.

Phase 4. As in phase 3. The participants: eight occupants working in four buildings.

Phase 5. Usability testing of a prototype. The prototype was connected to a building, so the user actions had a real effect on room conditions. A short questionnaire was conducted before and after the usability test. The system was built in one room that was visited by eight participants.

2.2. Interviews and observation

The goal of the user research was to study user needs, motivation, knowledge and behaviour, and to create the user requirements (Section 4) for user control of the room temperature. The research method was interviews that were performed in actual context, in the interviewees' offices in phases 1–2. The questions were open-ended. An important part of the interviews was observation. Short questionnaires were conducted in place of the interviews in phases 3–5. The results of the interviews and observation are presented briefly in Section 3.

2.3. Usability testing

The method for usability testing was an informal walkthrough [20]. There are no pre-defined test tasks in an informal walkthrough, but the participant goes through the user interface at his/her own pace and in his/her preferred order. The idea is to simulate a real use situation. The participant is observed while using the system in the way he/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 intuitive and easy to learn the user interface is, and to gather user opinions. During the session the observer asked questions to clarify whether the participant understood the features of user interface correctly, and whether he/she thought the features were necessary or not. The discussions were taped for later analysis.

In phases 2–4 the participants tested working prototypes that were not connected to the building; only the phase 5 prototype was connected to the building's systems and had a real effect on room conditions. No working prototype was developed in phase 1, but paper prototypes were shown to the test users. Each test user only participated in a test once, and new participants were used for each phase.

The usability of the prototypes was analyzed 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 workers. The results of the heuristic analysis are not presented in this paper.

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

2.4. Participants

The 54 participants are office workers in the Helsinki area of Finland, working in different professions, see Table 1. They are between 23 and 67 years of age (43 years on average). The educational level is high on average, which is typical for Finnish office workers, and about half of the people have a university degree. Most of the participants do typical office work with a computer. Most of them work in a single-person room.

Table 1. The participants in each phase of the work. Code P1-2 refers to participant 2 in phase 1.

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
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

3. Office workers as users of temperature controls

The interviews and observation conducted in phases 1 and 2 revealed characteristics of office workers as users of temperature controls. The general findings are briefly summarized as:

- Most of occupants have very little knowledge of the heating, cooling and ventilation systems of the office building they work in.
- Most of occupants have little motivation to save energy in offices (because they don't pay for the energy themselves and because they consider their own energy use to be negligible).
- Most of occupants do not use the thermostats, even they are dissatisfied with the thermal environment, as they have fundamental problems with using thermostats, see also [16].
- Some of occupants are more critical of thermal environments than others.

4. User requirements for control of room temperature

The goal is to create user interfaces that enable office workers to adjust the room temperature of their own office. Novice users should also be able to use the user interface with effectiveness and satisfaction without a learning period. User requirements describe the properties that are required to satisfy users. The user requirements presented here are based on the interviews and observation in phases 1 and 2, but have been iterated after the experiences gained from the user interface development and usability testing.

The user requirements for user-adjustable temperature controls of office rooms are:

Findability, identification and reachability. The availability of the temperature controls should be made clear. The temperature control should be easily identifiable. Identifiably is enhanced by symbols that refer to temperature, a degree sign, a thermometer, and red and blue colour (denoting warm and cool); text can also be used to clarify the purpose of the temperature control. If the temperature control is a physical object, it should be located in the room it affects and it should be placed in an easily reachable position, not high up on the wall.

Shared user interface with heating and cooling system. There should not be separate temperature controls for heating and cooling systems. If both heating and cooling systems exist in a building, the user interface should be shared (and simultaneous heating and cooling should be prevented). If there are separate controls for the systems, users do not always know which system is active and may try to adjust a passive system.

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

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

Clear way of using. The user interface should very clearly represent how to increase and decrease the room temperature set point. All symbols should be easy to understand. For example, 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. Red and blue colours denote warm and cool more clearly. If temperature values are shown in the user interface, it reduces the possibility to adjust the temperature in the wrong direction.

Clear and sufficient feedback. The user interface 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. The user should also receive feedback that informs the user that the requested change to the room temperature has been realized 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 of this paper). If it is not possible to reach the adjusted room temperature, the user should be informed (and given an explanation). In addition, the user interface should clearly indicate whether the system is currently active or not.

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

Adequate effect. The necessary range of individual temperature control is at least 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.

5. User interface prototypes

5.1. 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.

Figure 2 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 "–".

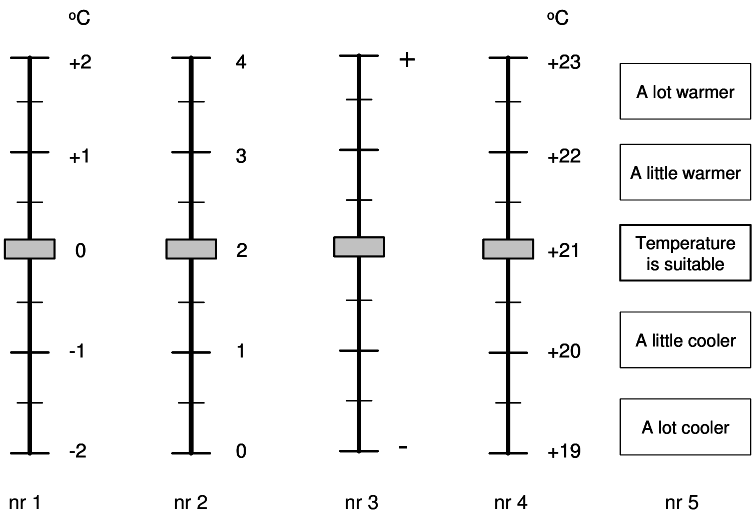

Fig. 2. Temperature scales for adjusting room temperature in the paper prototypes of phase 1.

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 (nr 4 in Figure 2). Nine participants out of twelve preferred it. The other three participants chose the verbal scale (nr 5 in Figure 2).

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 (nr 5) was found to be clear but indeterminate. The three other alternatives (nr 1–3 in Figure

2) 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 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 bulb, 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.

5.2. Phase 2

Based on the results from the first phase six user interface prototypes were developed in the second phase (Figure 3). 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.

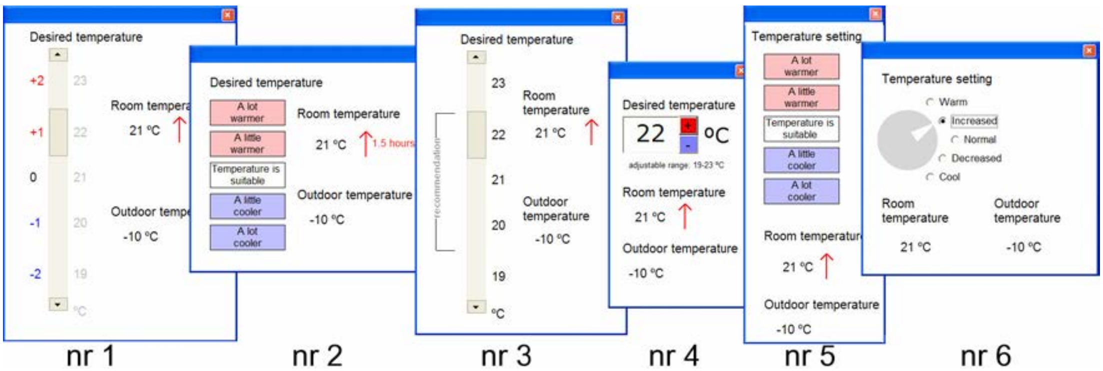

Fig. 3. Six user interface prototypes of phase 2.

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 nr 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 nr 2 and nr 5. Verbal scale. Buttons.
- Prototype nr 3. Absolute scale. Slider.
- Prototype nr 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 nr 6. Verbal scale. Rotatable with radio buttons.

Other differences between the user interface prototypes are shown in Table 2. In addition, some terminological differences existed between the prototypes.

Table 2. 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	+		
2	+	+	
3	+	+*	+
4	+		
5	+	+*	
6			

* 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 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 (Figure 4). All the respondents said that they understood the influence of the absolute scale.

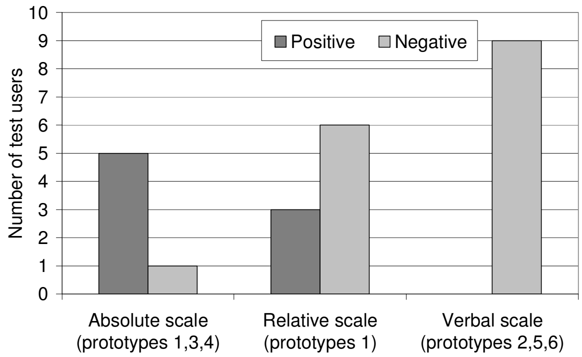

Fig. 4. User attitudes to the different temperature scales in phase 2 prototypes.

In designing the user interface prototypes, special attention was given to the feedback user interfaces give. Several variations of the feedback were developed (Table 2). 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: "room is getting warmer, and it takes [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 to 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 Figure 5. According to the results, both the arrow and the time should be included in the user interface.

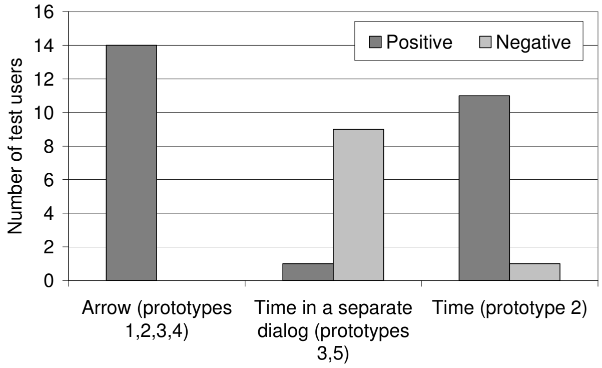

Fig. 5. User attitudes to the feedback in phase 2 prototypes.

The user interface prototype nr 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 nr 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 nr 4 (Figure 3) 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 she or he 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 nr 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 nr 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 personal computer, but after they had seen the prototypes and had had an opportunity to try them, all the 15 test users would like to have that kind of user interface for their own use.

5.3. Phase 3

Based on the results from the second phase one user interface prototype was developed in phase 3 (Figure 6). The prototype was based on the prototype nr 4 of the previous phase. 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 paper concentrates on the temperature control, and the results concerning ventilation and lighting are not presented in any detail.

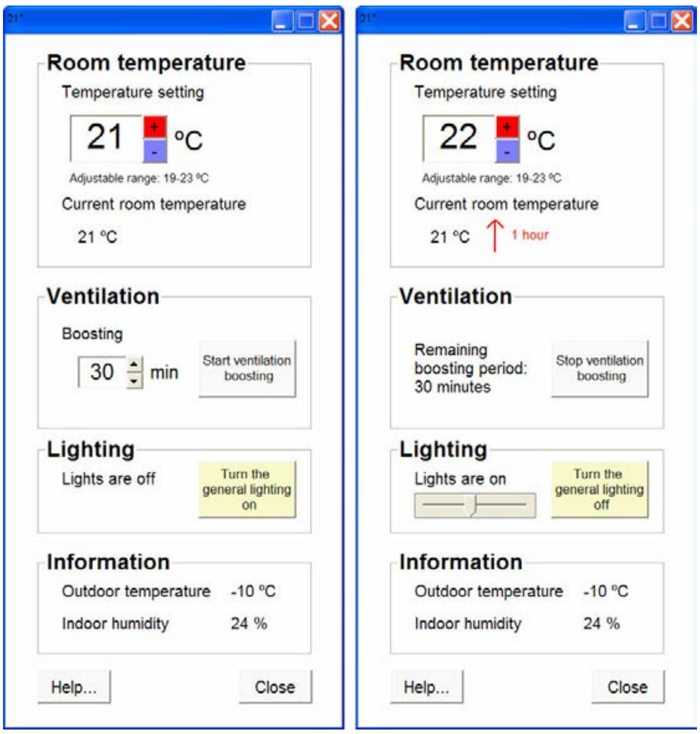

Fig. 6. User interface prototype in phase 3. The figure shows the user interface before and after user adjustments.

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. User can also see the current room air humidity (%). The arrow and the time information (see phase 2) are shown when the temperature is adjusted (Figure 6).

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; is an accuracy of 1 ºC enough, or do users want to adjust the temperature more accurately?

In general, the user interface prototype received very positive comments from the test users. All the eleven test users would like to have the user interface for their own use (Table 3). 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 (Table 4).

Table 3. Results of the questionnaire that was filled in after testing the user interface prototype of phases 3, 4 and 5. The format: phase 3/phase 4/phase 5. Percentages are given for sums of phases 3–5.

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
Is 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 necessary	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 4. Interest in the three main features of the user interface in phases 3, 4, 5. The participants made the rating after testing the user interface. The format: phase 3/phase 4/phase 5. Percentages are given for sums of phases 3–5.

	Most interested	Between the most and least interested	Least interested
Temperature control	8/5/5 67 %	3/3/3 33 %	0/0/0 0 %
Ventilation boost	2/2/0 15 %	6/4/2 44 %	3/2/6 41 %
Lighting control	1/1/3 19 %	2/1/3 22 %	8/6/2 59 %

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 in 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 5.

Table 5. 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 (+/–) *	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 %

* 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.

5.4. Phase 4

The prototype for phase 4 (Figure 7) 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 visualize the time.
- 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 and opened from the question marks, see Figure 7.
- Several modifications concerning ventilation and lighting were made.

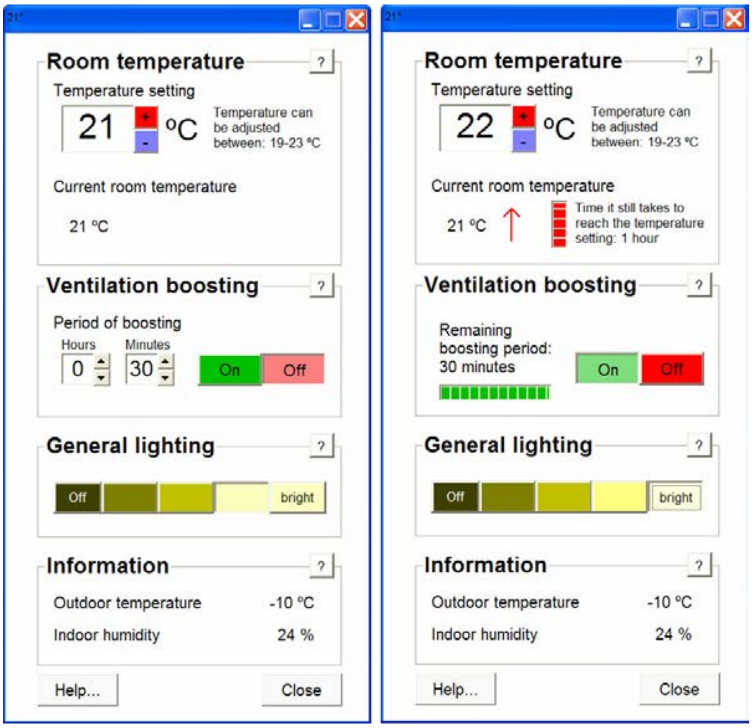

Fig. 7. User interface prototype in phase 4. The figure shows the user interface before and after user adjustments.

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 visualize 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 novice 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 Tables 3–5 as in phase 3.

5.5. 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 visualizing 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 effectiveness and satisfaction. Many of the test users were delighted when they noticed that they really can adjust room conditions with personal computer. The effect on temperature could not be perceived because of the delay, but the lighting changed instantly, and increased noise informed 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 were a lot of interest to use that kind of system also at home. The results are shown in Tables 3–5 as in phases 3 and 4.

5.6. Alternative user interface design

Although the user interface developed in this work received very positive feedback from the test users, it should not be seen as the only alternative. The primary goal is to fill the user requirements (Section 4). In the prototypes of phases 3–5 the user adjusts the temperature with the "+" and "–" buttons or by typing in a new value. An alternative design solution is shown in Figure 8: the measured value of the room temperature is shown on a thermometer, and the temperature is adjusted with a slider nearby. The user interface is compact as control of temperature, ventilation, and lighting are on separate tabs. The usability of this version was not tested.

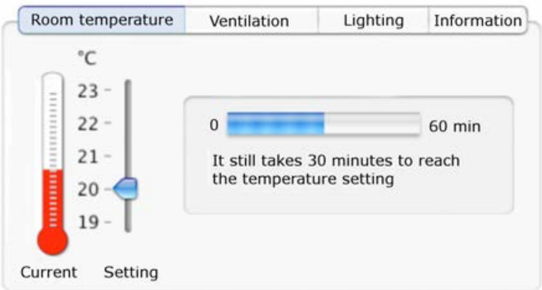

Fig. 8. Alternative user interface design.

6. Discussion

In addition to the user requirements, there are other requirements for control of room temperature. The other main parties during the occupancy period are the employer, the owner of the building, and the real estate management. They share the target of creating satisfactory working conditions for office workers. Office workers should be able to use the temperature controls efficiently and to create an individually satisfying environment.

The user requirements do not conflict with the other requirements. It is clear, however, that energy saving is more important for the party that pays for the energy than for the office workers. Although office workers have low motivation for saving energy in offices (see Section 3), user interfaces should be developed to target energy savings. The user interfaces, and the systems, should be designed so that the normal way of use leads to energy efficiency. Bordass et al. [21] note that "when discomfort arises, what gets operated first is what comes easiest, not what is desirable technically". For a behavioural model of temperature control use and energy saving, see [22].

It is 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.

7. Conclusion

User-centred methods were applied in developing user interfaces for office workers 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 effectiveness and satisfaction. This is a remarkable improvement as users have serious problems with the thermostats currently in offices. All the 42 participants in the usability tests would like to have that kind of new user interface for their own use.

User requirements for user-adjustable temperature controls in offices were developed according to the results from the interviews and observation and the user interface development. Because the change rate of room temperature is slow, it is important that the user interface gives the user clear feedback so that the user knows that the system is working to fulfil the request.

In this work a software user interface was developed for a personal computer, but the user requirements and the user interface solutions can also be applied to other than software user interfaces.

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