TALKING BACK TO BUILDINGS: INTERFACING FOR SENTIENT ENVIRONMENTS

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ABSTRACT: We explore in this paper the requirements and functionalities of user interfaces for sentient environments. We compare a number of commercial user-interface products for building control systems. Thereby, we consider three aspects, namely control options, information types, and hardware. The outcome of this comparison is expected to serve as the starting point for developing a new generation of user interface models to promote higher levels of connectivity between occupants and sentient environments.

KEYWORDS: sentient buildings, user interface, environmental controls.

1 INTRODUCTION

1.1 *Motivation*

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.

This paper explores the requirements and functionalities of user interfaces for 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). Thus, a sentient building may be defined 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 (Mahdavi 2004). Given this view of building sentience, we explore in this paper the requirements of an adequate user interface system to facilitate effective communication and interaction between building occupants and environmental systems. We compare twelve products in the market that offer such interfacing functionalities. 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.

1.2 *Background*

In IT (information technology) terms, a user interface (UI) enables information to be passed between a human user and hardware or software components of a computer system (IEEE 1990). Graphical User Interfaces (GUI) allow to narrow the gap between users and devices (Chiu 2005). As to the role of user interfaces in the context of intelligent built environments, there are a number of precedents. For example, the ubiquitous communicator – 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 2005). 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).

2 APPROACH

2.1 *Requirement profiles*

To conduct a comparison of available user interfaces in the context of intelligent buildings, we first propose an evaluative matrix involving three dimensions:

a) 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 CO2 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 infor-

mation includes system data regarding supply air terminals, windows, VAV systems, blinds, ambient lighting systems, task lighting, humidification and dehumidification systems.

b) 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 dryer, and more fresh 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).

c) Hardware - Hardware components address information input, output, mobility, network function, and reconfigurability. 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. We further consider if a hardware device can be reconfigured (reprogrammed) or not.

2.2 *Selection of products*

We selected 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. Thereby, we considered three types of products (see Table 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 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

2.3 *Comparison of product in view of aspects*

The selected user interface products (see section 2.2) were compared and evaluated based on the previously mentioned evaluative matrix (see section 2.1).

3 RESULTS

3.1 *Comparison matrices*

In this section, we compare the selected products. 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 2, 3, and 4 in accordance with the previously described dimensions (categories), namely information (Table 2), control options (Table 3), and hardware (Table 4).

Table 2. Comparison matrix for the Information 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. 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	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 extensions	Control via Schedule						●		●	●			●	●
	Control via micro-zoning			●	●		●	●	●	●		●	●	●

Table 4. 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					●	●	●	●	●	●	●	●

3.2 *Product comparison*

The collected and classified data may be further analyzed via image and positioning maps. Image and positioning maps are constructed, in this case, by placing a product in a two-dimensional evaluative space, whereby the dimensions 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). Based on the analysis of the selected products, four image maps were obtained (see Figures 1 to 4). Thereby, the products are specified in terms of the code given in Table 1 (A1 to A4, B1 to B4, and 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.

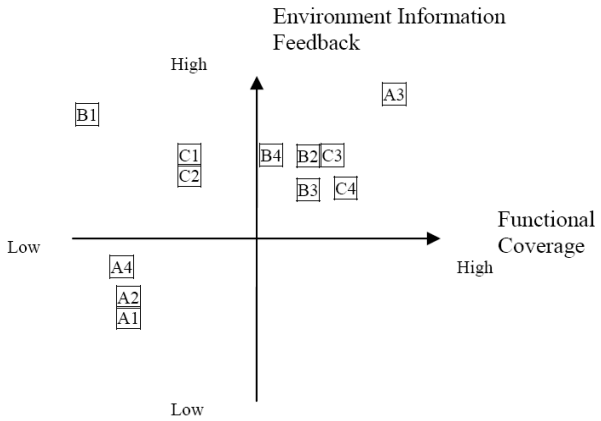

Figure 1. Image map: Functional coverage versus environmental information feed back.

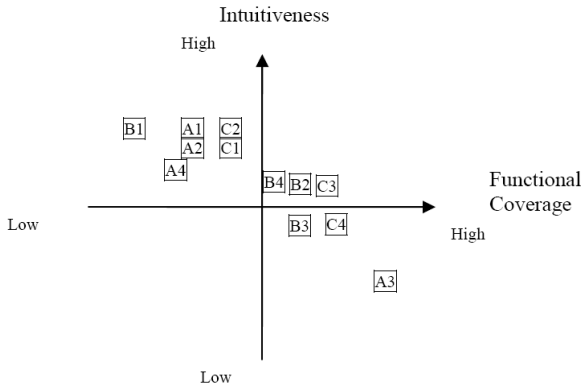

Figure 2. Image map: Functional coverage versus intuitiveness.

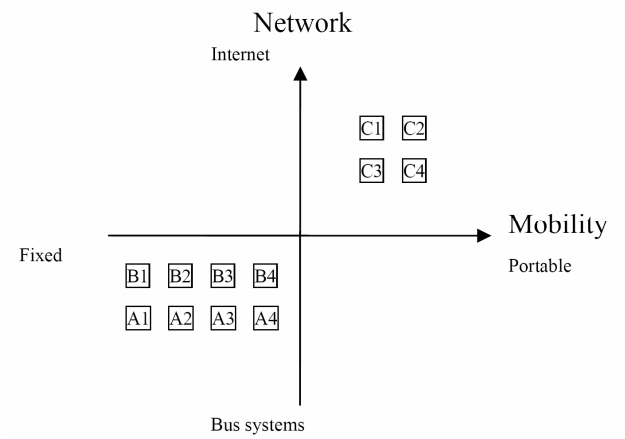

Figure 3. Image map: Mobility versus Network.

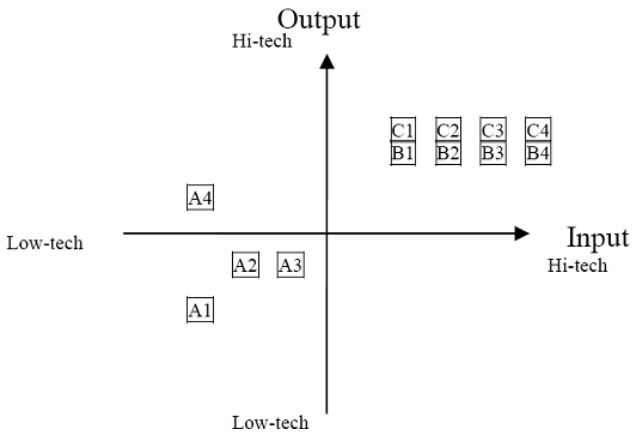

Figure 4. Image map: Input versus Output.

We may obtain from the above image maps further product evaluations in terms of positioning maps, which provide a more clear depiction of product distributions and characteristics. Thereby, instead of 12 individual products, the respective 3 product types (A, B, and C) are considered (see Figures 5 to 8).

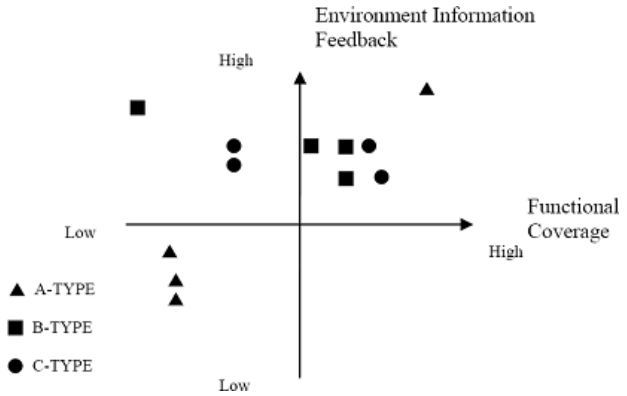

Figure 5. Positioning map: Functional coverage versus environmental information feedback.

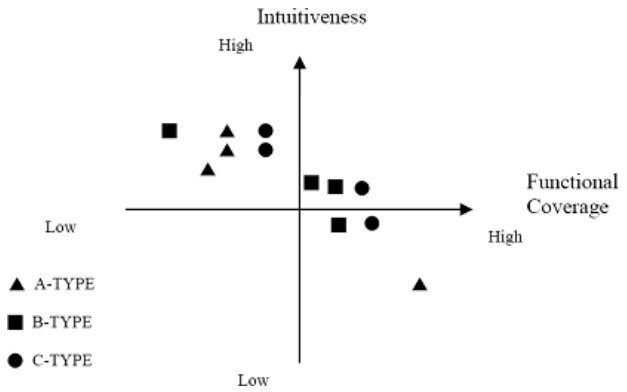

Figure 6. Positioning map: Functional coverage versus intuitiveness.

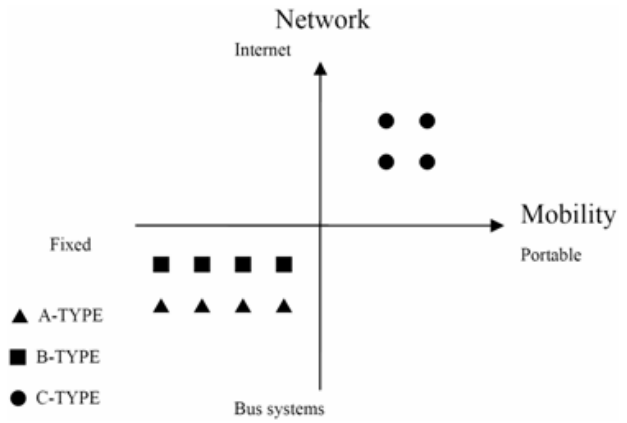

Figure 7. Positioning map: Mobility versus Network.

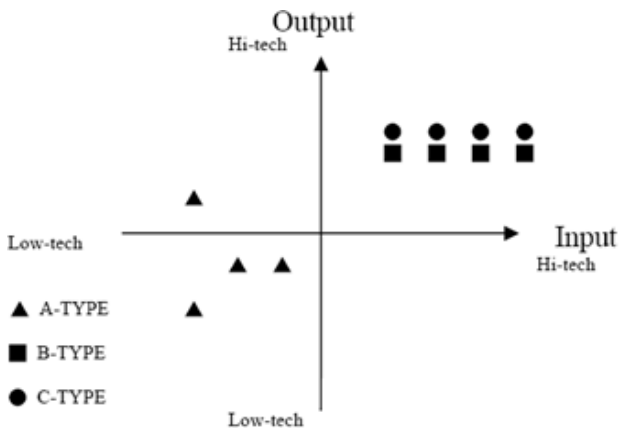

Figure 8. Positioning map: Input versus Output.

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 face 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, we briefly discuss certain areas of deficiency in the status quo and consider possible remedies.

4.1 *Control options and functional coverage*

In sentient environments, one key point is how the occupants interact with the tight integration of technology and the associated high information loads 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 my be considered: *a)* control via devices, *b)* control via Parameters, and *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 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 Figures 2 and 6). On the other hand, there are products (particularly type A) with functional options, which, while limited in number, are intuitive (see Figures 2 and 6).

4.2 *Provision of information*

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 independent of their functional coverage (see Figures 1 and 5). However, in most cases these products provide feed back 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). This means that the occupants are expected to modulate the environment with the condition of insufficient information.

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)* reconfigurability: 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 Figures 3 and 7). 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 traditional A-type products are software-wise rather difficult to upgrade (see Table 4).

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 effective manipulation possibilities and support the users in comprehending and instructing 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 4 and 8).

5 CONCLUSION

While we have not offered a detailed design for desirable user interfaces for future sentient environments, we have outlined a framework for the formulation of requirements for such interfaces. 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. We have tested and evaluated an array of existing user interfacing products for intelligent built environments against this framework and have thus identified areas of relative strength and deficiency. 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 in-

door climate conditions while meeting the goals pertaining to a sustainable building operation regime.

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