TECHNISCHE UNIVERSITÄT WIEN

VIENNA UNIVERSITY OF TECHNOLOGY

D i s s e r t a t i o n

A User Interface Model for Systems Control in Buildings

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines Doktors der technischen Wissenschaften unter der Leitung von

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E 259.3

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eingereicht an der Technischen Universität Wien
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Dedicated to my parents

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KURZFASSUNG DER DISSERTATION

Nutzer-basierte Steuerungsaktionen in einem Gebäude (i.e., die Benutzerinteraktion mit den technischen Systemen für Heizung, Kühlung, Lüftung und Beleuchtung) können erhebliche Auswirkungen sowohl auf das Raumklima, als auch auf die Energie-Performance von Gebäuden haben. Dennoch wurden bislang relativ wenige systematische Anstrengungen unternommen, um zu beobachten und zu analysieren, wie sich derartige Benutzer-System-Interaktionen auf die Performance von Gebäuden auswirken. Insbesondere wurden die notwendigen Anforderungen für die Konzeption und Erprobung von Hardware- und Softwaresystemen für die Benutzersystemoberfläche nicht in einer genauen und zuverlässigen Weise formuliert. Diese Arbeit umfasst: *i*) eine Auseinandersetzung mit den Anforderungen und Funktionalitäten der Benutzeroberflächen von Steuerungstechnisch relevanten Gebäudesystemen für "sentiente" Gebäude; *ii*) Prototypisierung einer neuen Generation von entsprechenden Benutzeroberflächen. Das Ergebnis dieser Bemühungen, realisiert als eine Web-basierte Benutzeroberfläche, würde eine höhere Konnektivität zwischen den Bewohnern und der sentienten Gebäude ermöglichen.

ABSTRACT

Occupant control actions in a building (i.e., user interactions with environmental systems for heating, cooling, ventilation, lighting, etc.) can significantly affect both indoor climate in and the environmental performance of buildings. Nonetheless, relatively few systematic (long-term and high-resolution) efforts have been made to observe and analyze the means and patterns of such user-system interactions with building systems. Specifically, the necessary requirements for the design and testing of hardware and software systems for user-system interfaces have not been formulated in a rigorous and reliable manner. This thesis includes *i*) an exploration of the requirements and functionalities of user interfaces for building systems; and *ii*) prototyping of a new generation of user interface model for building systems in sentient buildings. The outcome of these efforts, when realized as a web-based user interface, would allow the occupants to achieve desirable indoor climate conditions with higher levels of connectivity between occupants and sentient environments.

ACKNOWLEDGEMENT

This dissertation is developed during my study at the Department of Building Physics and Building Ecology in Vienna University of Technology. First of all, I would like to deeply thank my supervisor, Univ. Prof. Ardeshir Mahdavi, who had a giant influence on my thinking and perspectives in general, as well as in terms of scientific research throughout these three years.

I also want to acknowledge Univ. Prof. Thomas Grechenig and a.o. Univ. Prof. Christian Kühn for their valuable reviews and examinations.

The thesis is supported, in part, by a grant from Austrian Science Foundation (Fonds zur Förderung der wissenschaftlichen Forschung), project number L219-N07. Also, I appreciate Ministry of Education of Taiwan for its support of this work. Along this way, a number of current and past colleagues involving this project have contributed insights, assistance, and suggestions to this thesis. These include a.o. Univ. Prof. Georg Suter, Sergio Leal Camara, Matthias Schuss, Sokol Dervishi, Josef Lechleitner, Oğuz İçoğlu, Klaus Brunner, and Bojana Spasojević. In addition, I would like to express my deepest gratitude to the following individuals for their contributions to this work, for which I am greatly indebted: Huang Hsini, who edited the video showcase of this prototype; Grace Li and Kristina Orehounig, who overhauled the German abstract of this thesis; and Chen Yuhsing for her many insights into the contents of this work. Likewise, I would like to thank Elisabeth Finz, Albana Rexhepi, Claus Pröglhöf, Lyudmila Lambeva-Szepessy, Abdolazim Mohammadi, Elham Kabir, and Ulrich Pont, who gave me assistance and consideration in Vienna.

But above all, I would like to thank my family, particularly my parents, for their endless support, encouragement, and understanding.

Szu-Cheng CHIEN

Vienna, October 2008

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1 Introduction

1.1 Overview

Occupant control actions in a building (i.e., user interactions with environmental systems for heating, cooling, ventilation, lighting, etc.) can significantly affect both indoor climate in and the environmental performance of buildings. Based on advancements in IT (information technology) in recent years, new possibilities have emerged to better connect the occupants with environmental systems of buildings. Particularly in large and technologically sophisticated buildings, multi-faceted interactions between building occupants and the multitude of environmental control devices and systems need to be tightly integrated in order to assure effective building operation and performance. Nonetheless, relatively few systematic (long-term and high-resolution) efforts have been made to observe and analyze the means and patterns of such user-system interactions with building systems. Specifically, the necessary requirements for the design and testing of hardware and software systems for user-system interfaces have not been formulated in a rigorous and reliable manner (Chien & Mahdavi 2008a).

This thesis includes *i*) an exploration of the requirements and functionalities of user interfaces for building control systems; and *ii*) prototyping of a new generation of user interface model for building systems in sentient buildings. The outcome of these efforts - when realized as a web-based user interface - would allow the occupants to achieve desirable indoor climate conditions with higher levels of connectivity between occupants and sentient environments.

Chapter 1 includes motivation for selecting the thesis topic along with background of the existing approaches pertaining to Building Information Modelling (BIM), intelligent environments, and user interface design. Chapter 2 gives the summary of research methodology. Such methods include interface products evaluation and user interface implementation. Chapter 3 details 2 steps of interface products evaluation. Firstly, a comparison of 12 commercial user-interface products for building control systems is conducted, whereas three dimensions (information types, control options, and hardware) and seven criteria (functional coverage, environmental information feedback, intuitiveness, mobility, network, input, and output) are considered. Secondly, this thesis presents the results of an experiment, in which 40 participants examined and evaluated a selected number of user interfaces for buildings' control systems, mainly in view of their first impressions, user interface layout design, and as well as ease of learning. Chapter 4 comprises the implementation of a user interface model for sentient buildings. An introduction of this interface model is presented in this chapter, namely testbed context, base technology, and system development/features. Chapter 5 concludes the contributions and future perspectives of these research efforts.

1.2 Motivation

In the time of modern living, more and more advanced devices and appliances have been introduced to the buildings. Particularly in large and technologically sophisticated buildings, the occupants, confronted with complex and diversified manipulation possibilities for environmental controls, are forced to deal with these devices via a wide range of distinct and uncooperative interfaces. These situations can lead to a frustration of the occupants when improvement of their comfort (visual/thermal, emotional and psychological) is necessary (Lambeva 2007).

Thus, the goal of this thesis is to enhance the knowledge related to the usability of user interfaces for building control systems and propose a new generation of user interface models with novel possibilities for interactions between occupants and sentient environments. "Sentience" denotes here the presence of a kind of computational second-order mapping (or meta-mapping) in building systems operation. This requires that the flow of raw information collected around and in a building is supplied to a building's continuously self-updating model of its own constitution and states (Mahdavi 2005). Given this view of building sentience, such research could bring along the following benefits. Firstly, it enhances the insights of such user-system interactions with building systems, which is crucial for the developers and user interface designers to analyze and clarify in order to design and develop certain technologies in a rigorous and reliable manner. Secondly, desirable integrated building control services (i.e., the timely provision of appropriate and well-structured context information together with intuitive representation of the type and range of devices and parameters) could contribute to more convenient and human-centered control tasks while the occupants are confronted with the multitude of environmental control concepts and devices. Finally, the explorations in both interface products' evaluations and interface implementation can provide a solid basis for future developments in user interface technologies for sentient buildings while meeting the goals pertaining to a sustainable building operation regime.

1.3 Background

This thesis presents a perspective of the study of user-system interactions with intelligent environment. In recent years a number of developments have occurred in issues related to intelligent buildings and interface usability/technologies that have been profoundly affected interface design. Thus, related works in these fields are reviewed as follows. First, the development of Building Information Model (BIM) is discussed. Then, the intelligent environments and related projects are described. Finally, since the goal of this thesis is to explore the usability and propose a prototype of user interfaces, a variety of approaches to user interface are surveyed, including user-system interactions and interface design methods.

1.3.1 Building Information Model

Information modelling has been commonly conducted as a preferred technique to illustrate the static, functional, and dynamic aspects of a domain (Suter 2003). Building information modelling (BIM), as such, was generated to demonstrate the whole building life cycle including the period of construction and building operation. This term ”BIM” is used to distinguish the next generation of information technology (IT) and computer-aided design (CAD) for buildings from traditional CADD (computer-aided drafting and design), which focused on drawing production in the architecture, engineering, and construction (AEC) industry (Lee et al. 2006). Up to now, a number of works related to the field of building information modeling have been done on software tool and protocol developments to achieve the goal of creating semantic models for buildings, mainly to improve collaboration in lifecycle (i.e., design, construction, and facility operation phase) of buildings (Eastman 1999; Holness 2008). Here, related domains for collaboration are introduced as follows.

1.3.1.1 Industry Foundation Classes

The Industry Foundation Classes (IFCs) is a data model definition with some object-oriented features aiming to capture all aspects of building projects

throughout their lifecycle (IAI 2006; Brunner 2007). The data format of IFC specification is commonly provided for describing, exchanging and sharing information within the building and facility management industry. The IFC system standardizes the product model for the building industry and defines aechitectural and constructional CAD graphic data as 3D real-world objects in a range of diverse concepts. As to the current version IFC2x Edition 4 alpha (IAI 2008), such domains comprise, for example, building controls, HVAC, electrical, architecture, structural elements, construction management, structural analysis, facilities management.

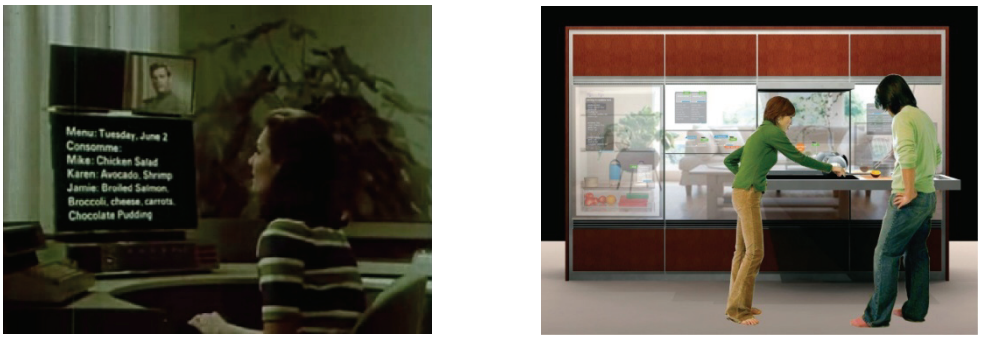
1.3.1.2 Building Information Modelling aspects

Building Information modeling (BIM) denotes the process of generating and managing building data through the lifecycle of a building (Lee et al. 2006). Thereby, IFCs based data structures (or other representations) are employed. A Building Information Model encompasses a range of characteristics such as building geometry, spatial relationships, geographic information, and quantities and properties of building components. It also includes environmental data from weather stations, indoor sensors, system maintenance, and occupancy information sources. Thus, it can support three-dimensional, real-time, intelligent, dynamic modelling applications to facilitate successful coordination and achieve sustainability in building design and construction (Holness 2008). For example, building management may intend to remove an internal wall to plan a new space usage in a building. Instead of checking the actual building, they may review the piping systems located in the planed location via their BIM reference. Also, certain pipe specifications, manufacturer, and other necessary information could be retrieved to the building management to better evaluate the strength and deficiency of the plan without information loss in the model. In this study, BIM may provide high resolution, comprehensive representation of the current state of the building (e.g., the performance monitoring of heating and lighting system) for the occupants/building management in terms of building control operations and services.

1.3.2 Intelligent Buildings

1.3.2.1 The visions of intelligent environments

It is human nature to keep dreaming and expecting for the imminent advent of "dream house" or "sentient environments" (Mahdavi 2005) with smart solutions and technologies to satisfy occupants' needs and prospects (see Figure 1-1). In the last 20 years, a number of efforts have been made to make this dream come true. Nowadays, it may be more close to reality because of the following technological revolutions: i) micro products- computing devices become personal, mobile, and lightweight; ii) accelerated living- the transportation period has been shortened from office, school, museum, to home; iii) connection- people could communicate to each other anytime and anywhere via the wired or wireless technologies; iv) digital services- when services are available digitally, people start to inquiry digital services via internet (Chiu 2005). The emergence of above-mentioned trends have posited us in the midst of an unprecedented technological transition, influenced our daily life, and made a "big switch" (Carr 2008) regarding the living environment of the future. Architectural space, being no longer a "machine for living" (Corbusier 1985), is going the way of an intelligent and sentient environment where all kinds of smart devices are continuously working on making occupants' lives more comfortable. Particularly, this intelligent environment may respond and adapt to the occupants' needs and context transitions whilst novel technologies such as sensorial components, wireless communication, and simulation-based control algorithm are integrated in certain spaces.



(a) (b)

Figure 1-1 (a) a screenshot of "1999 A.D." film, which released in 1967, described a vision of the future environment (Philco-Ford Corporation, 1967); (b) an illustration of GE's Kitchen of the Future depicting a perspective of the life in year 2035 (General Electric Company, 2006)

1.3.2.2 The definitions of intelligent environments

The concept of intelligent environment (closely related to notions of smart house, smart home, intelligent building, intelligent office, digital home, etc.) has been addressed in press, media, industry, as well as academia continuously. These terms may differ from one to one in view of different requirements and functionalities, such as:

i) Mahdavi (2004) defined a sentient building as one that possesses a multi-faceted internal representation of its own context, structure, components, systems, and processes. It can use this representation, amongst other things, toward the full or partial self-regulatory determination of its indoor-environment status. "Sentience" denotes here the presence of a kind of computational second-order mapping (or meta-mapping) in building systems operation. This requires that the flow of information collected around and in a building is supplied to a building's continuously self-updating model of its own constitution and states (Mahdavi 2005);

ii) Cook & Das (2004) described that "smart" or "intelligent" involves the ability to autonomously acquire and apply knowledge, while environment refers to our surroundings. The insights of environment intelligence may be able to acquire and

apply knowledge about an environment and also to adapt to its occupants in order to improve their experience and task performance in that environment; and

iii) In the term of "ambience intelligence", Aarts & Marzano (2003) stated that "ambient" which relates to the embedded and context-aware qualities may move electronics into the background. On the other hand, "intelligence" regarding human-centric computing (e.g., adaptive and anticipatory features) may move the user into the foreground. Ambient intelligent environments may exhibit "intelligence" through the user interface and by the extent to which the system could adapt itself to its users and environment.

1.3.2.3 Existing projects

Related fields on intelligent environments cover the most innovative technologies such as human-computer interaction, building information modeling, sensor technologies, mobile communication, model-based control, etc. Whilst the needs of intelligent environment increase to better construct a comfortable environment of the future, a number of academic and industrial institutions are involved in the research and development of intelligent environments. For example, the Aware Home project at Georgia Tech "is devoted to the multidisciplinary exploration of emerging technologies and services based in the home" and was one of the first "living laboratories" launched in 1998 (Georgia Tech 2008). HomeLab project, as another example from Philips, is created to test "its new home technology prototypes in the most realistic possible way, the essential facility for speeding up the time-to-market for technological innovation" and will play a prominent role in the studies on feasibility and usability aspects of Ambient Intelligence (Philips 2008). Also, the MavHome (Managing an Adaptive Versatile Home) project, at UT Arlington, is a smart environment-lab with state-of-the-art algorithms and protocols used to provide a customized, personal, safe and energy-saving environment to the users of this space (Cook et al. 2003). Other projects include Pervasive Computing project at IBM, House_n project at the MIT Media Lab, the Adaptive House at University of Colorado, ePerSpace project at France Telecomm, Connected Homes Project in Singapore and many others around the world.

1.3.3 User Interfaces

In IT (information technology) terms, human-computer interaction (HCI) denotes the "communication of information from computer systems to a human user and influencing the operation of the computer system by a human user" (Schmidt 2005). Research in human-computer interaction has been employed since 1960 (Myers 1998), and has built a historical foundation during the 1970's and 1980's to develop a science of "software psychology" (Shneiderman 1980). The goal was to "establish a psychological approach to clarify software design and the use of computer systems, as well as to guide system developers in considering human factors in improving design" (Patel & Kushniruk 1998). It has emerged as a highly successful field which devotes fundamental efforts to the integration of cognitive psychology and applied work in computer science for the design and development of user interfaces in recent years. For example, Graphical User Interface (GUI), which is a type of user interface involving graphical icons and visual indicators (see Figure 1-2), enables users to better interact with devices/applications such as web browsers, home appliances and office facilities in terms of time-consuming and ease of use. As to an evolving science field, HCI facilitates the human interactions with computers in many domains, and is making a great impact in the area of user system interactions in building control systems toward narrowing the gap between users and devices (Chiu 2005).

Figure 1-2 An example of modern Graphical User Interfaces (GUIs)

1.3.3.1 User system interactions in Buildings

Up to now, it is still a common experience to have a separate user interface for every controllable device (e.g., lighting, heating, and blinds). One example of this type of control solution is a one from IZD office building, Vienna, which is completed in 1999 (see Figure 1-3). In this traditional installation, each controllable device within a certain space is directly mapped to one user interface. Every device manufacturer may have its own style and size in their interfaces. Moreover, most devices with their provided functions may need some special control options so that it may not be possible to apply the same (or similar) interface product to control different appliances. In the past, the occupants may bear this "one for one" inconvenience because of the limited devices in living environment. However, along with the growth of life quality and technology, more and more devices are embedded into our living space and lead to the increase of the needs of control device controls.

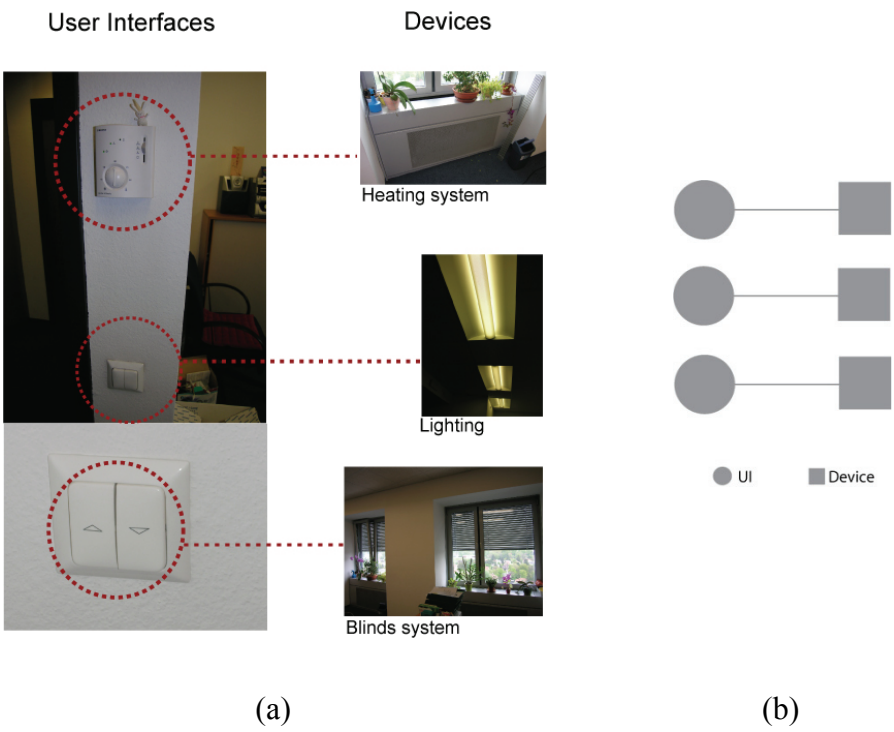
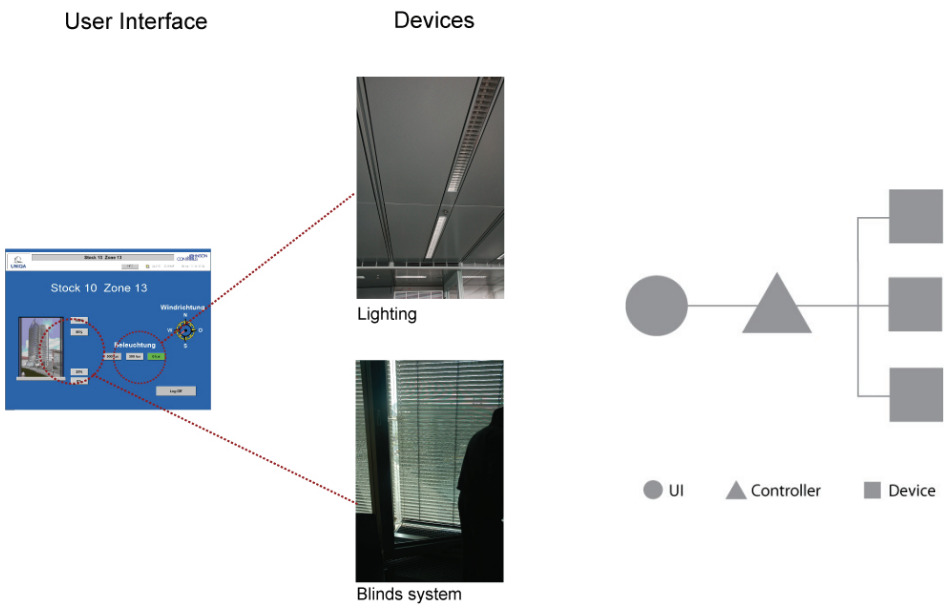


Figure 1-3 (a) shows a traditional control solution in buildings. Technologies used and products and services provided are very heterogeneous and lack compatibility. Figure (b) shows an "one for one" mapping typology.



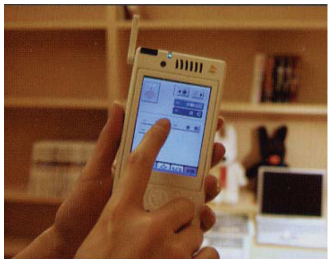
(a) (b)

Figure 1-4 (a) shows an advanced control solution in buildings. Technologies used and products and services provided are integrated in one single user interface. Figure (b) shows an "one for all" mapping typology.

In these days, there have been several advanced interface products available in the market. With this type of "one-for-all" interface product, the occupants may manipulate different devices in one interface. One example of this "one-for-all" type of control solution is a one from Uniqa office building, Vienna, which is completed in 2002 (see Figure 1-4a). In this advanced installation, all controllable devices are wired in a bus system and mapped to one single user interface. Some indoor/outdoor environment information (e.g., outdoor wind direction) along with general information (e.g., date/time) are initially provided to the occupants. Furthermore, it is also possible for the occupants to control devices via internet in a different place. Also, whilst new devices are added in this environment, the interface product could be technologically upgraded and reconfigured without replacing the hardware to take account this new situation. Although this may be not an everyday condition but could still be the stumbling block in terms of

usability and the cost of rapid obsolescence for the occupants and building management.

As to the role of user interfaces in the context of intelligent built environments, there are a number of precedents as well. For example, the ubiquitous communicator (UC) – the user interface of PAPI intelligent house in Japan – is developed as a communication device that enables the occupants to communicate with people, physical objects, and places (Sakamura 2006)(see Figure 1-5a). The other example of this type of user interface is one from Samsung (see Figure 1-5b). Samsung's homevita system gives occupants a full view of their home network and allows them to manage daily household tasks such as controlling lights, air conditioners, and even washing machines (Aving 2007). More recent works on the integration of user interfaces into intelligent environments include Swiss house project in Harvard University (Huang & Waldvogel 2004), and Interactive space project by SONY (Rekimoto 2003).



(a)

(b)

Figure 1-5 (a) the ubiquitous Communicator of PAPI house; (b) Samsung's homevita system

1.3.3.2 Usability

User interaction with technological artifacts (e.g., above-mentioned interfaces) is a serious issue for occupants faced with a constantly evolving range of sophisticated technologies, services, as well as many factors related to the features of the occupants (Pirhonen et al. 2005). Typical questions often addressed include: how the occupants know what this interface may provide, how can they complete a task goal in a time-saving way, why is it too difficult to access what is offered, or is the system designed to support effective learning? Nielsen (1993) stated that

usability comprises all aspects of a system with which a human may interact and is traditionally associated with the following five features: *i*) easy to learn; *ii*) efficient to use; *iii*) easy to remember; *iv*) low error rate during maipulation; *v*) satisfaction. Preece (2007) further argued that usability is also associated with utility (i.e., have good utility) and slightly differs from the difinition of user experience. Usability goals are concerned with "satisfying certain usability criteria" (e.g., efficiency) while user experience goals are higher level and largely concerned with "explicating the quality of the user experience" (e.g., to be pleasant to use, enjoyable, helpful, fun). Another concept of usability is in view of design principles. These are generated principles for guiding designers as a framework of their designs. For example, Norman's (2002) description of the key principles includes visibility, feedback, constraints, maping, consistency, and affordance in his bestseller *The Design of Everyday Things*. Usability, furthermore, may also be extended to two approaches, namly usability testing and usability engineering. Nielsen (1993) stated that usability testing pertains to a technique to evaluate a product via discovering strengths and deficiencies in terms of ease of use, whereas usability engineering involves the research and design process that ensures a product with good usability.

1.3.3.3 Interface evaluation and design methods

Nowadays, there are a number of usability testing methods conducted and developed to evaluate the usability of existing or proposed products in order to provide timely feedback and high-resolution framework to the designers and developer for a solid support in design phase. The methods of usability testing are capable of utilizing a range of diverse concepts including:

i) Scenario technique: A scenario-based approach (Rosson & Carroll 2002) is the process of eliciting and describing the future use of the system in its context and to help determine the system and design requirements. A secondary advantage is that the scenario descriptions may be created before a system/product is constructed and its impacts encountered;

ii) Extant Systems Analysis: Ringbauer et al. (2003) stated the extant system analysis may be conducted to analyze and evaluate concerning degree of being user-centered of system products in the market or currently being developed, whereas the real world system product may be investigated and observed with records. The generated results of certain analysis may be singled out for future analysis and design basis;

iii) Focus groups: a focus group is a focused discussion of qualitative research in which a group of people is asked about their attitude towards target issues, such as product, service, concept, etc. Questions are asked in an interactive group setting where participants are free to talk with other group members in order to obtain consensus related to these issues (Greenbaum 1993; Krueger & Casey 2000).

iv) Questionnaires/interviews: surveys are a key technique used in Human-Computer Interaction (HCI) to provide feedback and information regarding users' preferences and comments about the design in many phases of the interface development. Questionnaires and interviews are two forms commonly conducted to gather quantitative and qualitative data respectively in survey-research field. HCI researchers utilize questionnaires as tools/methods to capture what is in users' mind. The data collected from the users is recorded onto a permanent medium to be analyzed and referenced later (Shneiderman 1997; Kuter & Yilmaz 2001). Compared with questionnaires, interviews may typically gather more information and go into a deeper level of details regarding the target issues of the interface/product, such as subjective reactions, opinions, and insights into how interviewees reason about issues (Brehob 2001). Since questionnaires provide merely quantitative data, interviews' qualitative data may supplement the research to better interpret the statistical results correctly.

Along these lines above, the importance of design involving early and rapid prototyping and many design iterations has emerged, particularly with regard to design of user interfaces (Carroll 1995). Many efforts have been made to explore new methods to design user interfaces that are suitable for multiple distinct target devices (Mori, Patern`o, & Santoro 2004). Clerckx et al. (2007) considered context as a whole in collaboration with the development of interactive systems because context can influence the tasks the user wants to, can or may perform. They proposed a development process to design context-aware interactive systems that could be relevant to the efforts to bridge the gap between users and intelligent environments. Also, Carter et al. (2008) used literature survey and interviews to illustrate issues that are relevant to prototype design and evaluation and could be encountered in ubiquitous computing systems development for intelligent environments. Calvary et al. (2001) described a development process to build context-sensitive user interfaces. This development process involves four steps: to build a task-oriented specification, to mock up the abstract interface, to build the concrete interface, and finally to build the context-sensitive interactive system. In this focus, a mechanism for context detection and how context information can be conducted to adapt the UI with following three-step process: *i*) recognizing the current situation; *ii*) calculating the reaction; and *iii*) executing the reaction.

2 Research Methodology

This chapter describes the methodology underlying of this thesis. It employs the two following methods as the main ones amongst a set of techniques that arrive at interface implementation from usability research. Such methods are: *i*) chapter 3: an exploration of the requirements and functionalities of user interfaces for building control system; and *ii*) chapter 4: implementation of a user interface model for building systems based on the approaches in chapter 3.

2.1 Interface products evaluation

The purpose of chapter 3 is to explore the requirements of an adequate user interface system to facilitate effective communication and interaction between building occupants and environmental systems. In order to achieve this goal, twelve products in the market that offer such interfacing functionalities are evaluated based on the following four steps, namely

i) the specification of the considered requirement profiles involving three dimensions (i.e., provision of information, control options and extensions, and hardware) ;

ii) selecting twelve products from the marketplace, whereby three types of products (i.e., “physical” devices, control panels, and web-based interfaces) were considered;

iii) comparing the selected interface products in terms of specification profiles, whereby 7 criteria (pertaining to functional coverage, environmental information feedback, intuitiveness, mobility, network, input, and output) are considered;

iv) conducting interviews with test users to clarify the deficiencies and advantages of a subset of these products and presentation of the results of an experiment, in which 40 participants examined and evaluated a selected number of user interfaces for buildings' control systems, mainly in view of their design, ease of learning and use, as well as effectiveness.

The data analysis involved *i*) categorization of the selected products based on three dimensions (information types, control options, and hardware); *ii*) product comparison and evaluation based on seven criteria (functional coverage, environmental information feedback, intuitiveness, mobility, network, input, and output); *iii*) analysis of interview sessions with participants to obtain subjective evaluation results regarding three evaluative categories (first impressions, user interface layout design, and ease of learning) as applied to a subset of the selected products.

2.2 Interface Implementation

In chapter 3, the analysis of product comparison and interviews highlighted a number of basic principles and expectations regarding the design of desirable user interface products for sentient environments. Moreover, the requirements and functionalities of user interfaces for building systems have been explored. Starting from these results, in chapter 4, an effort has been made to further articulate the background, base technology, interface development, and system features of such interface product implementation utilizing the previous approach. The resulting interface is served as a user interface model for building systems of a research project "self-actualizing sentient buildings" in the building physics laboratory in Vienna Technical University, Department of Building Physics and Building Ecology. To better prototype the interface, the following three steps are conducted:

i) Discussion of the testbed background (i.e., infrastructure, comprehensive building information, and model-based strategy);

ii) Reviewing the base technology of the interface development based on software development environment, communication protocol, and wireless IP Camera;

iii) In order to transform the requirements to design, certain techniques (such as defining interface posture, building primary/secondary user models, requirements profiles, and interface design process) are employed to develop the user interface prototype of building control systems.

3 Interface designs Evaluation

3.1 Introduction

In this chapter the requirements of an adequate user interface system are explored to facilitate effective communication and interaction between building occupants and environmental systems. Twelve products in the market that offer such interfacing functionalities are compared. The results of an experiment are presented, in which 40 participants examined and evaluated a selected number of user interfaces for buildings' control systems, mainly in view of their design, ease of learning and use, as well as effectiveness. The insights gained from this comparative evaluation can be used to initiate a user interface model for sentient environments toward achieving new levels of connectivity between occupants and the environmental systems for indoor environmental controls in buildings.

3.2 Approach

The evaluations of the interface designs for user-system interaction are based on the following four steps, namely *i)* specification of the requirement profiles, *ii)* selection of twelve products from the marketplace, *iii)* comparison of the selected interface products in terms of the specification profiles; *iv)* conducting interviews with test users to clarify the deficiencies and advantages of a subset of these products.

3.2.1 Requirement Profiles

To conduct a comparison of available user interfaces in the context of intelligent buildings, first an evaluative matrix involving three dimensions is proposed (see also Chien & Mahdavi 2008a):

i) Provision of information – Primary types of information include general information, indoor information, outdoor information, and device states. General information pertains, for example, to time and date. Indoor information includes indoor climate parameters such as room air temperature and relative humidity, air velocity and CO_2 concentration level (an indicator of indoor air quality), and illuminance level. Outdoor information includes general weather conditions (e.g., sunny, cloudy, and rainy), outdoor air temperature, relative humidity, wind speed and direction, as well as global irradiance and illuminance. Device state information includes system data regarding supply air terminals, windows, VAV systems, blinds, ambient lighting systems, task lighting, humidification, and dehumidification systems.

ii) Control Options and extensions – This dimension comprises control options (based on devices, parameters, perceptual values, and scenes) and control extensions (involving schedules and spatial micro-zoning). Control options applied to devices imply that the user directly manipulate the state of

environmental control devices to achieve the conditions they desire. Such devices include, for example, supply air terminals, windows, VAV systems, blinds, ambient lighting system, task lighting, and de/humidification system. Control options pertaining to parameters imply that the users request specific target values or ranges for certain indicators of indoor climate. Such indictors include, for example, temperature, humidity, air movement, air change rate, and illuminance. Control options via perceptual values imply that the users communicate their preferences regarding indoor conditions not in terms of the numeric values of indicators for such conditions, but in perceptually relevant qualitative terms. Such terms include, for example, warmer/cooler, brighter/dimmer, more humid versus drier, and fresher air. The realization of the above control options may be further specified via user-based definitions of temporal and/or spatial extensions. An example of a temporal extension is a user-defined time-based variations of (schedules for) the position of a certain device or the value of a certain control parameter. An example of a spatial extension is a user-defined assignment of a control parameter value to a certain point in space or location in a room, thus supporting differential environmental conditioning (micro-zoning).

iii) Hardware - Hardware components address information input, output, mobility, network function, and re-configurability. Data input hardware elements include, for example, buttons, wheels, mice, keyboard, and touch panels. Data output hardware elements include response lights, monochrome screens, touch monitors, LCD screens. Mobility denotes if a hardware device has a fixed position (e.g., if it is wall-mounted) or if it is portable. Network function denotes, for example, if a hardware device is networked via bus systems or internet. It is further considered if a hardware device can be reconfigured (reprogrammed) or not.

3.2.2 Selection of products

In this section, a number of products from the market that are designed to facilitate the communication of relevant control states from users to building control and automation systems are selected. Thereby, three types of products are considered (see Table 3-1):

a) "Physical" devices – These kinds of products are often equipped with physical buttons and wheels for users to manipulate;

b) Control panels – In this case, users can operate the (typically wall-mounted) products via their touch panels;

c) Web-based interfaces – These interfaces can be used to communicate control intentions via internet at anytime and from anywhere.

Table 3-1 Overview of the selected products

Product type	Product	Company	Illustration	Code
A Type: Physical devices	Circle point (cp. Zumtobel 2007)	Zumtobel		A1
	Uniqa Control Point	Johnson controls		A2
	LONVCU (cp. Warema 2007)	Warema		A3
	CM900 (cp. Honeywell 2007)	Honeywell		A4
B Type: Control panels	Emotion (cp. Zumtobel 2007)	Zumtobel		B1
	Companion-8 (cp. Convergent Living 2007)	Convergent Living		B2
	OmniTouch (cp. Home Automation 2007)	Home Automation		B3
	DDC4000 (cp. Kieback-peter 2007)	Kieback & Peter		B4
C Type: Web-based interfaces	Uniqa web-interface	Johnson controls		C1
	iSkin (cp. Zumtobel 2007)	Zumtobel		C2
	Serve@ Home (cp. Siemens 2007)	Warema & Siemens		C3
	merten@ home (cp. Merten 2007)	Merten		C4

3.2.3 Comparison of product in view of aspects

The selected user interface products (see section 3.2.2) were compared and evaluated based on the previously mentioned evaluative matrix (see section 3.2.1). In order to obtain a clear depiction of product distributions and characteristics, these products were further placed in a two-dimensional evaluative space, whereby the criteria are selected from the following set: Functional coverage, Environmental Information Feedback, Intuitiveness, Mobility, Network, Input, and Output.

3.2.4 Interviews

To gain additional insights regarding the attitudes of potential users toward user interface products, "hands on" sessions were conducted with 40 participants (26 females and 14 males, average age of 29 years, resident in Vienna, Austria, see Table 3-2) who examined and evaluated demo-versions of four of the above products (see Table 3-1, products A1, B2, B3, and C2). Product A1 is a physical device with certain limited preprogrammed scenes. Products B2 and B3 are control panels (touch screens) that can provide indoor environmental information and offer advanced control options/extensions. Product C2 is a web-based interface with likewise advanced control options/extensions. These products selected for interviews mainly because we found them to be quite representative of the aforementioned three product types.

The main evaluation objectives were to:

i) realize if modern (high-tech) interfaces or conventional physical devices are preferred;

ii) examine the correlation between high functional coverage and intuitiveness of interfaces;

iii) identify those interface features that hamper or facilitate the completion of prescribed tasks.

Table 3-2 Participant profile of the interviews (N=40)

Age	15-26 years (50%)
	26-55 years (50%)
Gender	Male (35%)
	Female (65%)
Education	high school (10%)
	undergraduate (30%)
	masters and above (60%)

Table 3-3 The structure of the questionnaire

Categories	No.	Indicators	Questions
First Impressions	Q1	First impression	What is your first impression of this user interface (UI)?
	Q2	Ease of Use	Is this UI easy to use?
	Q3	Effectiveness	Is this UI effective?
	Q4	Attractiveness	Is this UI attractive?
User Interface Layout Design	Q5	Flexibility	Is this UI flexible?
	Q6	Organization of information	How well is the information in this UI screen organized?
	Q7	Sequence of screens	Is the sequence of screens clear?
	Q8	Readability	Is this UI screen readable?
	Q9	Terminology	Is the terminology in this UI screen clear?
	Q10	Input Position	Is the input (mask) position easy to locate?
Ease of Learning	Q11	Easy to learn	Is this UI easy to learn?
	Q12	Easy to Understand	Are the commands easy to understand?
	Q13	Task Sequence	Is the task sequence clear?

List the most positive and negative points regarding per interface

- Positive Aspect
- Negative Aspect

As each participant needed to examine all four products, the counterbalancing technique (Rubin, 1994) was applied in order to mitigate the problem of transfer of learning effects. Thus, eight sequences of product presentation were considered (i.e., A1-B3-C2-B2, B2-A1-B3-C2, C2-B2-A1-B3, B3-A1-B2-C2, A1-B2-C2-B3, B2-B3-A1-C2, C2-A1-B2-B3, and B3-C2-B2-A1). Each participant spent 15 to 20 minutes for each product and approximately 60 to 80 minutes to complete the whole evaluation. Figure 3-1 illustrated the evaluation sequence for one product (B3). This time included an initial brief familiarization with the product, performing a number of prescribed tasks, completion of a questionnaire (questions Q1 to Q13 plus final comments) regarding their experience with the interface. In order to avoid the misunderstanding of the questions, the participants were provided with supplementary verbal expositions prior to and during the completion of the questionnaires.

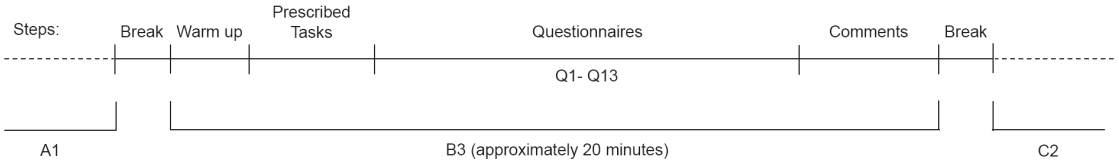


Figure 3-1 Illustrative representation to the timeline of a user evaluations session

The overall structure of the questionnaire and a summary of the questions are provided in Table 3-3. The questionnaire includes a series of thirteen indicators that were rated on a five-point qualitative Likert scale (for example, Q1 involved a scale ranging from “very poor”, “poor”, “ok”, “good”, to “very good”). Altogether three semantic categories were considered. These comprise first impressions (first impression, ease of use, effectiveness, and attractiveness), user interface layout design (flexibility, organization of information, sequence of screens, readability, terminology, and input position), and ease of learning (easy to learn/understand, task sequence).

3.3 Results

The data analysis involved *i)* categorization of the selected products based on three dimensions (information types, control options, and hardware); *ii)* product comparison and evaluation by the author based on seven criteria (functional coverage, environmental information feedback, intuitiveness, mobility, network, input, and output); *iii)* analysis of interview sessions with participants to obtain subjective evaluation results regarding three evaluative categories (first impressions, user interface layout design, and ease of learning) as applied to a subset of the selected products.

3.3.1 Comparison matrices

In this section, the selected products are compared. A previously mentioned, we have classified these as Type A ("Physical" devices), Type B (Control panels), and Type C (Web-based Interfaces). The comparison results are arranged in Tables 3-4, 3-5, and 3-6 in accordance with the previously described dimensions, namely information types (Table 3-4), control options (Table 3-5), and hardware (Table 3-6).

Table 3-4 Comparison matrix for the Information types dimension

CODE of classification			A. Physical devices				B. Control Panels				C. Web-based Interfaces			
			A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Info Types	General Info	Date/ Time				●	●	●	●	●	●		●	●
	Indoor Info	Temperature			●	●		●	●	●			●	●
		Humidity			●									
		Air Velocity								●				
		Carbon Dioxide												
		Illumination		●			●	●	●					
	Outdoor Info	Weather						●	●		●		●	●
		Temperature						●		●	●		●	●
		Humidity									●			
		Wind Speed								●				
		Wind Direction									●			
		Global Irradiance					●							
	Device Status	Supply Air Terminal			●					●				
		Windows			●					●				
		VAV System			●				●	●			●	●
		Blinds			●						●	●	●	●
		Ambient Lighting		●	●		●	●	●		●	●	●	●
		Task Lighting					●							
		De/- Humidification												

Table 3-5 Comparison matrix for the Control Options dimension

CODE of classification			A. Physical devices				B. Control Panels				C. Web-based Interfaces			
			A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Control Options/ Extensions	Control via device	Supply air terminal			●			●	●	●				
		Windows			●					●				
		VAV System			●	●		●	●	●			●	●
		Blinds	●		●						●	●	●	●
		Ambient Lighting System	●	●	●		●	●	●		●	●	●	●
		Task Lighting					●							
		De-/Humidification System							●					
	Control via Parameters	Air Movement (path)												
		Air Change Rate (times/hr)												
		Temperature (℃ or ℉)			●	●		●	●	●			●	●
		Ambient Illuminance (Lux or %		●	●		●	●	●		●	●	●	●
		Task Illuminance (Lux or %)												
		Humidity (%)							●					
	Control via perceptual values	Warm/Cool												
		Brighten/Dim												
		Humidify/Dry												
		Ventilate(Air Flow)												
	Control via scenes	Entering						●						
		Leaving					●					●		
		Screen Task	●				●					●		
		Desktop Task	●				●					●		
		Meeting	●				●					●		
		Presentation												
		Break										●		
		Energy Saving										●		
		Cleaning					●							
		All lights on					●	●						
		All lights off					●	●						
		All lights Normal						●						
		User-based Scenes			●	●	●	●	●	●		●	●	●
	Control via Schedule						●		●	●			●	●
	Control via micro-zoning			●	●		●	●	●	●		●	●	●

Table 3-6 Comparison matrix for the Hardware dimension

CODE of classification			A. Physical devices				B. Control Panels				C. Web-based Interfaces			
			A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
Hardware	Input	Buttons	●	●	●	●								
		wheel		●	●									
		Mouse									●	●	●	
		keyboard									●	●	●	
		Touch Panel					●	●	●	●				●
	Output	Response Light	●											
		Monochrome screen		●	●	●								
		Touch Monitor					●	●	●	●				
		LCD screen									●	●	●	●
	Mobility	Fixed	●	●	●	●	●	●	●	●				
		Portable									●	●	●	●
	Network Function	Bus systems	●	●	●	●	●	●	●	●				
		Internet									●	●	●	●
	Reconfigu -rability	No	●	●	●	●								
		Yes					●	●	●	●	●	●	●	●

3.3.2 Product comparison

The collected and classified data may be further analyzed via combined image and positioning maps. These maps are constructed, in this case, by placing a product in a two-dimensional evaluative space, whereby the criteria are selected from the following set: Functional coverage (number of functions offered, from low to high), Environmental Information Feedback (from low to high), Intuitiveness (from low to high), Mobility (fixed versus portable), Network (bus systems versus internet), Input (low-tech versus high-tech), and Output (low-tech versus high-tech). High-tech denotes in this context the use of more recent (advanced) technologies involving LCD monitors, touch panel, etc. Low-tech technologies are associated, in contrast, with traditional physical buttons, light signals, and monochrome screens. Based on the analysis of the selected products, four maps were obtained (see Figures 3-2 to 3-5). Thereby, the products are specified in terms of the code given in Table 3.1 (Type A: A1 to A4, Type B: B1 to B4, and Type C: C1 to C4). Note that the placement of the product images (codes) in these maps (along the evaluative axes) was based on the authors' qualitative judgment.

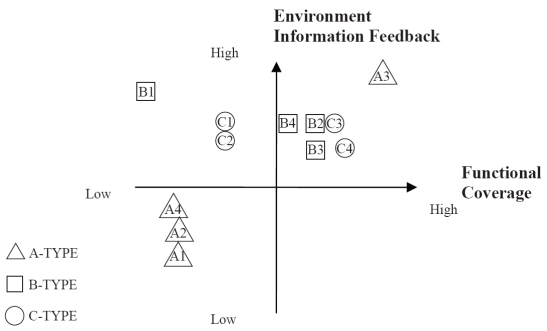


Figure 3-2 Map of functional coverage versus environmental information feedback

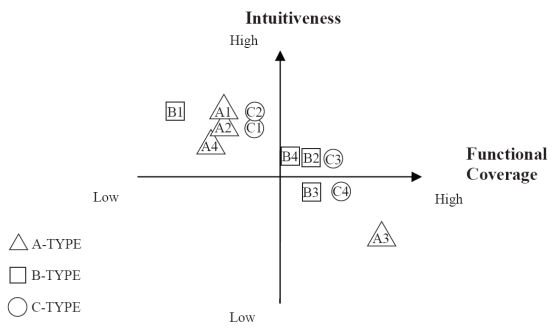


Figure 3-3 Map of functional coverage versus intuitiveness

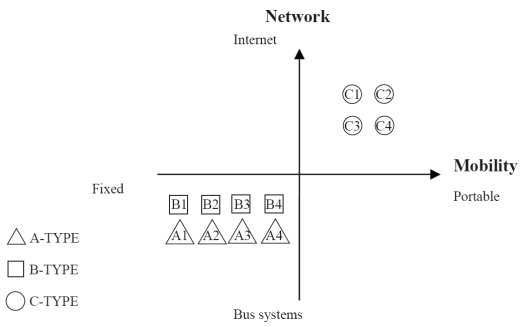


Figure 3-4 Map of mobility versus network

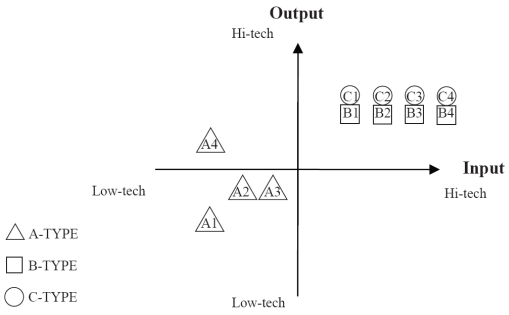


Figure 3-5 Map of input versus output

3.3.3 Sessions with participants

The results of the above mentioned sessions involving 40 participants who evaluated four products each were currently analyzed in terms of three categories of indicators pertaining to *i)* first impressions; *ii)* user interface layout design; and *iii)* ease of learning. Thereby, the five-point qualitative Likert scale of the questionnaire (see section 3.2.4) was further converted to numerical values (from 1 to 5). Initial results of the analysis of these sessions are given in Figures 3-6 to 3-9 as mean values. Figure 3-6 (mean values together with standard deviations) compares the overall evaluation results regarding the three main categories of the inquiry. Figure 3-7 shows a detailed comparison of the four indicators of the first category (first impressions). Figure 3-8 does the same for the six indicators of the second category (user interface layout design). Figure 3-9 related to the comparison of the three indicators of the third category (ease of learning).

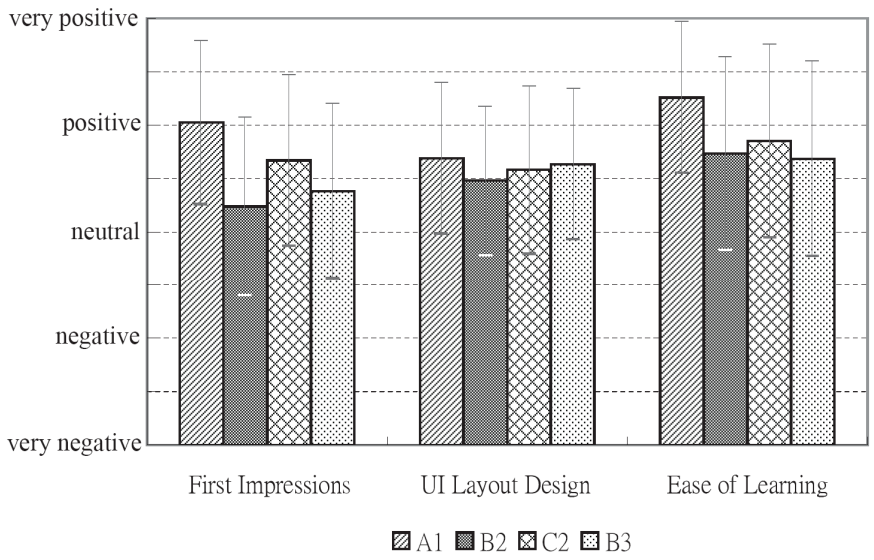


Figure 3-6 Evaluation results of four interface products by 40 subjects (mean values together with standard deviations of first impressions, user interface layout design, and ease of learning)

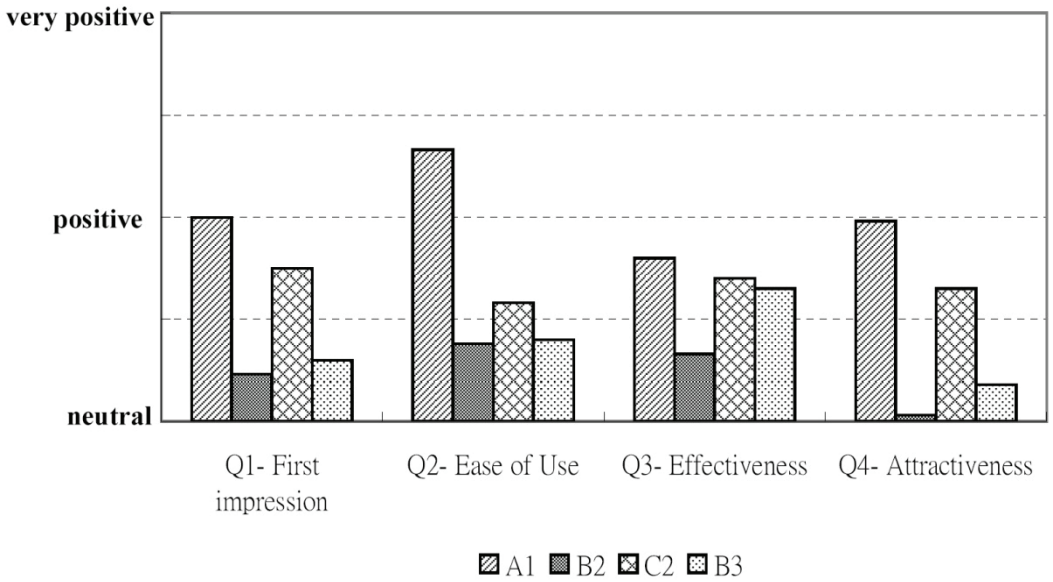


Figure 3-7 Evaluation results of four interface products in view of the "first impressions" category (mean values of indicators: first impression, ease of use, effectiveness, and attractiveness)

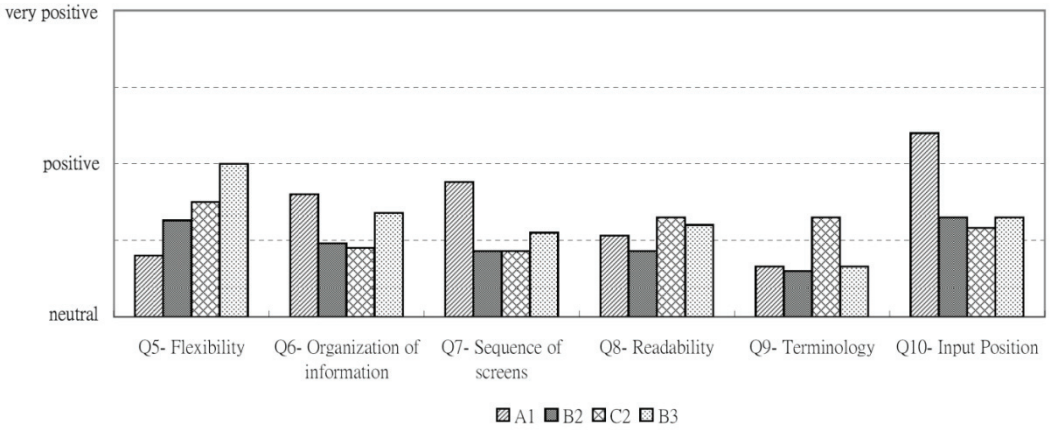


Figure 3-8 Evaluation results of four interface products in view of the " user interface layout design "category (mean values of indicators: flexibility, organization of information, sequence of screens, readability, terminology, and input position)

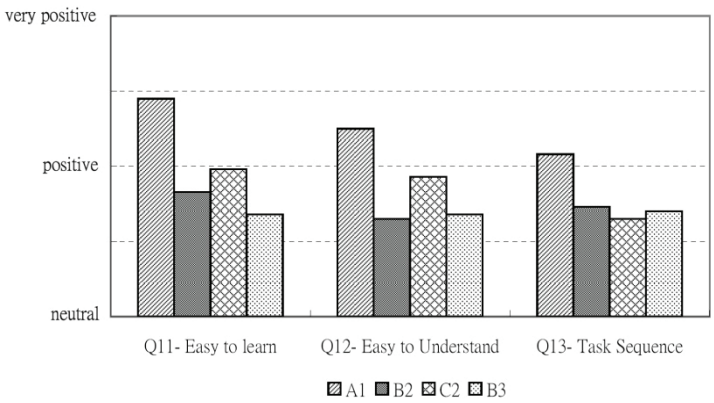


Figure 3-9 Evaluation results of four interface products in view of the "ease of learning" category (mean values of indicators: easy to learn, easy to understand, and task sequence)

3.4 Discussion

Comparison results of the selected user interfacing products for intelligent environments warrant certain conclusions regarding their features and limitations. Interfacing with radically new kinds of environments that involve sentient technologies may require rethinking the occupants' requirements and attitudes. In addition, new interfaces encounter problems associated with numerous new technologies simultaneously embedded into a sentient building. Thus, to arrive at effective and comprehensive user interface models for sentient buildings, it is not only necessary to better understand the features and strengths of the available solutions, but also to anticipate and avoid negative consequences of interface technology integration in this critical domain. In the following, certain areas of deficiency in the status quo are briefly discussed and possible remedies are considered.

3.4.1 Control options and functional coverage

In sentient environments, one key point is how the occupants interact with the multitude of environmental control devices and how they deal with the associated information loads (technical instructions, interdependence of environmental systems and their aggregate effects on indoor conditions) in an effective and convenient manner. For example, it may be more advantageous from the user point of view, not to focus so much on the control of individual devices, but on the communication of the desired outcome of a (potentially complex) control operation. Let us consider the basic options to communicate the desire to bring about changes in the thermal conditions in a space. For example, to change the temperature in a room, four distinct options may be considered: *a)* control via devices, *b)* control via Parameters, *c)* control via perceptual values, and *d)* control via scenes. Naturally, it seems, communicating desired changes in terms of perceptual values (e.g., "I would like to have it warmer/cooler") would be the most intuitive and convenient option for the user. However, as Table 3-5

demonstrates, none of the selected products offer this option. Moreover, many products (particularly type B and C) offer rather high functional coverage that is not very intuitive (see Figure 3-3). On the other hand, there are products (particularly type A) with functional options, which, while limited in number, are intuitive (see Figure 3-3).

As the results shown in Figure 3-6 and Figure 3-8 imply, the A1 product, which has a relatively limited flexibility, fairs better than the other three products in terms of first impressions and ease of learning categories. This result implies again that limited functional coverage and intuitiveness of use often correlate. This suggests (providing an affirmative response to the second inquiry formulated in section 3.2.4) that an overall high functional coverage imposes a large cognitive load on (new) users.

3.4.2 Provision of information

The levels of information related to user-system interactions are defined as follows:

i) Control task: the information directly relevant to the control action. For example, the user intends to open the window and needs to know the position of the window.

ii) Context: the environmental information the users could query in order to arrive at a proper control decision. For instance, a user might require information on the prevailing temperature and humidity of the room before considering a specific control action.

iii) Consultation: The user interface may make suggestions and display alternative control options to the users

iv) Other: Additional information that cannot be neatly categorized based on the above levels.

The appropriate information would include *i)* control task, *ii)* context, and *iii)* Consultation.

If it is true, that more informed occupants would make better control decisions, then user interfaces for sentient buildings should provide appropriate and well-structured information to the user regarding outdoor and indoor environmental conditions as well as regarding the state of relevant control devices. Most of the B and C type products in our study provide the users with relatively high levels of information (the amount of details provided by the user interface) independent of their functional coverage (see Figure 3-2).

However, in most cases these products provide feedback regarding the state of the devices but do not sufficiently inform the occupants regarding indoor and outdoor environmental conditions. For example, information (state and meaning) pertaining to parameters such as indoor air relative humidity, air movement, and CO_2 concentration, or outdoor air relative humidity, wind speed, wind direction, and global irradiance are almost entirely ignored by these products (see Table 3-4). This means that the occupants are expected to modulate the environment with the condition of insufficient information.

3.4.3 Mobility and re-configurability

As mentioned earlier, the hardware dimension addresses two issues, namely, *i)* mobility: user interfaces with spatially fixed locations versus mobile interfaces; and *ii)* re-configurability: the possibility to technologically upgrade a user interface without replacing the hardware may decrease the cost of rapid obsolescence of technology protocols.

C-type terminals such as PDA and laptops connected to controllers via internet make the concept of mobility realistic. In contrast, Type A and B products are typically wall-mounted and thus less mobile (see Figure 3-4). Building owners and operators are often concerned about the durability of user interface devices and the rapid obsolescence of technology protocols. As such, a user interface with high re-configurability potential could be replaced without affecting other devices and UI hardware. For example, in Type B and C products, the user interface software may be easily upgraded, while the conventional A-type products are software-wise rather difficult to upgrade (see Table 3-6).

3.4.4 Input and Output

It is important that user interface products for sentient buildings are user-friendly and intuitive. Certain type-B and type-C products in our study provide the users with richer manipulation possibilities that – if transparent to the user – could support them in performing a control task. There are other products (particularly type-A), however, that are rather restricted in presenting to the users clearly and comprehensively the potentially available manipulation and control space (see Figure 3-5). Nonetheless, as Figure 3-6 suggests, the A1 product is more positively evaluated than the more modern/high-tech (type-B and C) products, especially in view of first impressions and ease of learning. This result represents a sobering answer to the first inquiry formulated in section 2.4. Here, there is a challenge. Modern (high-tech) interface products that offer high functional coverage, must also pay attention to the cognitive user requirements so that formulation and execution of control commands are not overtly complicated.

3.4.5 Additional observations

In addition to the quantitative processing of the feedback provided by the 40 participants in the above mentioned experiment, a number of their individual statements (open-end comments) regarding the interface products tested were also considered. Thereby, cognitive problems in navigation are specifically highlighted.

Table 3-7 Illustrative participants' comments

No.	Participant	Statement
1	Participant 16, Product B3	*I would like to regroup these elements in this ... menu framework of this interface, not only put it in a more rational way but clarify the ... tree structure of the control panel.*
2	Participant 39, Product B3	*I would like to have a quick overview while getting started. But the layout of this interface is really a chaos without "focal points". I really have no idea where to start my task in the beginning.*
3	Participant 36, Product A1	*I am so impressed by the scene function. It is very easy; it leads me straightforward to where I desire to go. You wouldn't need to take you time and set up the devices one by one. Just one button and all is done, that was very good.*
4	Participant 20, Product C2	*The triangle-shape iconic button in the main menu ...I found quite confusing. It took me a while to recognize that is a "forward" button…It's so indistinct. It should be tagged with an appropriate label.*
5	Participant 16, Product C2	*I would like to make the blinds move up and down. But it was so difficult to find these buttons. Finally I found the gray buttons that look like as if they cannot be clicked. If the buttons would be black, I could immediately recognize that these buttons are usable. That would be nice. Because then I wouldn't actually ignore them so easily.*
6	Participant 27, Product B3	*There are too many levels in this interface. I would only like to adjust the temperature values but I still have to go through four pages in this ... interface. The worst thing is that each page is so different. I had to spent a while finding the "next" button to go forward, and I had to go forward again and again - it was rather clumsy.*

3.4.5.1 Organizational layout

In the experiment with the participants, there was an interest to know if they considered the existence of a clear organizational layout of the interface important. As it can be seen from Table 3-7 (cp. Rows 1 and 2), some participants found indeed the layout of one of the tested products (B3) rather disorderly and confused. In other words, they missed a clear visual hierarchy and semantic structure. These comments suggest that a well-organized layout may effectively guide the users' attention in the task manipulation and facilitate thus the interactions between users and control devices and systems.

3.4.5.2 Shortcuts and repetition

A scene function provides the possibility to define multiple set points for multiple environmental parameters simultaneously. Thus, proper combination of such set points can be pre-programmed in conjunction with typical use scenarios (e.g. reading tasks, computer work, meeting, informal conversations, etc.). Offices, for example, usually possess a number of different devices. With pre-programmed scenes, occupants may press just one button to achieve the desired effect.

As an alternative to designs that require the repetitious execution of identical manipulations, the "Scene" function appears to provide a straightforward shortcut for the users to communicate their preferences via a single keystroke. Taking an example of product A1, many participants expressed their appreciation regarding the existence of scene functions that save them much time and effort (see, as an example, the statement in row 3 of Table 3-7. Scene functions thus offer participants shortcuts to simplify the execution of repetitive (and often time consuming, dull and error prone) tasks.

3.4.5.3 Clarity of terms and icons

The labels (i.e., iconic buttons, tags, and text items) play an important role in how navigation proceeds. Thus, such labels should be plainly worded and clearly visualized. They must be simple and easy to understand. Otherwise, as certain comments imply (see rows 4 and 5 of Table 3-7), frustration may result particularly in the earlier phases of interface usage, as the users are not fully familiar with the product.

3.4.5.4 Navigation memory

By their nature, conventional physical devices for communication (such as product A1), appear to provide more simple layouts helping the users to operate in a "one-page" depth. In contrast, other products require moving from one page to the other. Many participants felt that some products (e.g., product B3) require too many jumps in navigation, whereby each screen much different from the other (see, as an example, participant comment in row 6 of Table 3-7). This may make learning and retaining of the required manipulation sequence difficult. A smaller number of jumps amongst screens seem to be preferred by most participants.

It was mentioned earlier that a product with a relative limited flexibility might fair better that more sophisticated ones in terms of overall impression and learning ease. This seems also to be true of sequence of screens and how they lead to communication of a request (see Figure 3-8 and Figure 3-9). The above mentioned participants' comments imply that limited functional coverage and navigational ease often correlate. This suggests that an overall high functional coverage can impose a larger cognitive burden especially on new users. Interface design must thus pay particular attention to supporting cognitively friendly use patterns while offering richness in manipulation options.

3.5 Summary

While a detailed design for desirable user interfaces for future sentient environments has not been offered, a framework for the formulation of requirements for such interfaces has been outlined. This framework embodies a system for typological product differentiations (a product type terminology) and a set of dimensions for product specification and evaluation involving information types, control options, and hardware. An array of existing user interfacing products for intelligent built environments against this framework has been tested , evaluated. Thus, the areas of relative strength and deficiency have been identified. Moreover, interviews were conducted with a number of participants testing a selected number of user interface products. The corresponding results provide a solid basis for future developments in user interface technologies for sentient buildings. Thereby, the guiding principles are the timely provision of appropriate and well-structured information to the user together with intuitive representation of the type and range of devices and parameters that could be manipulated by the users toward achieving desirable indoor climate conditions while meeting the goals pertaining to a sustainable building operation regime.

4 Implementation

4.1 Overview

In previous chapter, the requirements and functionalities of user interfaces for building systems have been explored. In order to evaluate the effects of the framework for the formulation of requirements for such interfaces, it is helpful to have a look at the resulting interface that has been implemented utilizing this approach.

The resulting interface that wraps these features derived in chapter 3 is named as BECO- "Built Environment communicator", which serves as a user interface model for building systems of a research project "self-actualizing sentient buildings". In this chapter, firstly, in order to better understand how the interface development utilizes certain framework in its design, the relevant background (testbed infrastructure and base technology) and interface development are described. Furthermore, the features of this user interface model are introduced in view of user manipulation experiences, implemented services (based on control options, provision of information, settings and hardware), layout design (involving layout framework, center stage, and use of color), as well as navigation (such design patterns as card stack, accordion, target guiding, continuous scrolling, terms/icons).

4.2 Test bed

4.2.1 Infrastructure overview

A testbed infrastructure is set up to simulate office-based sentient environments where a set of services are deployed and seamlessly integrated. The testbed is installed for "self-actualizing sentient buildings" research project as a 1:1 mockup of two office rooms located in the building physics laboratory in Vienna Technical University, Department of Building Physics and Building Ecology. This testbed infrastructure involves a system controller associated with a variety of network protocols (based on the Internet, LAN, and LON Network), devices, and services (see Figure 4-1). In order to create a realistic office environment, this existing light-weight test bed is equipped with systems for heating, lighting, ventilation, shading, and de-/humidification. These devices include: *i)* HVAC system; *ii)* Radiator; *iii)* Electrical windows; *iv)* Electrical shading; *v)* Ambient lighting system (2 luminaires and 1 task spot for each room); *vi)* De-/Humidification system (see Figure 4-2). An overview of the test bed layout is shown in Figure 4-3.

Based on this testbed infrastructure, a user interface model - BECO - is developed and presented in the following sections to demonstrate the implementation and to provide a solid basis for future developments in user interface technologies for sentient buildings.

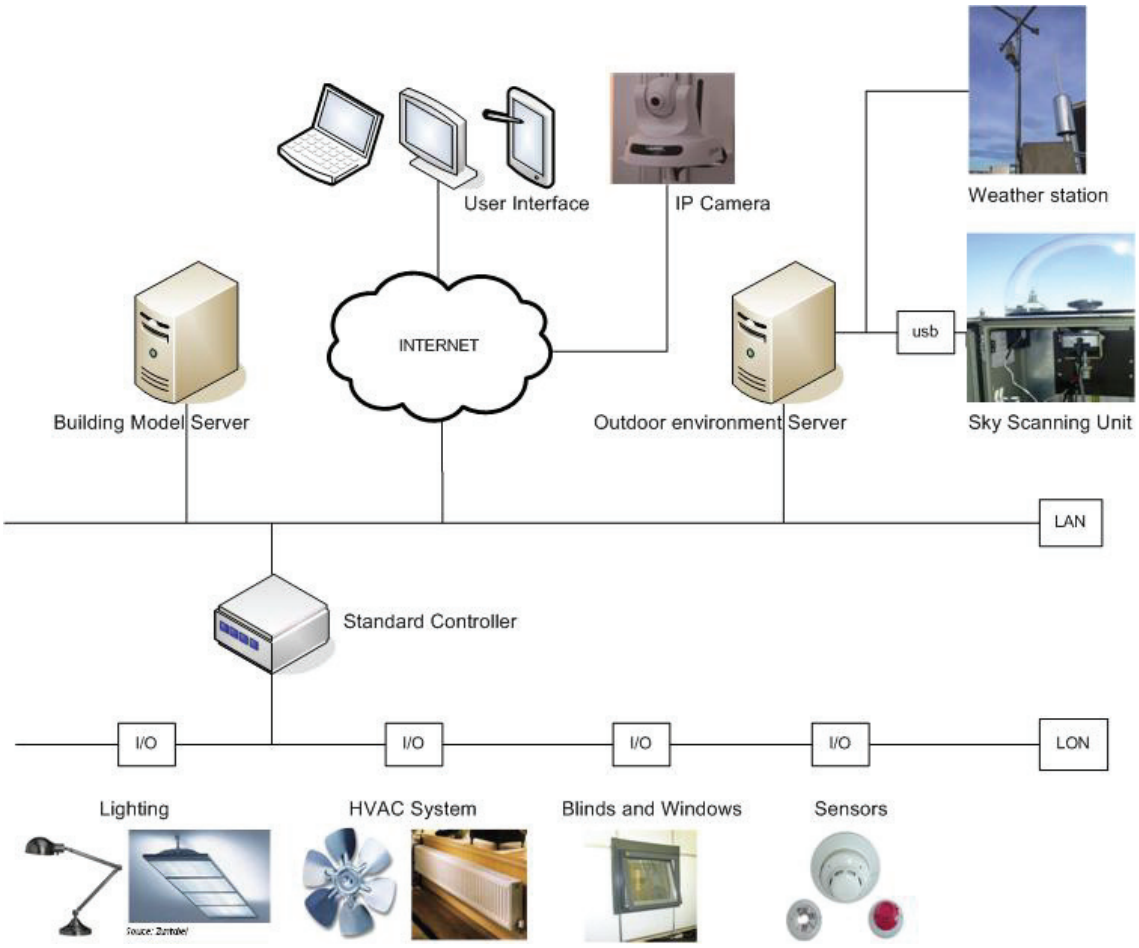


Figure 4-1 Testbed infrastructure

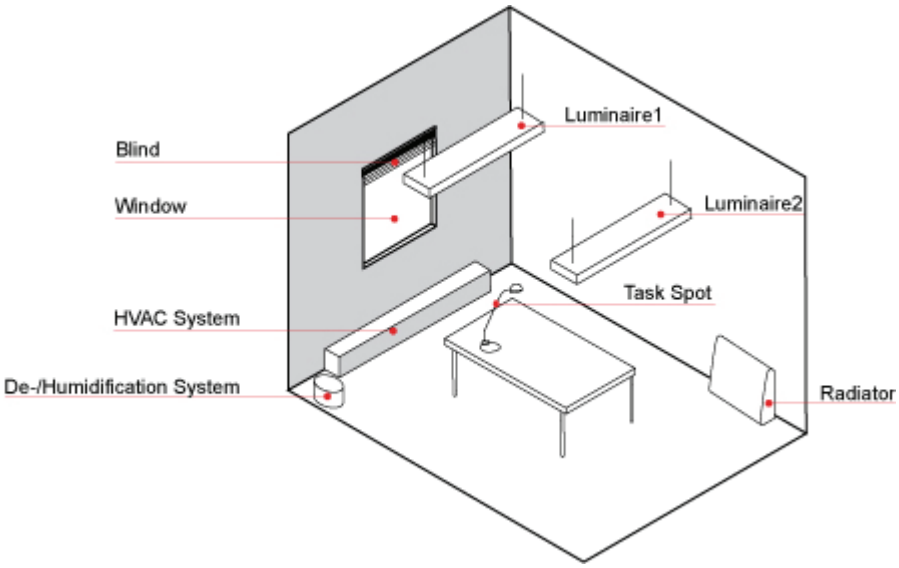


Figure 4-2 Schematic representation of the equipped devices in a test room (Lab 1)

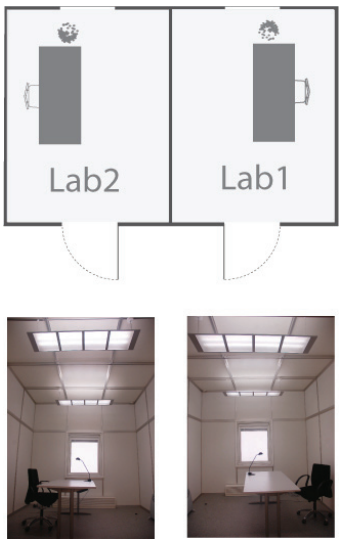


Figure 4-3 Overview of the testbed layout

4.2.2 Comprehensive building information model

Along with the testbed infrastructure, a comprehensive building information model (BIM) is built for the requirements of this research project that aimed to provide the information on building context (e.g., weather conditions), building topology, components, and systems, as well as building occupancy (user presence and actions) in the testbed. Specifically, this model is updated real-time via a sensory infrastructure (including sensors for outdoor and indoor environmental conditions, occupancy presence and actions, state changes in control devices) and provided to multiple applications (pertaining to facility management and control systems). Such applications use various tools (including building performance simulation, trend analysis and learning algorithms) in order to anticipate the state of building and indoor climate as a result of alternative control options. For example, the state of weather conditions (monitored via a weather station), indoor environment data (such as temperature, relative humidity, air flow speed, illuminance), and device states are regularly updated in the model and provided to the building systems control unit along with users' feed-back regarding their indoor climate preferences (Mahdavi et al. 2007).

4.2.3 Model-based control strategy

A comprehensive building information model underlines all operative entities and activities in the life-cycle of the building and is provided to model-based control strategy in building control systems (Mahdavi et al. 2007). In the concept of model-based control, the controller application possesses an internal digital representation involving models of the environment (e.g., the room, the context, and the occupancy) to arrive all the control decisions. As to the case of lighting and shading systems control in an office space (Mahdavi and Spasojevic 2006), for instance, the controller application in this system can control the position of window blinds and the status (on/off, dimming level) of the luminaires. Also, the room and sky (context) models are updated dynamically to provide a real-time basis to serve the controller application in this system for considering occupancy settings and provide/maintain the desired performance (e.g., preferred illuminance levels, weights in the prescribed objective functions). Given the role of model-based control strategy, the manipulation of control devices toward desirable indoor climate may be more intuitive for the occupants, resulting in a more efficient, time-saving, and sustainable operation regime. A flow diagram of model-based control in this building control system is shown in Figure 4-4.

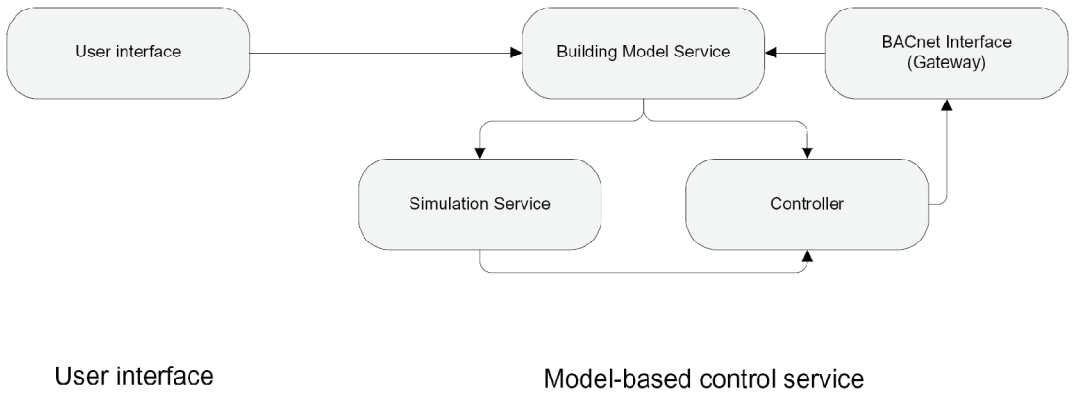


Figure 4-4 Flow diagram of model-based control strategy (Camara, 2008)

4.3 Base technology

Prior to the implementation of an interface model, the following technologies and tools are reviewed from the development perspective. First, the software development environment, communication protocol, as well as wireless IP camera are introduced. Then, the interface design tools are investigated.

4.3.1 Software Development Environment

This interface development is based on Silverlight 2 which is a major tool for building rich interactive user experience that incorporates user interface and media (see Figure 4-5). Silverlight 2 includes a cross-platform, cross-browser version of the .NET Framework and enables a rich Microsoft .NET development platform that runs in the browser (e.g., Microsoft explorer and Firfox). Visual Studio 2008 (based on C#, as a .NET language) is used as a development tool for coding this silverlight-based user interface framework and Adobe Illustrator for layout and graphic design. Specifically, in order to make the interface more graphical and interactive, XAML (Extensible Application Markup Language) is used as a user interface markup language to create user interface (dynamic) elements and animations. Also, a Microsoft SQL Server, which is a relational database and management system produced by Microsoft, serves as a database server of this interface application. ASP .NET AJAX was developed to improve performance in the browser space by making communications between the web-based interface and database server asynchronously. In addition, a specific socket-based communication protocol is conducted to connect to the model-based service via a socket port (see appendix A).

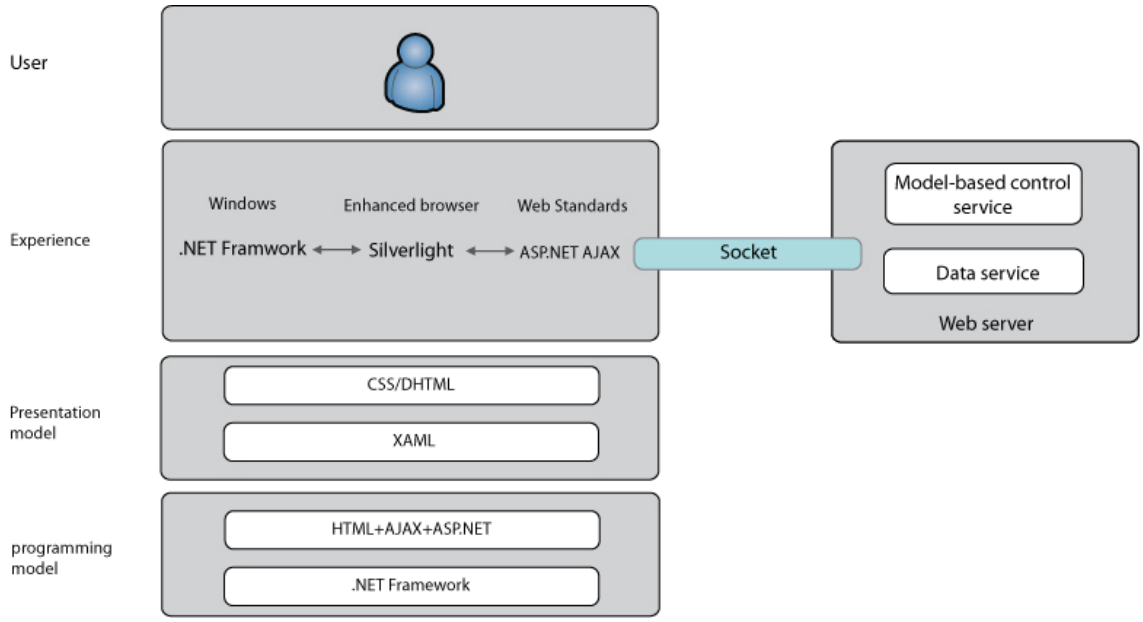


Figure 4-5 Interface architecture

4.3.2 Wireless IP Camera

The wireless pan/tilt internet camera is a standalone device which can be directly connected to Ethernet/Internet, and supported by the wireless transmission based on the IEEE 802.11g protocol (Sparklan Inc. 2008). Also, it can provide the occupants wit real-time video images for monitoring the target space. Here, the video images of the camera are embedded in this interface model and allow the occupants to view the device states (e.g., the position of the blinds and the illuminance of the room) of their office (see Figure 4-6). In addition, the camera's pan/tilt function (45/90 degrees and 170/170 degrees) may allow the occupants to adjust the camera for optimal viewing angle.

Figure 4-6 The installation of IP Camera

4.4 Interface development

In Chapter 3, the analysis of product comparison and interviews highlighted a number of basic principles and expectations regarding the design of desirable user interface products for sentient environments. Starting from these results, in this section, an attempt has been made to further articulate user requirements toward actual design of such interface products.

4.4.1 Defining Posture

Posture is a way of talking about how much attention a user will devote to interacting with a product, and how the product's behaviors respond to the kind of attention a user will be devoting to it (Cooper, Reimann, & Cronin 2007). According to previous research (Mahdavi et al. 2007), it may be concluded that the essential feature of the indoor climate control user interface is its short-term usage patterns. This kind of user interfaces with a transient posture (Cooper, Reimann, & Cronin 2007) must offer very short-term manipulation possibilities. They must efficiently offer important and frequently needed functionalities and

the appropriate accompanying requisite information, and then quickly step to background, letting the occupants continue their normal activities (such as working on paper-based and screen-based tasks in offices).

4.4.2 User Models and expectations

Workers/employees are the target user group in this interface development. For this major user group, two user models, which capture the most important aspects, are identified as follows (see also Chien & Mahdavi 2008b):

4.4.2.1 Primary model and extensions

In this type of model, the users always have a great amount of workload (e.g. paper/screen tasks) that monopolizes their attention for long periods of time while working. They tend to have certain organizational and time-saving techniques to structure the course of their working day. Despite the factual importance of the interface for the users' daily activities and conditions, users of a primary interface model are willing only to dedicate a very limited time-budget to learn it. Rather than attempting to load extensive functionalities into a primary user interface product, it must be designed such that it is perceived as being simple and easy to use. The users in a primary user interface model scenario, expects the least possible time (minimum navigation) to complete a certain control action and to immediately return to their office activities. Thus, the most frequently needed control options and corresponding required information must be identified and offered in a primary user interface model. In this case, additional options/information may be expected to disturb the users. Primary model may be further augmented in terms of an extended version with additional (yet non-extensive) options and information features (e.g. indoor/outdoor environment conditions).

4.4.2.2 Secondary model

The human targets of the secondary interface models might have as much as a working load as those of the primary interface models, but they value more a sense of control over their environment and the associated devices and tools. Thus, they are more willing to allocate time and patience to manipulate their control user interfaces and to deal with rather complicated settings and details. Likewise, they would be open to and interested in acquiring more information about their environmental conditions and means and ways of controlling their workplaces. As a result, a secondary user interface model needs to be more detailed and versatile. It must provide the users with much more options and information than primary models, as the secondary model users can be expected to master all kinds of control options, assign/modify their customized scenes, and acquire multiple categories of indoor/outdoor information.

4.4.2.3 User conflict

With a growing number of occupants using a finite resource (control devices) in order to experience diverse array of desirable indoor climate pursuits, the occurrence of direct or perceived conflict between occupants has increased to critical proportions. As to the office-based environment, conflicts may arise amongst different user groups or amongst users within the same group. Here, conflict pertains to control and use of devices, expectations/attitudes toward and perceptions of the environment, level of tolerance for others (Wild Wilderness association 2008), shared interaction spaces, etc.. The above-mentioned factors may result in the poor usability/satisfaction and the difficulty in providing system services (McGee-Lennon & Gray 2006). In order to eliminate conflicts within a group of users, the system may provide a suitable platform involving identification hierarchy and negotiation functionality. In this testbed, for example, the occupants are given different limits of authorities to access to the user interface model in terms of their system identification, namely guest, default user (worker/employee), and administration (building management).

4.4.3 Requirement profiles

We generated a set of requirement profiles arranged in accordance with the previously described dimensions, namely information types (see Table 4-1), control options (see Table 4-2) and hardware (see Table 4-3). In this context, a desirable user interface product may serve both user models mentioned above. Moreover, these schemas can embody the integration of the functionalities associated with these two user groups.

Table 4-1 The requirements for the information types dimension.

CODE of classification			User Types		
			Primary		Secondary
			B*	E**	
Info Types	General Info	Date/ Time	●	●	●
	Indoor Info	Temperature	●	●	●
		Humidity	—	●	●
		Air Velocity	—	—	●
		Carbon Dioxide	—	—	●
		Illumination	—	●	●
	Outdoor Info	General Weather conditions	●	●	●
		Temperature	●	●	●
		Humidity	—	●	●
		Wind Speed	—	—	●
		Wind Direction	—	—	●
		Global Irradiance	—	—	●
	Device Status	HVAC System	●	●	●
		De-/Humidification System	—	●	●
		Windows	—	—	●
		Blinds	—	—	●
		Ambient Lighting System	—	●	●
		Task Lighting	—	—	●

(* Basic; ** Extended)

Table 4-2 The requirements for the Control Options dimension

CODE of classification			User Types		
			Primary		Secondary
			B*	E**	
Control Options/ Extensions	Control via device	HVAC System	●	●	●
		De-/Humidification System	—	●	●
		Windows	●	●	●
		Blinds	●	●	●
		Ambient Lighting System	●	●	●
		Task Lighting	●	●	●
	Control via Parameters	Air Movement (path)	—	—	●
		Air Change Rate (h^{-1})	—	—	●
		Temperature (℃ or ℉)	●	●	●
		Ambient Illuminance (lx or %)	●	●	●
		Task Illuminance (lx or %)	●	●	●
		Humidity (%)	—	●	●
	Control via perceptual values	Warm/Cool	●	●	●
		Brighten/Dim	●	●	●
		Humidify/Dry	—	●	●
		Ventilate (Air Flow)	—	●	●
	Control via scenes	Entering	●	●	●
		Leaving	●	●	●
		Screen Task	●	●	●
		Paper Task	—	—	●
		Meeting	—	●	●
		Presentation	—	—	●
		Break	—	—	●
		Energy Saving	—	●	●
		Cleaning	—	—	●
		All lights on	—	—	●
		All lights off	—	—	●
		Lights default	—	—	●
		User-based Scenes	—	●	●
	Control via Schedule		—	●	●
	Control via micro-zoning		—	—	●

(* Basic; ** Extended)

Table 4-3 The requirements for the hardware dimension

Aspect	Requirement
Input	Users may input their data and commands via mouse, keyboard and touch panel (12 inches plus recommended for secondary level)
Output	Users are provided with data via LCD screen and Touch panel (12 inches plus recommended for secondary level)
Mobility	Primary level could be realized both spatially fixed and mobile interfaces. Secondary level should be rather realized in desktop terminals for long-term detailed manipulation
Network function	Users may access all resolution levels (basic, extended, secondary) via internet
Re-configurability	All interface types must be technologically upgradable without replacing the hardware

4.4.4 Interface design process

Design process begins once the above-mentioned requirements have been proposed. These requirements offer a solid concept model for the implementation of the detailed design of this interface model, such as framework, screens, icons, and navigation plans. Here, the conducted design goes through a "design-evaluation-redesign" process involving users (Sharp, Rogers, & Preece 2007). In the early stage of development, three design concepts are proposed and discussed interactively via sketches and paper mockups (see appendix B). While the design progress become more detailed and concrete, by comparing the features and deficiencies, a design strategy is selected and further developed for an interactive version prototyping and construction. Through the whole process, focus groups and interviews are conducted to polish the details of interface design in the methods of scenarios, picture-driven animation using powerpoint, as well as interactive mockup manipulation.

4.5 Occupants' manipulation experiences

The prototyping of web-based interface is implemented with the goal of allowing the occupants to achieve desirable indoor climate conditions and enhancing the experiences of interface manipulation. The system is realized as a web-based user interface and is presented to the occupants via web browser (e.g., Microsoft explorer). To describe BECO, certain illustrative scenarios are presented as follows.

4.5.1 Illustrative scenarios

To better portray the interface, illustrative scenarios with manipulation steps are described and demonstrate how the occupant adjust the indoor climate conditions.

Location: *One office of an electrical company*

Persona: *Alice (32), who is a mother of three-kids, works in this company as a manager. She likes everything to be straightforward and easy to handle, but sometimes she also needs to be patient to deal with the details.*

Background: *It used to be necessary to switch and adjust diverse devices separately in this modern office. These routine manipulations had to be made repeatedly every day. These tasks were extremely time-consuming and annoying for Alice. She needed to stop her work and adjust the devices. Sometimes she was too busy to do so and worked in an uncomfortable environment unconsciously. Now this user interface model may help Alice to achieve a desirable indoor climate in an easy way.*

8:30 am.

Start of a working day

It is Friday morning, 8:30 am. Alice enters her office and announces her arrival by logging in BECO via the browser. She feels the indoor air is already "fresh" when she comes in. As a matter of fact, at 8:00 am the system has activated the "standby" mode, which she set up the previous day. She then presses the "screen task" button, which enables the screen scene. This scene illuminates the office at the specified level, properly focusing extra light on her desk, to enhance her screen task.

2:00pm.

Midstream of the day

Alice is working on a paper task and trying to finish it before leaving. However, her room is facing the afternoon sun and the high irradiance makes it difficult for her to concentrate and to handle her work. Thus, she calls up "control via perceptual values" in "Home" control groups and chooses "brightness" option. A control box is triggered on the main control zone of the interface screen. She presses "dim" button twice. That way, Alice has control over the illuminance of the room, while the model-based system (Mahdavi & Spasojevic 2006) *modifies her input with its own simulation to create an appropriate control action involving the related devices. Subsequently, the system changes the position of the blinds, the illuminances of two luminaires, as well as the task spot of her office room. Meanwhile, the animated icon in the control box becomes dim by 2 levels, as an information feedback of the brightness transition. This control feature is very useful because the system spares her attention and does what it is good at. Once the control task is finished, she clicks somewhere else to terminate the control box and the screen reverts to a default view of "Home" control group. Now she could work on her paper work comfortably again.*

4:30pm

Early evening

As the weather cools down, Alice calls up the "information booth" on the righthand of the screen to check the outdoor weather information. It shows that it is going to rain. She then activates the "window" control box in the "Devices" group. She adjusts the window state from open to close via the slider and clicks somewhere else to end the control box. After a while, she begins to think about her family tour tomorrow and then checks her watch. She is aware that it is about time to leave. It occurs to her that she should set up a "weekend" scene so that she just needs to click the "weekend" scene. This would make it easy for her to operate the system in the future. She triggers the shortcut button on the screen and immediately it displays a scene editing screen which shows the details about adjusting device, date/time together with a guiding route for her to configure clearly. Once she finishes the setting, she clicks the save button and a screen pops up to let her name this scene as "weekend" and assign a suitable icon for it. The "weekend" scene is now available on the scene zone. She clicks this new "weekend" button and logs out BECO. After a while, she leaves the office whilst all the devices shut down. Alice can relax to change her control tasks and/or inquiry the room information via internet at any time during her vacation.

4.6 System features

To realize previous approach (sections 4.3 to 4.5), a user interface model involving three system feature categories (based on implemented services, layout design, and navigation) are considered and identified. All identified system features are implemented and aggregated in a web-based interface providing a central portal for the occupants to access to all control services. An overview of this user interface is given in Figure 4-7 and Figure 4-8 respectively.

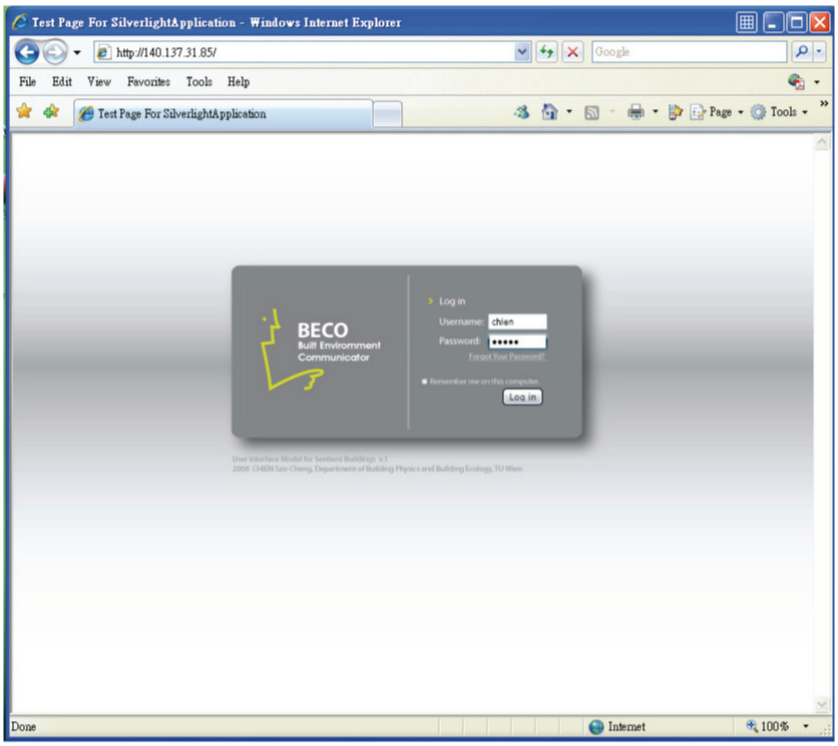


Figure 4-7 A screen shot of the login webpage

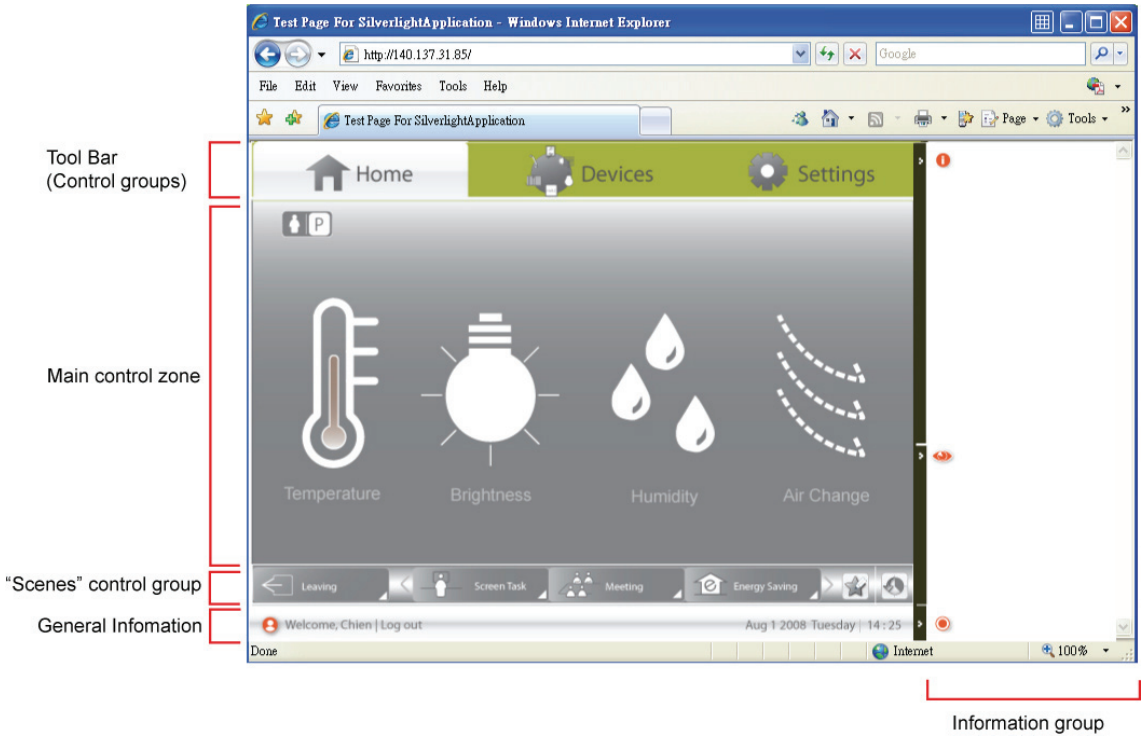


Figure 4-8 A screen shot of the main menu

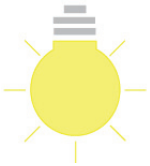
4.6.1 Implemented services

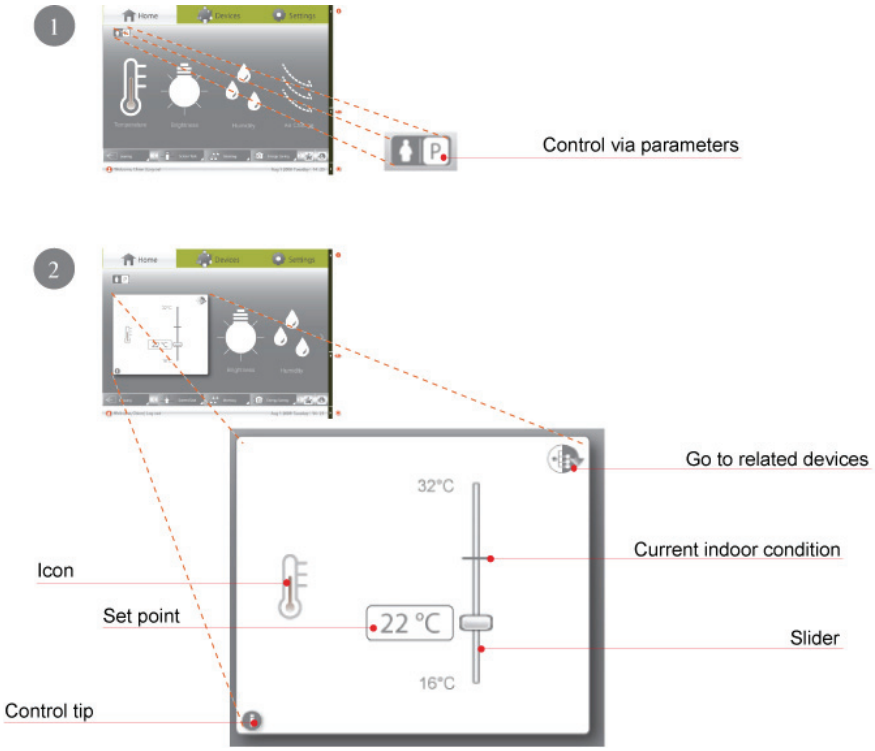
4.6.1.1 Control Options

Three control groups considered essential for the occupants of an office are implemented by means of the occupants' preferences and able to control the occupants' environment. These control groups include "Home" (based on control via perceptual values/parameters), "Devices" (involving control via devices) and scenes (encompassing control via scenes). All deployed control groups have been integrated in BECO providing a "one-for-all" and consistent interface to unify the control solutions to the environment.

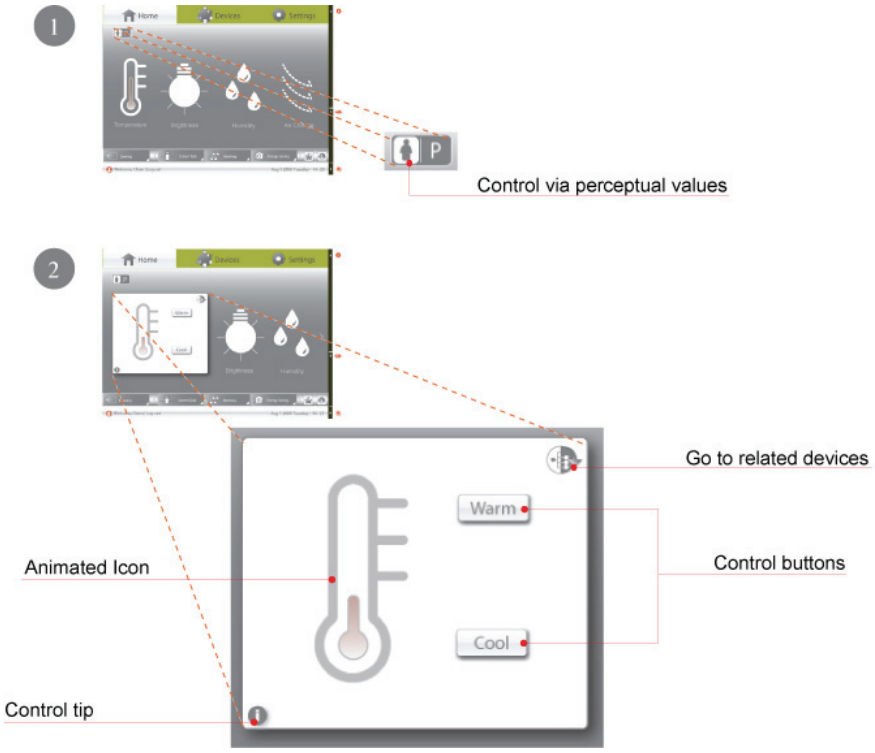
i) "Home" –"Home" group offers an integrated control view of this room in terms of indoor conditions (i.e., building performance) by means of utilizing model-based control strategy (see section 4.2.3). The control options of indoor conditions pertaining to parameters allow the users to request specific target values or ranges for certain indicators of indoor climate. Such indicators include temperature, illuminance (brightness), humidity, and ventilation (air change) (see Table 4-4). Sliders allow the occupants to input the desirable values visually in a bounded range (see Figure 4-9a). On the other hand, the occupants may communicate their preferences regarding indoor conditions not in terms of the numeric values of indicators for such conditions, but in perceptually relevant qualitative terms. Based on this concept, four control methods together with animated icons pertaining to perceptual values are mapped to the related indoor indicators (i.e., warm/cool: temperature, bright/dim: brightness, humidity/dry: humidity, more/less air: air change) and offered to the occupants whilst the occupants adjust the indoor conditions with "control via perceptual values" (see Figure 4-9b). Also, these two control groups may be further specified via micro-zoning extension. In addition, the occupants may also change their control preferences to other control options (e.g., from "temperature" to "brightness") and groups (e.g., , "Devices" and "Scene" groups) in the midstream of manipulation.

Table 4-4 Illustrative representation of the control state space of "Home" group

Indoor indicators	**Control via Perceptual Values**		**Control via Parameters**	**Related Devices**
	Animated icon	**Control button**		
Temperature		Warm/Cool; Levels:6	16 – 32 (℃); Interval: 0.5 (℃)	1. HVAC 2. Radiator 3. Windows 4. Blinds
Brightness		Bright/Dim; Levels:9	0–2000 (lx); Interval: 100 (lx)	1. Blinds 2. Luminaire1 2. Luminaire2 3. Task spot
Humidity		Humid/Dry; Levels:6	30–80 (%); Interval: 10 (%)	1. HVAC 2. Windows 3.De-/Humidification System
Air Change		More/Less Air; Levels:6	0.2–6 (h^{-1}) ; Interval: 0.5 (h^{-1})	1. HVAC 2. Windows



(a)



(b)

Figure 4-9 "Home" control groups: (a) control via parameters, and (b) control via perceptual values

ii) “Devices” –“Devices” group offers a direct and detailed control view of this room in terms of devices. “Devices” group imply that the occupants may directly manipulate the state of environmental control devices to achieve the conditions they desire. Such devices include HVAC system, radiator, windows, blinds, ambient light system (Luminaire 1 and 2), task spot, and De-/Humidification system. The occupants may choose “display all” to have a list of all devices or request a set of devices in terms of related “Home” indicator. For example, the occupants may request the devices pertaining to brightness for detailed control, whereby four devices (i.e., blind, Luminaire 1 and 2, as well as task spot) are displayed. The occupants may input their desirable values visually in a bounded range via sliders (see Figure 4-10). Also, these control options may be further specified in terms of schedules and micro-zoning (see iv-control extension and Figure 4-11). Yet again the occupants may easily change their control preferences to other control options and groups in the middle of controlling devices. Table 4-5 shows an overview of “Devices” group and illustrative control states. Note that the occupants may not control the devices via BECO while the system locks it for certain conditions involving security, time, and building management (e.g., the radiator is locked in summer)(see Figure 4-12). However, certain devices (e.g., windows) may be manually open in case of emergency.

Table 4-5 Illustrative representation of the control state space of "Devices" group

Control option	**Icon**	**States (Values)**
HVAC system		Temperature:16℃ - 32℃; Interval: 0.5℃ Ventilation:0%-100% Interval: 10%
Radiator		0%-100%; Interval: 10%
Window		0% and 100% open
Blind		0%-100%; Interval: 10%
Luminaire1		0%-100%; Interval: 10%
Luminaire2		0%-100%; Interval: 10%
Task spot		0%-100%; Interval: 10%
De-/Humidification system		30%-80%; Interval: 10%

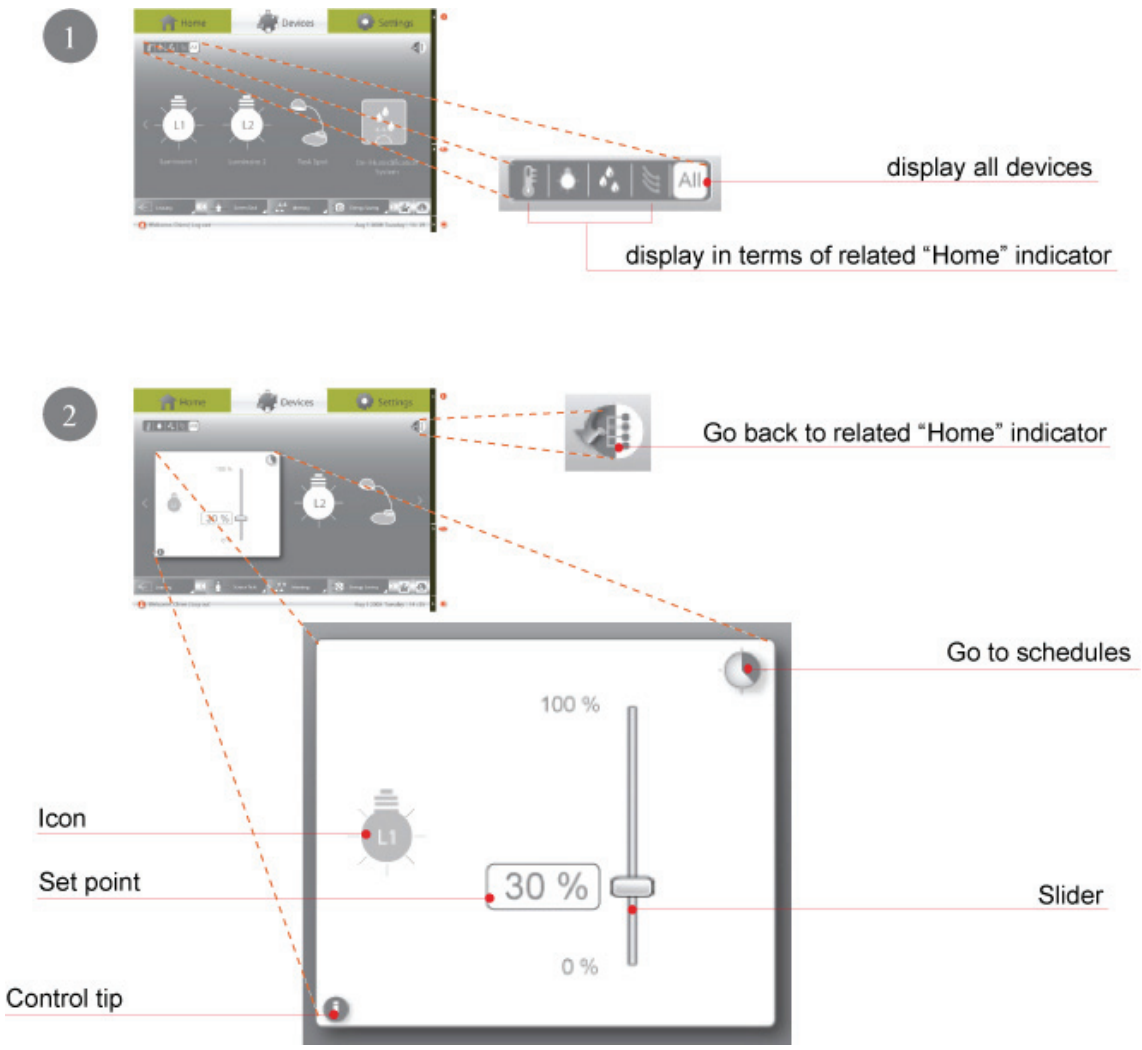


Figure 4-10 An example of "Devices" control option module

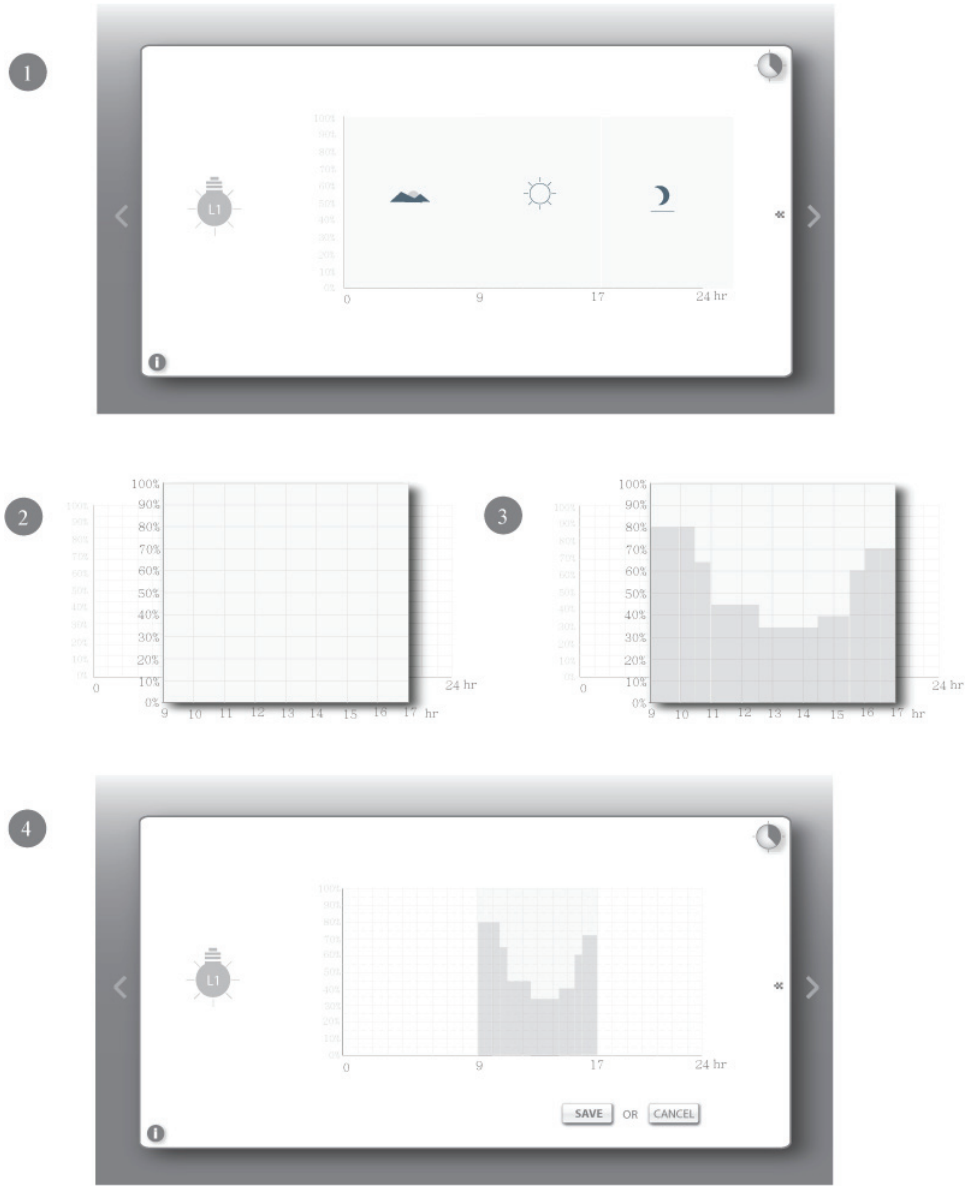


Figure 4-11 The steps to set schedule for devices

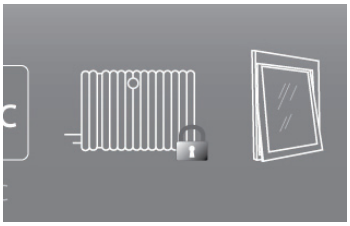


Figure 4-12 An example of a locked device

iii) “Scenes” –“Scenes” group provides the possibility to define multiple set points for multiple device states simultaneously. Thus, proper organization of such set points can be pre-programmed in conjunction with the occupant daily scenarios. Such scenarios include “entering/leaving”, “desktop task”, “screen task”, “meeting”, “presentation”, etc. (see Table 4-6). Based on the pre-programmed scenes, the occupants may achieve the desirable indoor climate at the push of a scene button on the main menu (see Figure 4-13). The occupants may also activate a scene configuration procedure at a press of “add a scene” shortcut or through “setting” button on the main menu (see section 4.6.1.3). These scenes, furthermore, may be programmed with control extensions (i.e., schedules and micro-zoning) (see Table 4-7). The occupants may then identify the icon and label that suit the scenario for which the scene is configured.

Table 4-6 Selected examples of “Scenes” group

Control option	**Icon**	**Related devices**
Leaving		1. HVAC system 2. Radiator 3. Windows 4. Blinds 5. Luminaire1 6. Luminaire2 7. Task spot 8. De-/Humidification System
desktop task		
screen task		
meeting		
presentation		

Figure 4-13 A set of "Scenes" group on the screen

iv) Control extensions –The realization of the above-mentioned control groups may be further customized via user-based definitions of spatial (micro-zoning) and/or temporal (schedule) extensions (see Table 4-7). An example of a spatial extension is a user-customized assignment of a control device state to a certain location (e.g., Lab1 or Lab2) (see Figure 4-14). Such spatial extension is deployed in these three control groups, namely "Home", "Devices", and "Scenes". An example of a temporal extension is a user-defined time-based variations of (schedules for) the position of a certain device/scene (see Figure 4-15). Such temporal extension is employed in control groups regarding "Devices" and "Scenes".

Table 4-7 Comparison matrix in terms of the control extensions

Control group	**Control extensions**	
	Control via micro-zoning	**Control via schedules**
"Home"	●	—
"Devices"	●	●
"Scenes"	●	●

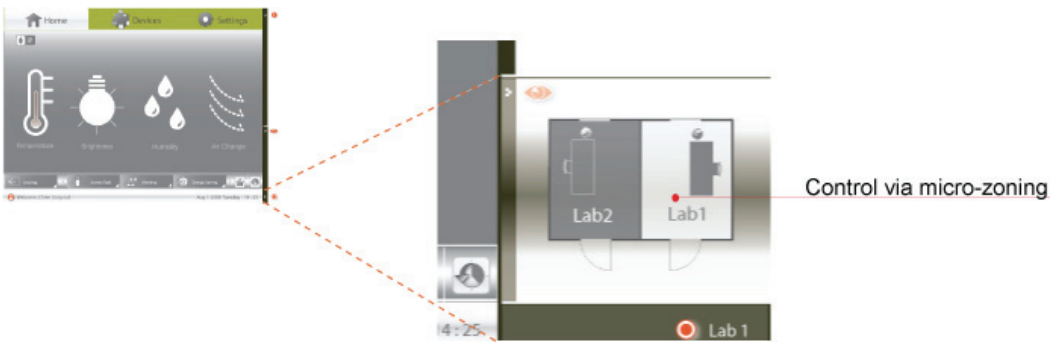
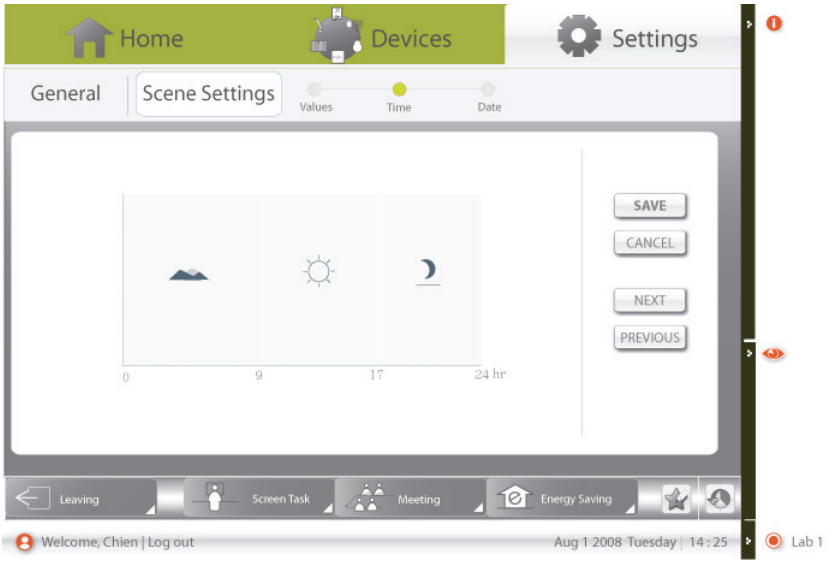


Figure 4-14 Control via micro-zoning



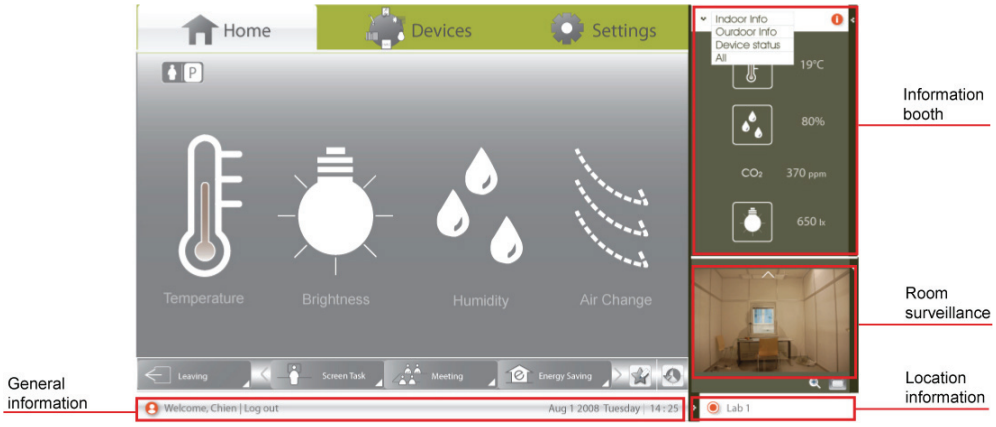
(a)

(b)

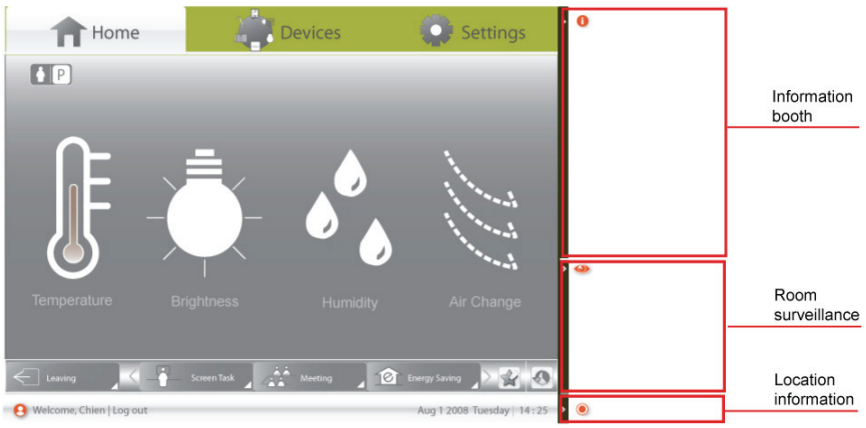
Figure 4-15 An example of temporal extension - schedule configuration in "Scenes" group (a) a screenshot of time setting (b) a screenshot of date setting

4.6.1.2 Information groups

Information groups implements a schematic information service for the office-based environment, which continuously updates information from Building information model. Primary information groups include general information, information booth, and information extensions. General information, which is in the bottom of the layout, provides the occupants with user information, time, and date. The occupants can inquiry the context information (i.e., indoor/outdoor information) and control task information (regarding device states) via information booth. Also, room surveillance (as linked to IP CAMERA) and location information may be obtained separately by the occupants. Among these information groups, the information booth, room image and location information are divided into sections and placed into panels that allow the occupants to inquiry one or two or close all at a time (Figure 4-16).



(a)



(b)

Figure 4-16 (a) information groups (b) closable panels are deployed in information booth, room surveillance and location information

4.6.1.3 Settings

"Settings" include general setting and scene setting. General setting pertains, for example, to startup page (based on "Home" and "Devices"), measurement (involving metric and English system), and suggestion notification marking (see Figure 4-17). Scene setting includes manipulation steps such as control states setting (regarding the control devices in section 4.6.1.1) and assigning name/icon. Also, the occupants may assign scene setting to timeline/date setting as optional extension (see Figure 4-18).

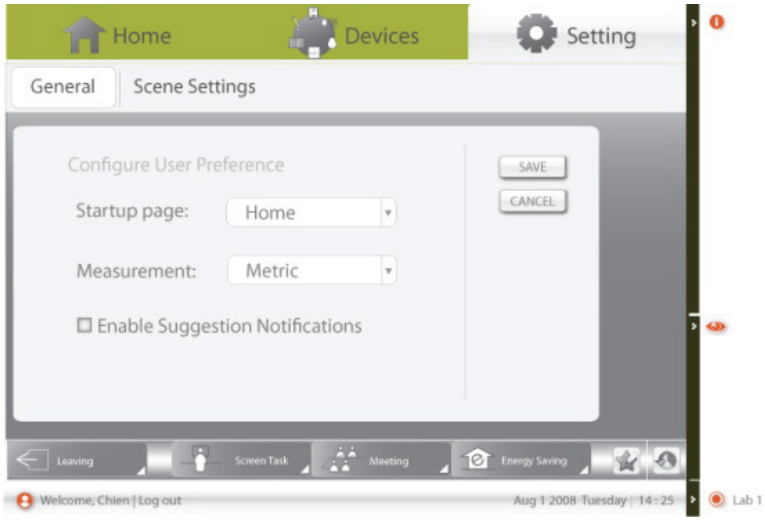


Figure 4-17 A screenshot of general setting

Figure 4-18 Four steps of Scene setting: step 1-adjust Device, step 2-Time seting, step 3-Date setting, step 4- Name/Icon assigning. The occupants may also jump from step 1 to step 4 without setting the time and date.

4.6.1.4 Hardware

Occupants may use mobile interfaces (e.g., laptop and/or tablet pc) to call up this web-based interface model – BECO - and achieve the desirable indoor climate via internet regardless of the spatial limits. Also, it is software-wise easy to upgrade to provide the occupants and building management with high re-configurability and flexibility potential.

4.6.2 Layout Design

In section 3.4.5.1, the results of the interviews show that occupants consider the existence of a clear organizational layout of the interface important. In order to achieve a clear visual hierarchy and semantic structure, this section discusses certain strategies to organize versatile groups and objects in this interface model.

4.6.2.1 Layout framework

The users typically favor the interface to be easy to use/learn and to navigate through independent of the functional coverage ranges (see section 3.4). Keeping the user interface simple and clear makes it easier for the users to adapt to. Furthermore, changes in the appearance of the layout should clearly relate to users' intention and operations. Thus, the first step in the design is achieve a visually consistent and easily-recognizable framework. Firstly, a closure grouping strategy is deployed to form a focal point for short-term user-system interactions (see Figure 4-19b). Then, related attributes are gathered together and separated from other distinct attributes. For example, most information groups are constantly employed in the right side of the layout to keep them unambiguous separate from the control groups in view of navigation memory (see Figure 4-19c).

4.6.2.2 Center stage

The primary job of a transient posture user interface with its short-term usage patterns is to accomplish an indoor climate control task. For establishing a visual hierarchy and guiding the occupants' focus immediately to the main control zone where the most important task take place, an obvious and large area is anchored in the center of this interface layout, whereas the auxiliary contents are clustered around the "center stage" (Warren & Ram, 1998; Tidwell, 2005) in small panels/pieces (see Figure 4-19d).

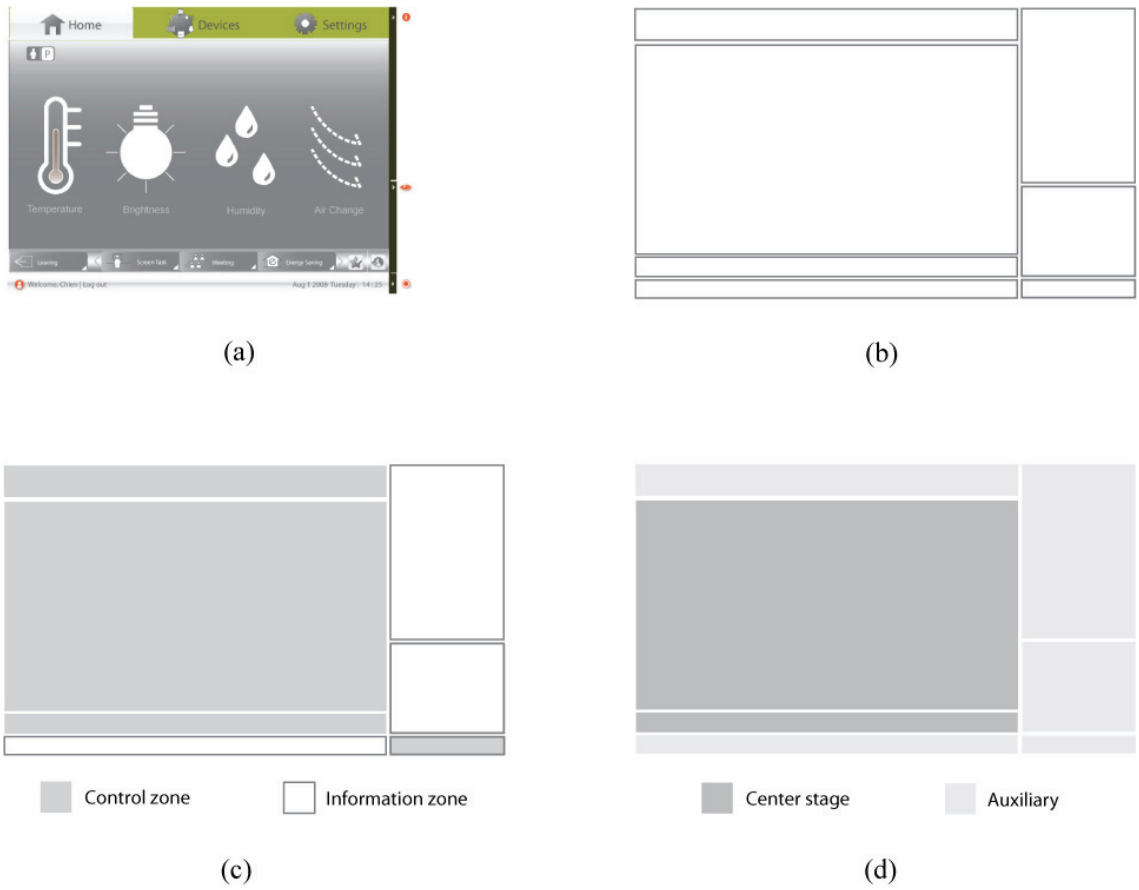


Figure 4-19 (a) interface layout; (b) closure grouping; (c) layout zoning in terms of attributes; (d) visual hierarchy: center stage and auxiliary content

4.6.2.3 Use of color

For undertaking a variety range of assigned tasks, this user interface is designed and organized into many subsections in view of the layout. In addition to using the above-mentioned layout framework to integrate them visually, making each subsection distinct and capturing the users' attention immediately is also an important issue. As Figure 4-20 shows, fives series of high-contrast colors are assigned together with the layout framework to identify and "echo" separate attributes in this user interface layout.

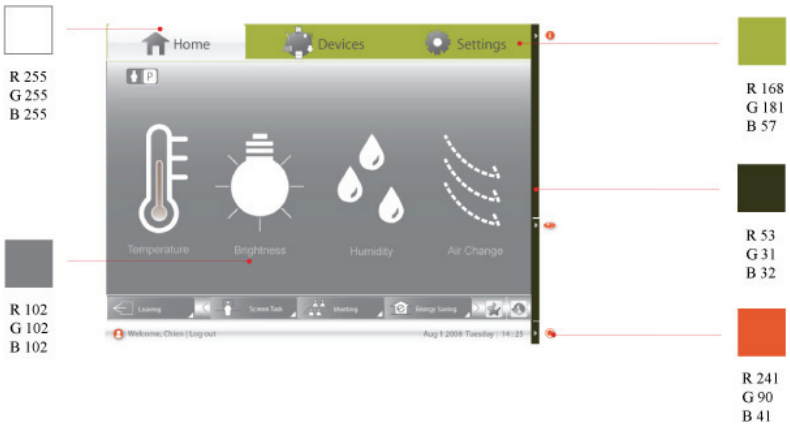


Figure 4-20 Use of colors in the layout

4.6.3 Navigation

As to the navigation experience, instead of offering too many "jumps" to satisfy a wide range of flexibility/functional coverage, it is a key issue to provide a more straightforward manipulation memory helping the occupants to get around safely in a quasi "one-page" depth. A strong layout framework discussed in section 4.6.2.1, consistently shown on each sequence page, makes learning and retaining of the required manipulation sequence easy and relieves occupants' cognitive burden to handle varying page content by a wide margin. Moreover, certain cognitively friendly user patterns are used to support the occupants whilst offering richness in manipulation options.

4.6.3.1 Card stack

A number of control options are required for this interface, whereas the occupants may need only one group at one time. Thereby, the control options are grouped into three separate “cards” (Tidwell 2005) together with titled tabs (i.e., “Home”, “Devices”, and “Settings”) to allow the occupants to access them one at a time (see Figure 4-21).

Figure 4-21 The implementation of horizontal card stack. It allows the occupants to click each tab to access to its mapped card.

4.6.3.2 Accordion

Instead of overwhelming the occupants, each information group on the right-hand of the layout (based on context, surveillance image, and location information) are embedded in accordion-like panels and may be opened and closed separately from the others simply when needed (see Figure 4-22). However, the occupants may also trigger these three groups simultaneously and keep them in view all the time. In this aspect, the occupants may experience a neat layout while offering richness in manipulation options.

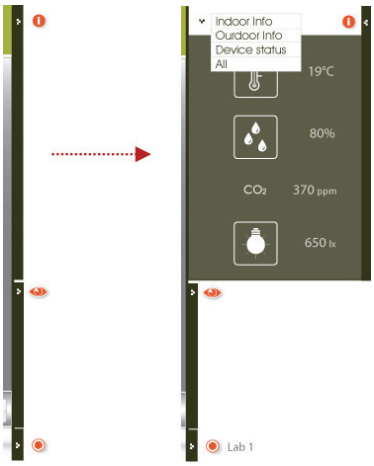


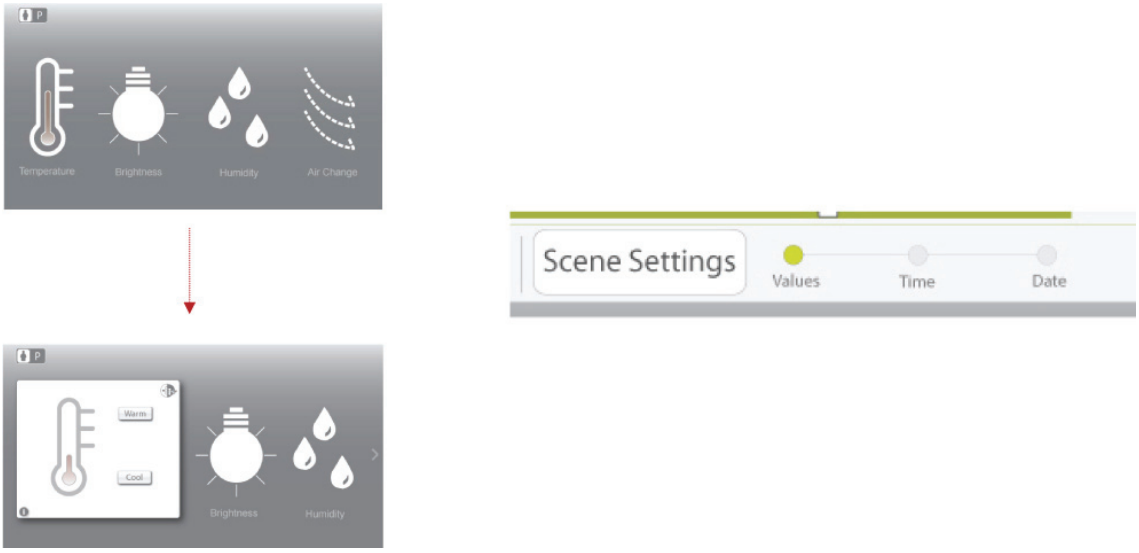
Figure 4-22 An example of accordion-like panel (context information group)

4.6.3.3 Target guiding

Guiding the occupants to go through so many jumps may distract their attention and let them get lost easily in navigation. Two patterns are used to guide the occupants to effectively accomplish the control task, whereby the perceived complexity of the interface is decreased.

i) Control "in place"- The pattern of Control "in place" is deployed on two main control groups (i.e., "Home" and "Devices") which deserve specialized manipulation effect: trigger the control box immediately over the original icon, instead of going to another separate screen (see Figure 4-23a). The occupant may then conduct the control task and/or click somewhere else to end the control box. Specifically, animated effects are applied to echo the transition of the control box while triggering/ending.

ii) Sequence guiding – Scene settings is a relative complex control task involving certain sequences, namely value adjusting, name/icon assigning, and optional extension (Time/Date setting). In order to guide the occupants to accomplish the tasks without being lost in sequences, a linear rout is shown to indicate their current location and completed/rest sequences as a navigational compass (see Figure 4-23b).



(a) (b)

Figure 4-23 (a) The triggered box allows the occupants to control the values "in place" (b) The sequence guiding in scene settings

4.6.3.4 Continuous scrolling

Going through long lists of items may also impose a cognitive burden on the occupants. In order to present a long set of items effectively in "Devices" (control group) and context information panel, a pattern of continuous scrolling is used to enhance the occupants' rapid selection/review of the items (see Figure 4-24). The occupants may click the arrow to invoke the scrolling. In response to the click, a certain list of items on the display is scrolled through in a horizontal/vertical way. Thus, the occupants may jump to the desired items visually.

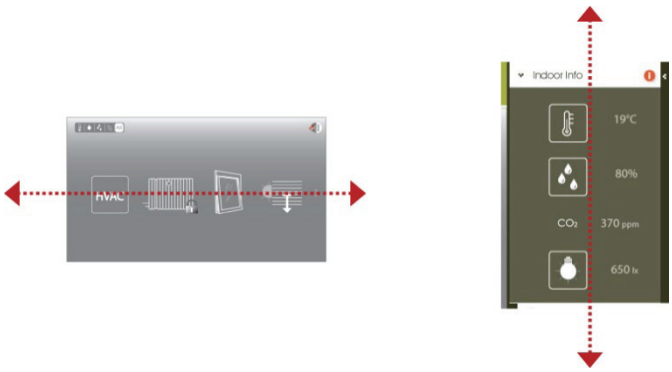


Figure 4-24 Two types of Continuous scrolling (horizontal and vertical flows)

4.6.3.5 Terms /icons

Labels (e.g., iconic buttons, tags, and text items; see section 3.4.5.3) are used here to communicate knowledge visually/verbally and to enhance navigation proceeding (see Figure 4-25 and Figure 4-26). For example, in order to convey the cognitive message regarding the main control tasks to the occupants, “Home” and “Devices” control groups are presented in terms of large language-neutral icons. Also, by means of assigning short and easy-to-understand titles, certain text items (together with mapped icons) are made convenient to use by the occupants.

Figure 4-25 A set of selected icons in this interface

Figure 4-26 Tips are hidden behind "i" icon and pop up for assisting occupants' manipulation

4.7 Summary

The requirements and functionalities of the user interface for office-based environment have been transformed to design phase, whereby the users' control behavior is considered. Furthermore, a prototype of user interface model is presented, which supports certain user interactions with the building systems for indoor climate control. With easily-recognizable icons and well-structured navigation, certain control solutions together with information groups have been integrated to make a wide range of control options easily available and keep occupants' manipulation simple. Furthermore, system features have been investigated by developing scenarios for control tasks and discussed in terms of implemented services, layout design, and navigations.

5 Conclusion

This chapter includes the contributions of thesis efforts and lists certain areas for further work as below.

5.1 Contributions

In this thesis, a framework has been outlined for the formulation of requirements for user interface models that support the interactions between occupants and environmental systems in sentient buildings. This framework embodies a system for typological product differentiations (a product type terminology) and a set of dimensions for product specification and evaluation involving information types, control options, and hardware. Also, an array of existing user interfacing products have been tested and evaluated for intelligent built environments against this framework and have thus helped identifying areas of relative strength and deficiency. Moreover, interviews were conducted with a number of participants testing a selected number of user interface products. The corresponding results provide a solid basis for the following developments in user interface prototyping for sentient buildings. Furthermore, the guiding principles together with intuitive representation of the requirements have been transformed to the provision of appropriate and well-structured patterns for interface design. Finally, this thesis presents an implementation of such an interface model for user-system interactions with sentient environments toward achieving desirable indoor climate conditions while meeting the goals pertaining to a sustainable building operation regime.

5.2 Future research

The issues of user interfaces for intelligent buildings have been studied and explored worldwide in the last two decades. The work presented in this thesis attempts to contribute this area focusing on how users can achieve desirable indoor climate conditions. Nowadays the expectations from building control

systems may differ from location to location (climate) and from users to users (e.g., office versus residential buildings). The methodologies and design described in this thesis offer the occupants and user interface developers certain perspectives to view and manipulate the building control system. Nevertheless, it is necessary to conduct further research on the user interactions with the building control systems in view of ethnography, building typology, and geographical features. Furthermore, studies on the self-adaptive user interface of the control system may contribute to build a more comfortable and friendly control environment for the occupants. Another aspect is to implement the versatile control services into the micro devices such as PDA and smart phones. Finally, the key perspective for further research is to integrate/utilize factors such as new technologies, user interface design and study, materials, space characters, and other resources to meet the challenges of dynamically changing environments and occupant requirements.

5.3 Related Publications

Regarding this thesis, a number of papers on earlier stages of this effort have been presented and published as follows:

Refereed Journal Paper

[1] Chien SC, Mahdavi A., (2008), "Evaluating interface designs for user-system interaction media in buildings"; ADVANCED ENGINEERING INFORMATICS (SCI)*, 22* (4), pp. 484-492.

Refereed Conference Papers

[1] Chien SC, Mahdavi A., (2008)*, "*User interfaces for building systems control: from requirements to prototype*",* Proceedings of the 7th European Conference on Product and Process Modelling, Sophia Antipolis, France, p369-374.

[2] Chien SC, Mahdavi A., (2007), “User interfaces for occupant interactions with environmental systems in buildings”, Proceedings of the 24th International Conference on Passive and Low Energy Architecture, Singapore, p780-787

[3] Chien SC, Mahdavi A., (2007), “Talking back to buildings: interfacing for sentient environments”, Proceedings of International Council for Research and Innovation in Building and Construction 24th W78 Conference Maribor 2007, Maribor, Slovenia, p581-586

[4] Mahdavi A., Suter G., Metzger A.S., Leal S., Spasojevic B., Chien SC, Lechleitner J., Dervishi S., (2007), "*An integrated model-based apporach to building systems operation*", Vortrag: WellBeing Indoors - Clima 2007 10-14 June - Helsinki - Finland, Helsinki, Finnland; 10.06.2007 - 14.06.2007; in: "*WellBeing Indoors - Clima 2007 10-14 June - Helsinki - Finland*"

[5] Mahdavi A., Suter G., Metzger A.S., Spasojevic B., Leal S., Chien SC, Dervishi S., Lechleitner J. , (2007), "*An integrated model-based apporach to building systems operation*", in “IEWT 2007 – 5th International energy science conference” at Vienna University of Technology, Vienna, Austria, February 2007, p. 267 - 268

[6] Chien SC, Mahdavi A., (2006), “User Interface for Sentient Buildings: Requirements and Functionality”, Proceedings of 2006 Symposium on Digital Life Technologies, Tainan, Taiwan, 1–2 June 2006.

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Carter, S., Mankoff, J., Klemmer, S., & Tara, M. (2008). Exiting the Cleanroom: On Ecological Validity and Ubiquitous Computing. *Human-Computer Interaction , 23* (1), pp. 47-99.

Chien, S., & Mahdavi, A. (2007). Talking back to buildings: interfacing for sentient environments. *Proceedings of International Council for Research and Innovation in Building and Construction 24th W78 Conference Maribor 2007* (pp. 581-586). Maribor: Maribor University Library.

Chien, S., & Mahdavi, A. (2006). User Interface for Sentient Buildings: Requirements and Functionality. *Proceedings of 2006 Symposium on Digital Life Technologies.* Tainan, Taiwan.

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Appendix A

Communication Protocol between Model-based service and Microsoft Silverlight 2

Last changes:

07.08.2008 Sérgio Leal

Ports

Known ports:

bacnet	47808/tcp	Building Automation and Control Networks
bacnet	47808/udp	Building Automation and Control Networks
#	47809-47999	Unassigned

Desired Port: #47810

Service Name: SDBM2Flash/Silverlight

Socket Type: String Socket

When starting, the application tries to connect to the service and port. If there is no service on that port available, the application should create the service and wait for connections.

If the service is available say "HELLO UNIX/POSIX-time" for synchronization.

➔ Connection should be non-persistent to improve performance.

How to start and end a message

Header

MsgLength	0000 to 9999 with fix length of 4 digits The length of the message from the beginning (including the message-length-field) until the last character of the message (excluding the end

	character <cr>)
MsgID	- either “flash###” for messages from the Flash interface to SDBM - or “sdbm###”for messages from SDBM to the Flash interface, where “###” stands for the SequenceNumber of variable size (max. 3 digits), which each node counts for itself
MsgTimeStamp	UNIX / POSIX time
ServiceType	! → actuate ? → poll = → report E → Error plus the following S → for sequence errors P → for parse errors U→ for unknown-device errors A→ for access-mode errors T → for type-mismatch errors O→ for out-of-service errors

Message-Data

Msg = *SxxxBxxxRxxxDxxxTxxxValue*

where *Sxxx* – Site,

Bxxx – Building,

Zxxx – Zone,

Dxxx – Device,

Fxxx – Function,

and *Value* – *VBc* for Boolean / Binary Values or *VAf* for analogue Values

“xxx” stands for a variable field-length with a maximum of 3 digits.

“B” stands for a Boolean Value (0 or 1)

“A” stands for an analogue Value (e.g. xxx.xxx), with or without a decimal point with a maximum of 32 digits.

'Values' always represent states (e.g., a space temperature); they never represent service invocations (commands, e.g., 'start the window blind drive'). No control loops are executed in the gateway daemon (BACnet-SDBM Interface).

Final Character: <cr>

Field Separator: #

How to format a message

MsgLength +"#"+ MsgID +"#"+ MsgTimeStamp +"#"+ ServiceType +"#"+ SxxxBxxxZxxxDxxxTxxxValue + "<cr>"

Any numbers of blank spaces are acceptable.

Any numbers of Message fields are acceptable.

Wildcards:

When sending a Wildcard (eg. S1B1Z0DxTxVx), everything after the "0" will be ignored by the BACNet-Gateway and only the corresponding values will be returned. (eg. for a Zone-Wildcard S1B1Z0DxTxVx the Gateway will return all zones of that Building but no devices, functions or values of the devices, which are in the specific zones).

Error-Handling

Parse error

If header MsgLength and received message length don't comply,

or if anything is wrong with the data in the message (wrong order of SxxxBxxx…, unspecified ServiceType, …) the message will be sent back as Parse-Error-Message and includes the complete erroneous Message in the Data-Field (from MsgLength until the end of the old Message, of course without the extra "<cr>").

Sequence error

If the message sequence is brocken, a Sequence-Error-Message will be sent, requesting retransmission by reporting the next expected sequence number (eg. "bacnet5" in the Data-Field when number 5 was expected).

All further messages will be ignored until the right (expected) sequence-number has arrived.

Unknown-Device-Error

If the Message-data contains information about a device that does not exist, respectively the wanted SDBM-String is not in the mapping-file, an Unknown-Device-Error-Message will be sent back with the same Data-Field as in the received Message.

AccessMode Error

If a value should be written on a read-only device / object an AccessMode-Error-Message will be sent back with the same Data-Field as in the received Message.

TypeMismatch Error

If a boolean Value should be written on an analogue device / object, a Type-Mismatch-Error-Message will be sent back with the same Data-Field as in the received Message.

OutOfService Error

If a device should be read or written and it is mapped but unreachable, an Out-Of-Service-Error-Message will be sent back with the same Data-Field as in the received Message.

Termination of the session or connection.

Close service and port

Detailed Message-Syntax in EBNF:

```
(* Predefinitions *)
Digit = "0" | "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9";
NonZeroDigit = Digit - "0";
UnixTime = 9 * [ Digit ], Digit;  (* values greater than 2^31 may be rejected as
unparsable *)
Data = Digit | 2 * Digit | 3 * Digit;

(* Allowed Spaces *)
Space = {" "};

(* Hello-Message *)
HelloMessage = "Hello", Space, UnixTime;

(* Header-Fields *)
MsgLength =    4 * Digit;
MsgID =        ( "bacnet" | "sdbm" ), Space, 2 * [ Digit ], Digit;
MsgTimeStamp = UnixTime;

(* Separator *)
Separator = Space, "#", Space;

(* Message-Header *)
MsgHeader = MsgLength, Separator, MsgID, Separator, MsgTimeStamp;

(* ServiceType Definitions *)
ReportSignifier =              "=";
ActuateSignifier =             "!";
PollSignifier =                "?";
SequenceErrorSignifier =       "E", Space, "S";
ParseErrorSignifier =          "E", Space, "P";
UnknownDeviceErrorSignifier =  "E", Space, "U";
AccessModeErrorSignifier =     "E", Space, "A";
TypeMismatchErrorSignifier =   "E", Space, "T";
OutOfServiceErrorSignifier =   "E", Space, "O";

(* Messega-Data Fields *)
BinaryData = "B", Space, ( "0" | "1" );
AnalogData = "A", Space, { Digit }, [ "." , { Digit } ]; (* with a maximum of 32 Digits
*)

Site =                "S", Data,     Space;
SiteWildcard =        "S", "0",      Space;
Building =            "B", Data,     Space;
BuildingWildcard =    "B", "0",      Space;
Zone =                "Z", Data,     Space;
ZoneWildcard =        "Z", "0",      Space;
Device =              "D", Data,     Space;
DeviceWildcard =      "D", "0",      Space;
Function =            "F", Data,     Space;
FunctionWildcard =    "F", "0",      Space;

Value =               BinaryData | AnalogData;

(* normal or Wildcard Messages *)
MsgData =             ( Site, Building, Zone, Device, Function, Value );
MsgWildcardData =     ( SiteWildcard, [ Building, Zone, Device, Function, Value ] ) |
                      ( Site, BuildingWildcard, [ Zone, Device, Function, Value ] ) |
                      ( Site, Building, ZoneWildcard, [ Device, Function, Value ] ) |
                      ( Site, Building, Zone, DeviceWildcard, [ Function, Value ] ) |
                      ( Site, Building, Zone, Device, FunctionWildcard, [ Value ] );

(* Message-Types and Definitions *)
(* Actuate-Message *)
ActuateMessage =      MsgHeader, Separator, ActuateSignifier, Separator, MsgData,
                      { Separator, MsgData }, "<cr>";

(* Poll-Message *)
```

```
PollMessage =          MsgHeader, Separator, PollSignifier, Separator, ( MsgData |
                       MsgWildcardData ), { Separator, ( MsgData | MsgWildcardData ) },
                       "<cr>";

(* Report Message *)
ReportMessage =        MsgHeader, Separator, ReportSignifier, Separator, MsgData,
                       { Separator, MsgData }, "<cr>";

(* Error Messages *)
CompleteErroneousMessage =    ".*"; (* the received erroneous message with any given
                              number of charaters*)

ExpectedSequenceNumber =      MsgID; (* the MessageID with the expected SequenceNumber *)

SequenceErrorMessage =        MsgHeader, Separator, SequenceErrorSignifier, Separator,
                              ExpectedSequenceNumber, "<cr>";

ParseErrorMessage =           MsgHeader, Separator, ParseErrorSignifier, Separator,
                              CompleteErroneousMessage, "<cr>";

UnknownDeviceErrorMessage =   MsgHeader, Separator, UnknownDeviceErrorSignifier,
Separator,
                              MsgData, "<cr>";

AccessModeErrorMessage =      MsgHeader, Separator, AccessModeErrorSignifier, Separator,
                              MsgData, "<cr>";

TypeMismatchErrorMessage =   MsgHeader, Separator, TypeMismatchErrorSignifier, Separator,
                              MsgData, "<cr>";

OutOfServiceErrorMessage =   MsgHeader, Separator, OutOfServiceErrorSignifier, Separator,
                              MsgData, "<cr>";
```

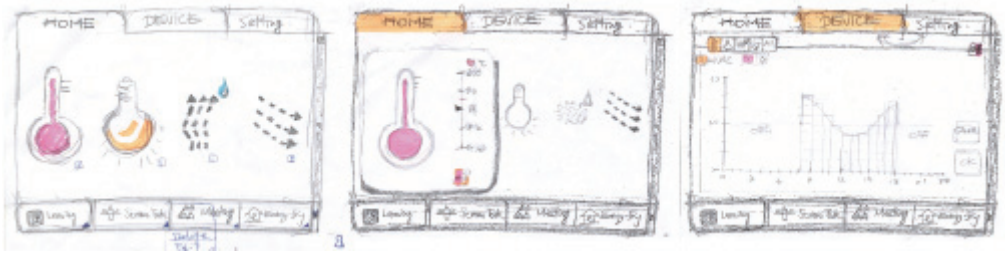
Example of variable and value used:

```
/SITES
public static final int SITE_ALL = 0; // "all sites" wildcard
public static final int SITE_KARLSPLATZ = 1;
public static final int SITE_PANIGLGASSE = 2;

//BUILDINGS
public static final int BUILDING_ALL = 0; // "all buildings" wildcard
public static final int BUILDING_TU_GEBAEUDE = 1;
public static final int BUILDING_BPI_LABOR = 2;

//ROOMS
public static final int ZONE_ALL = 0; // "all rooms" wildcard
public static final int ZONE_BPI = 1;
public static final int ZONE_LAB1 = 2;
public static final int ZONE_LAB2 = 3;

//DEVICES
public static final int DEVICE_ALL = 0; // "all devices" wildcard
public static final int DEVICE_CL1 = 1;
public static final int DEVICE_CL2 = 2;
public static final int DEVICE_DL = 3;
public static final int DEVICE_DL_COLD = 4;
public static final int DEVICE_DL_WARM = 5;
public static final int DEVICE_WINDOW = 6;
public static final int DEVICE_BLINDS = 7;
public static final int DEVICE_FAN = 8;
public static final int DEVICE_DAMPER = 9;
public static final int DEVICE_RADIANTE_HEAT = 10;
public static final int DEVICE_VALVE_HEAT = 11;
public static final int DEVICE_TEMPERATURE_SENSOR = 12;
public static final int DEVICE_AIR_FLOW_SENSOR = 13;
public static final int DEVICE_OCCUPANCY_SENSOR = 14;
public static final int DEVICE_AIR_CHANGE = 15;
public static final int DEVICE_LAB_EQUIPMENT = 16;

//TYPES
public static final int FUNCTION_ALL = 0; // "all types" wildcard
```

```
public static final int FUNCTION_ANALOG = 1;
public static final int FUNCTION_BINARY = 2;
public static final int FUNCTION_V_BLINDS = 3;
public static final int FUNCTION_H_BLINDS = 4;
public static final int FUNCTION_WINDOW = 5;
public static final int FUNCTION_SUPPLY_AIR = 6;
public static final int FUNCTION_RETURN_AIR = 7;
public static final int FUNCTION_OUTDOOR = 8;
public static final int FUNCTION_ROOM = 9;
public static final int FUNCTION_LAB = 10;

double[] blindsSteps = new double[]{ 0, 20, 40, 60, 80, 100};
double[] luminareSteps = new double[]{0, 20, 40, 60, 80, 100};
double[] radianteHeatSteps = new double[]{0, 1};
double[] airChangeRateSteps = new double[]{0.0, 0.1, 0.2, 0.3, 0.4,
0.5, 0.6, 0.7, 0.8, 0.9, 1.0};
double[] supplyDamperSteps = new double[]{0, 20, 40, 60, 80, 100};
double[] returnDamperSteps = new double[]{0, 20, 40, 60, 80, 100};
double[] heatValveSteps = new double[]{0, 20, 40, 60, 80, 100} ;
double[] fanSteps = new double[]{0, 20, 40, 60, 80, 100};
double[] occupantSteps = new double[]{0, 1};
```

Appendix B

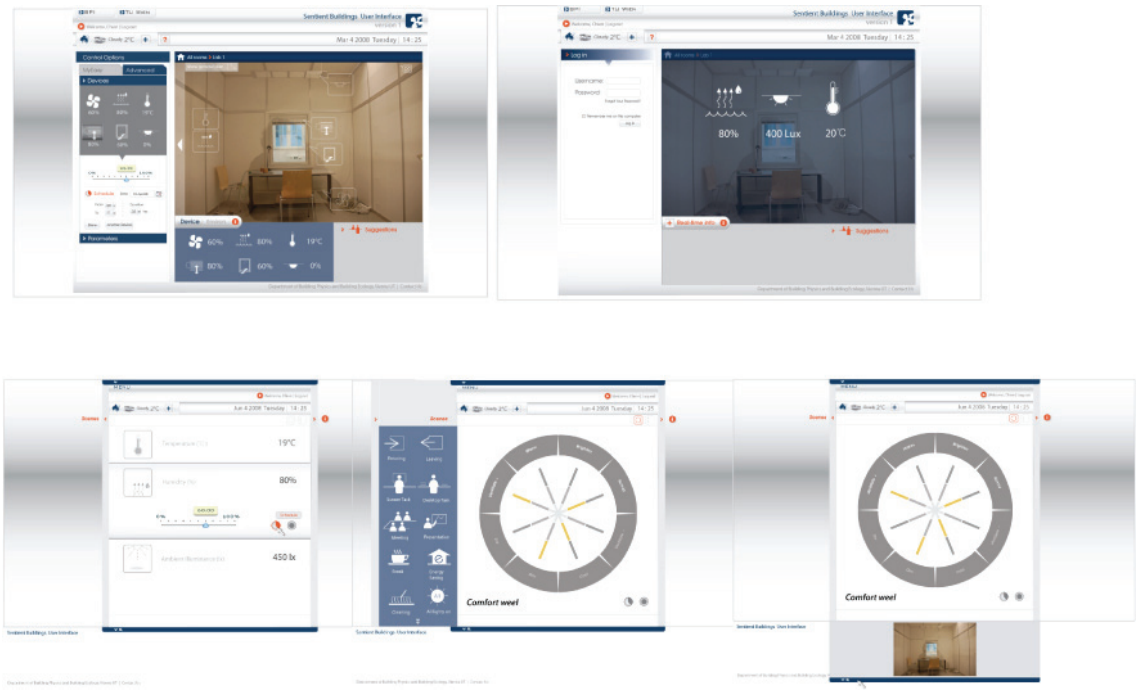
Selected sketches and mockups in interface design process



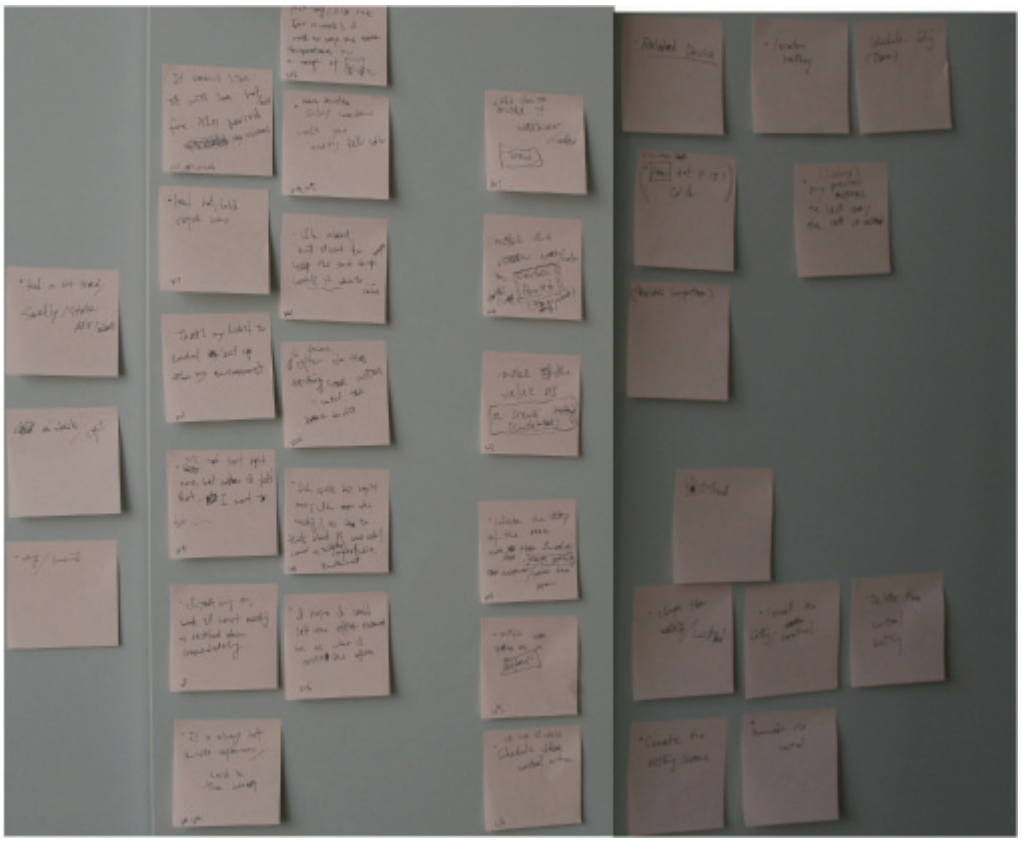
(a)

(b)

Figure 1 Examples in the design process: (a) some sketches for early stage prototyping; (b) an example scenario;



(a)



(b)

Figure 2 (a) paper-based prototypes; (b) CARD techniques to understand the overall flow of the work

Appendix C

Architecture of user-system interactions in user interface model

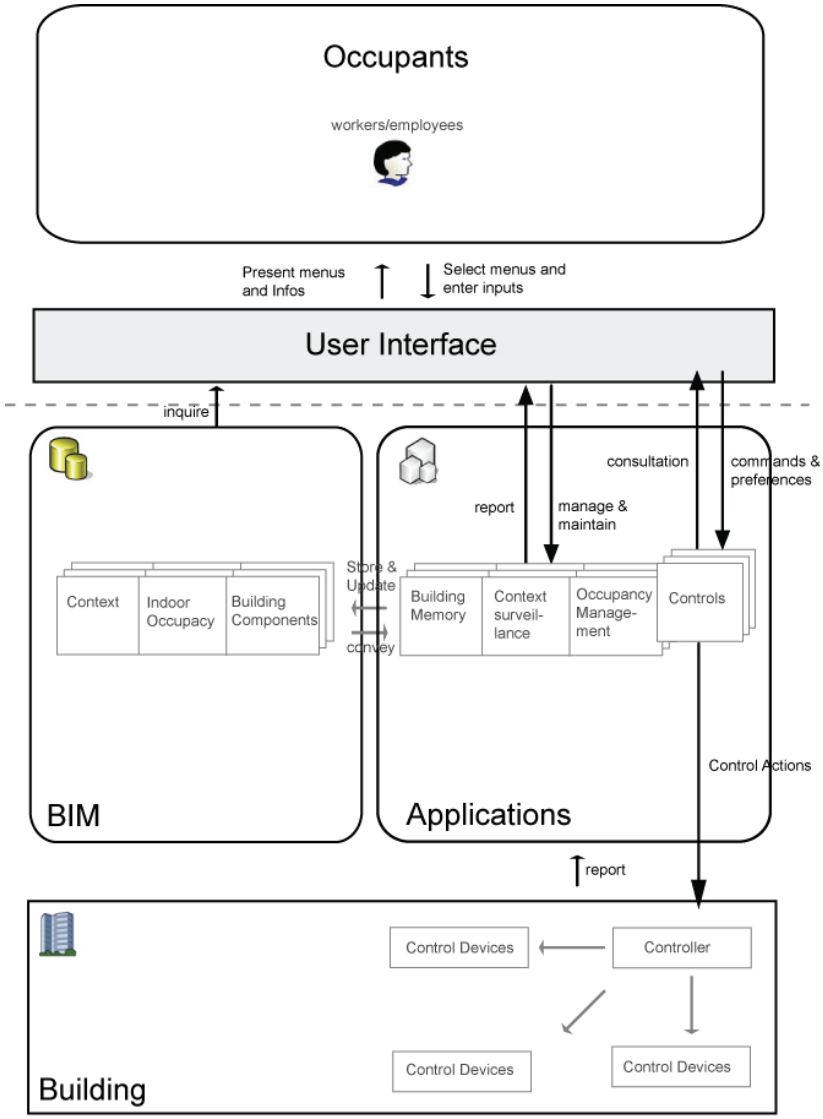


Figure 1 Architecture of user-system interactions

Appendix D

User interface in sentient buildings

***Overview**:* In information technology, the user interface (UI) is an interface that enables information to be passed between a human user and hardware or software components of a computer system (IEEE 1990). Specifically, the user interface in sentient buildings should include the following basic characteristics: *i)* input: allow the users to control the system and transmit messages to the sentient buildings (e.g. instructions, commands and preferences); *ii)* output: allow the sentient buildings to inform the users of data such as space conditions; *iii)* user network: the user may communicate to other users via a user-web.; *iv)* the source of information: the operational processes become part of the self-updating building model and building representation (overtime: building memory, history)

We first describe a typical control process. Secondly, we illustrate the extended control process model related to the user and user interface.

A basic control process:

A basic control process involves a sensor, a controller, a control device, and a controlled entity (see the schematic illustration in figure1). An example of such a process is when the occupant (the controller) of a room opens a window (control device) to change the temperature (control parameter) in a room (controlled entity) (Mahdavi 2005).

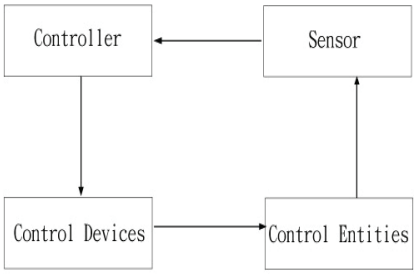


Figure 1 A typical control process

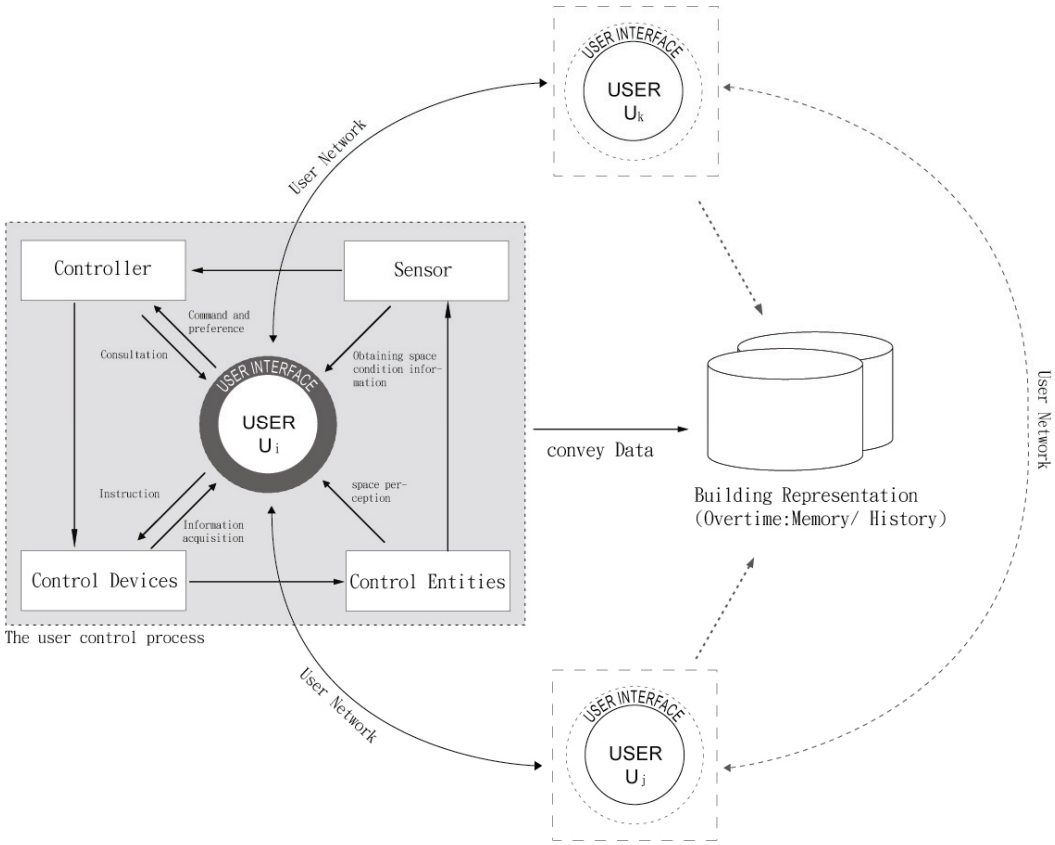


Figure 2 A user control process model

***User control process model*:**

In this version of user control process, the four concepts (sensor, controller, control device, control entities) can be seen as a dynamic cycle with which the user interacts. Moreover, the interactions – incorporating the information and messages which may be exchanged or conveyed – are carried out amongst these components of the control process model via a user interface (See Figure 2) .

-*Obtaining space condition information:*Sensing technologies are increasingly being used to provide implicit input for natural interaction interfaces. In terms of sentient buildings, the sensors may provide the source of building information (processes, occupancy, and context). As to the relationship between sensor and user-interface, the actual information about the space conditions in a sentient building can be obtained through the sensors and delivered to the user via user

interface. For example, indoor temperature could be sensed by a sensor and become a reference data to be queried by the user. Upon encountering a new source of sensor data, the model service will register its identification and wait until the respective location information for it is received. Once this has occurred, a sensor object is instantiated and linked to the space containing the given coordinates (Brunner & Mahdavi 2005).

-*Space perception:*The components of control entities include building, section, space, and enclosure. As to the relationship between control entities and users, they can directly perceive the conductions in the control entities. An example of such a process is when the user perceives the room to be too warm, too cold, too bright, too dark, too loud, etc.. These perceptions might be queried and logged by the system for future reference.

-*Command, preference, and consultation:*In the sentient building models, the controller responds to events – typically guided by the commands and preferences of the users – and invokes alterations to the environmental conditions. For example, the user commands the controller of the building to turn on the light (control device) via a computer-interface (controller). A controller may receive certain input variables from the user (preferred conditions) or inform the user regarding alternative control operations.

A two-way relationship exists between the users and the controller via a user interface in a sentient building model:

-*Command and preference*: the user may communicate to the system what to do in terms of a command or a preference via user interface.

-*Consultation:* A controller may make suggestions to the users and display alternative control options via a user interface. The controller assists the users to make a decision by utilizing embedded control logic and building memory.

-*Instruction and Information acquisition*

Two types of interactions may occur between the control devices and the users via a user interface:

-*Instruction:* The users may instruct the control devices directly or via the controller to adjust the states of the control devices. The users, for example, may adjust the blinds in order to change the illuminance (control parameter) of a room (control entity) via a user interface.

-*Information acquisition:* On the other hand, the users may receive the information on the control device states via a user interface. An example of such an interaction is when a user monitors the real-time states of the blinds of a room (control entity) via a user interface.

User control process Network

The user control process network specifies two distinct concepts:

-*Communication and dialogue:* A user's information may be transmitted to other users within the user control process network. The network could facilitate collaboration within a group of users.

-*The resolution of Conflict:* In order to eliminate conflicts within a network of users, the users' network may provide a suitable platform.

- *Interaction with Building Representation (Over time: Memory / History):*The total information and interactions in a user control process network mentioned above may be conveyed to building representation. The building representation must be updated autonomously to precisely capture the real-time state of the user control processes in a sentient building. The transmitted data in building representation may be stored to constitute building memory and history (information repository on the buildings past states and performance) (Mahdavi 2005).

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Current Institution

Vienna University of Technology, Austria | Oct. 2005~ present
Doctoral Candidate, Department of Building Physics and Building Ecology

education

National Cheng-Kung University, Taiwan | Sep. 2005~Jun. 2007
Doctoral Program, Department of Architecture
Tainan National University of the Arts | Graduate Institute of Architecture, Master of Fine Arts, Jun. 2001
National Cheng-Kung University | Department of Architecture, Bachelor of Science in Architecture, Jun. 1998

academic experience

Tutor (Tutorentätigkeit), Vienna University of Technology | Oct. 2006 ~present
1) Courses: Advanced Topics (Winter 2006 & 2007)
2) User interface development of "*Self-updating models for Sentient Buildings*" project by a grant from FWF (Fonds zur Förderung der wissenschaftlichen Forschung), project Nr. L219-N07

Teaching Assistant, National Cheng-Kung University | Aug. 2003 ~ Aug. 2004
1) Courses: Architectural Design (7)(Fall 2003) & (8)(Spring 2004)
2) The assistances of department affairs & international conferences

The Crit Jury, National Cheng-Kung University | Jun. 2003
The Final Review of Architectural Design (2)

Research Assistant, Graduate School of Public Health, National Cheng-Kung University | Jun. ~ Nov. 2001
Participating in 2 international healthy city conference & 4 national healthy city conferences: "Interchanging between Tainan ＆ Holland Cities ", "Healthy Community in Taiwan and Japan".

Research Assistant, Prof. W.H, Wang Studio, Tainan National University of the Arts | Sept. 1999－ Jun. 2001
Giving assistance in architectural research and projects, including schematic design, presentation drawings, models, and program analysis and interior details for a commercial Center in downtown of Hsinchu city.

Research Assistant, Prof. C.W, Sun studio, National Cheng-Kung University | Jun. 1998－Sept. 1998
Investigating and analyzing the current situation of *Chi-Ka* - one of the oldest urban district for 400 years in Taiwan

Research Student, Prof. M.L, Chang studio, National Cheng-Kung University | Jun. 1997－ Sept. 1997
Field Investigation, architecture research and behavior analysis for 5 selected university libraries

professional experience

Founder & Chief Designer, OOPS Atelier | Taiwan, Europe | Aug. 2005~present
Works involving architecture design, culture, and human behaviors.

Designer, Y.S. Tseng Architect/ C.F. Wu Architect | Tainan, Taiwan | Jun. 2001~2002/ May 2004~2005
1) Urban and architectural design, construction documents, models, and presentation drawings for two 20-floor mid-rise housings and one row-house residential project in northern Tainan.
2) Managing presentation drawings, models, program analysis and layouts for two competitions held by Tainan City Hall: a) Second place, Tainan's Fire Station Building Competition; b) Third place, An-shu Junior High School Competition

Designer, Construction and Real Estate Division, Coast Guard | Taipei, Taiwan | May 2002~ Jul. 2003
Overseeing and editing construction documents for the construction sites of Coast Guard. Competition documents review, schematic design and presentation for station projects with an officer of Coast Guard.

(continue)

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Webpage Designer, 12th Marine Patrol Group, Coast Guard | Hsin-chu, Taiwan | Apr.~ May 2002
Web page Design & maintenance for the 12th Marine Patrol Division.

Marine Patrol Police, Coast Guard | Hsin-chu, Taiwan | Dec. 2001~ May 2002
The Seashore patrolling, Security Maintaining and Suppressing Smuggling

Intern, O-Yang Yun Architect | Hsinchu, Taiwan | Jun.~ Oct. 1996
Part time and summer employment: construction documents, models, and presentation drawings for a large scale of residential project (600 houses) commissioned by a famous semiconductor company.

selected awards/honors

Nominee of "Best PhD-Paper Award ECPPM 2008", France | Sep. 2008

Academic scholarships for international conference, Austria | Jun. 2008
Awarded by Ministry of Education of Taiwan

Taiwan Merit Scholarships, Taiwan | 2006-2008
Award of US$25,000 for doctoral program by Ministry of Education of Taiwan

Second place, Taiwan Pavilion competition– Venice Architecture Biennale, the 9th International Architecture Exhibition | Dec. 2003
Work published in Art and Collection Magazine Vol. 144.

Third place, Cost Guard Web Design Competition, Taiwan | Apr. 2002

Excellent Prizewinning Work, Design Review 2001 Competition, JAPAN | Mar. 2001
Annual Competition held by Japanese Institute of Architect. Work published in the annual book: ***Design Review 2001***.

Research scholarship, Tainan National University of the Arts | Aug. 1998- Aug. 2000
Award of US$4,000 for architectural making of thesis research

selected exhibitions

Time index, Venice, Italy | Sept.~ Nov. 2004
Exhibition in Taiwan Pavilion, Venice Architecture Biennale, the 9th International Architecture Exhibition

Field, consciousness, and the counseling clinic, Tainan **|** Apr. 2004
Funded by National Culture and Arts Foundation

Conflicts: the Generation of Space, M. F. A. Thesis Exhibition **|** Jun. 2001

Anti-utopia house, Design Work Exhibition, Fukuoka, Japan **|** Mar. 2001