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USER BASED PREFERENCE INDOOR CLIMATE CONTROL

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ABSTRACT
In comfort control strategy there is an exciting development based on inclusive design: the user’s preferences and their behaviour have become central in the building services control strategy. Synergy between end-user and building is the ultimate in the intelligent comfort control concept. This new comfort control technology is based on the use of the latest development in agent technology and can further reduce energy consumption of buildings while at the same time improve individual comfort. The TU/e (Technische Universiteit Eindhoven) together with Kropman and ECN (Energy research Centre Netherlands) work together in the research for user based preference indoor climate control technology. Central in this approach is the user focus of the whole building design process which makes it possible to reduce energy consumption by tuning demand and supply of the energy needed to fulfill the comfort demand of the occupants building.

KEYWORDS
Integral design, agent technology, user based control

INTRODUCTION
There is a persistent discrepancy between increasing demands for comfort in buildings and the need to decrease the use of energy. Over the last years the average global temperatures has risen. Global warming, caused largely by CO₂ emissions as a result of energy consumption, shows an increasing effect. Climate change is becoming a major problem. As results of Global Warming (Alley et al. 2007) become more and more prominent, it is necessary to look for new possibilities to save energy and to generate sustainable energy to be used for comfort in the built environment (Randall&Randall 2001, Fali&Simpson 2004). Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable architecture. A major portion of primary energy consumption, about 40 %, is due to create thermal comfort in buildings by heating, cooling, ventilating and lighting. When design building services traditionally the main attention of the designers went to the heating demands. Due to the change in buildings, equipment and out door climate, there is a strongly growing demand for electricity instead of heating, see figure 1. As electricity has a completely different character as energy form compared to heat, a completely different strategy is needed to optimize the energy infrastructure of the built environment. Heat can be stored rather easily and efficient, were as electricity can only be stored in a limited amount in expensive and complex devices. As result of this change the focus of the design process will have to change too.

Figure 1. Development gas consumption and electricity demand the next 15 year (Ybema 2006)

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Therefore it is important to look at energy reduction especially for this growing electricity demand of a building. In office buildings most of the energy is needed for thermal comfort especially cooling. Present energy efficient technology is not sufficient to further reduce the energy use of buildings. New computer networks. A next step in their development is the intelligent connection of the building networks with the Internet. The exploited Web is an interesting and successful storage place of information resources that can be used (Akkermans 2002). Comfort control systems could use dynamic real-time information from the Web about weather forecast, availability of energy and price of energy. The information of the Web should be combined with information from the Building Management System (BMS) about the users, e.g. comfort demands or comfort preferences of the building occupants.

Agent technology

Therefore, a new generation of control systems was developed with technology based on agent mediated communication over local networks and the Internet. Intelligent agents are autonomous and intentional pieces of software. These agents are capable of searching and sorting information from the Internet in order to perform certain tasks for the users they represent. Multi-agent systems provide the essential technology for this ICT infrastructure (Akkermans 2002); - large numbers of actors are able to interact, in competition or in cooperation - local agents focus on local interests and negotiate with more global agents - implementation of distributed decision making by the negotiation processes between the different local or more global oriented agents - communication between actors is minimized to generic information exchange between agents.

Previous work by Akkermans shows that the new Internet agent technology makes it possible to integrate occupants’ behavior with information sources from the Internet (Akkermans 2002). To cope with different users and their different needs system wide information by agents is the basis. The different agents dynamically and continuously exchange information and negotiate with each other to get the best conditions for their representative. Through this mechanism there is an exchange of information about needs and supplies throughout the whole system. Only in this way the system can cope with the different users and their different needs. You could compare the way of working of the agents with the way some search engines, e.g. google, work on the internet. They search for the best possible answers to the questions or tasks they were given by the users. They always come back with the most suitable answer. In two projects, SMART (Smart Multi Agent internet Technology)
 Forgiving technology
A different type of technology to incorporate user behaviour, Forgiving Technology, was developed in another project, EBOB, Energy Efficient Behaviour in Office Buildings (Claesson-Jonsson 2005). EBOB investigated new combined technical and socio-economic solutions to make energy efficient behaviour natural, easy and intuitively understandable for the end-users of refurbished and new offices. Control scenarios for the HVAC systems were derived by analyzing occupants behavior and its effects on comfort and energy use. The EBOB project is an European 5th framework program project with eleven partners from five countries. EBOB ran from 2002 until 2005. The field test was held at Kropman’s office at Rijswijk (Grundelius et al. 2004).

User representation
The techniques used within SMART/IIGO and EBOB made it possible to use the user representation and combine it with optimization techniques. The representation of end-users was realized by developing an individual voting system. End-users were represented in the design by Fanger’s comfort model (Fanger 1970). This comfort model predicts user’s evaluations of the indoor climate in buildings. Using Fanger’s model, the percentage of dissatisfied users can be predicted for a given set of comfort parameters. The voting system allowed every user in a thermal zone to enter his vote (warmer/colder) within a voting period (e.g. one hour) while seeing the aggregated voting of other users in his zone at the moment of voting (Jelsma et al. 2002).

User domination
The users comfort needs dominate this control strategy. The control strategy is based on the description of the user behavior and implemented in a BMS (Building Management System). This BMS was extended with an external real-time information system to improve energy and comfort control. A learning curve is built from the user voting behavior. Responses of the user are interpreted differently depending on the overall trend of the comfort level in the building. Overall voting behavior as a function of the time of day is included in determining the action of the local comfort aspect controllers. Within this system the persistent use of user information is a leading strategy. By starting from the human perspective and using available and new technology (including IT, smart control, user interfacing) this dominate user strategy was achieved.

Optimisation strategy
The optimisation is based on user preferred comfort, cost weather conditions and energy use. Figure 6 shows an complete overview of the agent system as part of the building management system; the optimization utility function on the top left, the side predictive individual ventilation temperatures on the top right and the users with their individual voting behaviour on the bottom. All the agents are communicating with other agents, representing rooms or the floors of the building. Also there are agents representing the information about the weather forecast and the central process control of the air-handlings unit, see figure 2.

Figure 2: Central utilization function, air handlingsunit ventilation inlet temperature prediction and information of individual users, shown on the functional screen of the system (Hommelberg 2005).
In figure 3 the representation of the adjustments and the different energy needs of the different occupants is shown.

Different users = different needs

Figure 3: Individual adjustments and different energy demands for each office room is shown on the screen (Hommelberg 2005).

In the test-experiments the optimization of inner comfort of rooms was utilized to improve control of the central ventilation. The central ventilation part in the temperature build-up of the inner comfort in rooms in the old situation led to temperature overshoot. The new predictive control strategy allows more anticipation, and this results in less overshoot of the temperature. Normally due to the strong reaction of traditional process control units, the temperature adjustments results in temperature levels beyond the really desired levels. So small adjustments have to be made again and energy is lost.

In figure 4 the different profiles for the next 120 minutes are shown based on the individual comfort settings and the weather forecast.

Evaluation experiments

In the field test of the CB system, office building users were offered opportunities to optimise their comfort. The users also had an option for saving energy through an interface on their personal office
computer. The performed research revealed that initial expectations were not met. The frequency of CB use for comfort management appeared to be low. Users did not understand the energy saving option and users detected no improvement in comfort. The desired comfort could be only limited be influenced by the present mechanical climate systems with too low capacity. As a result the users could not actively influence their immediate comfort level. The building response due to the accumulation capacity of the building mass took longer than the occupants expected. To analyse the findings gained during the field test, the concept of design logic and user logic was introduced. The mismatch between these logics caused a loss of control of CB agents and introduced ambivalence for users. From this analysis it is concluded that it was not the design of CB proper that explains its poor performance. The clash of logics, design logic versus user logic, was the main reason. Implementation of smart climate systems for buildings can be improved by analysing and comparing such logics early on, i.e. in the design stage. There is a discrepancy between; and (i) the design objectives of comfort installations in utility buildings, and (ii) the realized functionality and (iii) user perception. More elaborate accounts of the project and its results can be found in (Jelsma et.al 2002). The final result of CB was the clash of logic in CB, design logic of the new comfort control system includes a conception of users as a collective and on the same hand has to take care of individual comfort.

METHODOLOGY

To work effectively with the new user based preference indoor climate control strategy, practitioners should learn to work with, and understand, the role of the user in the building design process. The building to be designed takes traditionally the central place in thinking of the design team. But in fact means and goal are mixed up. More and more the insight is growing that it is not the building to be designed that should be central but the needs of the humans for which the building is intended. This leads to a new approach in which the human needs both short term (comfort) and long term (sustainability) are key aspects that have to be fulfilled, see figure 5.

Value aspects design

Figure 5: Strategic design, Paul Rutten (Hasselt et.al.1998) versus conceptual representation of user interaction with the built environment

Integral Design methodology

Design is the key discipline that brings systems into being. In the engineering sciences, a lot of approaches have been developed to structure and optimize design processes: concurrent engineering, value engineering, design for manufacturability, systems engineering, quality function deployment, strategic design, etc. To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design by van den Kroonenberg (van den Kroonenberg 1978, de Boer 1989, Blessing 1992) into an Integral Design methodology. The Integral design process can be described at the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution. The original methodical design process is extended from three to four main phases, in which eight levels of functional hierarchical abstraction, stages can be distinguished. Starting by formulating the need, the program of demands is developed and transformed into functions to fulfill. This functional decomposition provides the means for decomposing complex design tasks into problems of manageable size. This functional decomposition is
hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is done until simple building components remain whose design is a relatively easy task, but each with each own focus, see figure 6.

![Figure 6: Hierarchical abstraction levels by functional decomposition](image)

Hierarchical abstraction implies the decomposition of information into levels of increasing detail, where each level is used to define the entities in the level above. In this sense each level forms the abstract primitives of the level above. The contents of the layers are based on the technical vocabularies in use, technology-based layers or levels. Each layer represents an abstraction of the levels below. For a more extensive description of the models that formed the basis for the notion of technology-based layers see (Alberts 1993, Zeiler 2000). Designing takes place in an environment that influences the process, it is contextually situated (de Vries 1994, Dorst & Hendriks 2001). The context of the model of designing is defined by a "world view". The our model consists of four worlds: the real world R, the symbolic world S, the conceptual world C and the specification world M. Thus, the four levels of aspect abstraction in the descriptive model of design are:

1. Information Level; knowledge-oriented, representing the "conceptual world"
   This level deals with the knowledge of the systems by experts. One of the essential ideas behind this is that human intelligence has the capability of search and the possibility to redirect search. This information processing is based on prior design knowledge. One of the major problems in modeling design knowledge is in finding an appropriate set of concepts that the knowledge should refer to, or in more fashionable terms; an ontology (Alberts 1993).

2. Process Level; process oriented, representing the "symbolic world"
   This level deals with physical variables, parameters and processes. The set of processes collectively determines the functionality of the variables that represent the device properties. Modelling at the functional level involves the derivation of an abstract description of a product purely in terms of its functionality. This abstraction reduces the complexity of engineering design to the specification of the product's desired functionality.

3. Component Level; device orientation, representing the "real world"
   This level describes the hierarchical decomposition of the model in terms of functional components and is domain dependent. Generic components represent behaviors that are known to be physically possible to realize. They are generic in the sense that each component stands for a range of alternative realizations. This also implies that the generic components still have to be given their actual shape.

4. Part Level; parametric orientation, representing "the specification world".
   This level describes the actual shape and specific parameters of the parts of which the components exist. Relevant technical or physical limitations manifest themselves in the values of a specific set of parameters belonging to the generic components. These parameters are used to get a rough
impression, at the current level of abstraction, of the consequences of certain design choices for the final result.

By implementing the insight that the user should become the leading factor within the process control, the following symbolic representation of the total process is shown in figure 7.

![Figure 7: Extended model analytic schematic interaction model of designing](image)

This user collective negotiates through agent technology about the levels and quality of common comfort. Figure 8 shows the new user interface and some of the main agent groups. The user agent allows personal control through individual setting, information and individual feedback. The user-agent interprets the user behaviour and takes care of giving feedback to the user.

![Figure 8: Overall system concept based on the new integral design methodology](image)

**CONCLUSIONS**

The goal of the research is to create practical solutions for a new generation of control technology in which the end-user behavior is integrated to reduce energy consumption and increase comfort at the same hand. By using Agent Technology it was possible to integrate user behavior into the climate control system and to improve energy efficiency of buildings. The results were prototypes that were implemented in the Kropman and ECN offices. From these prototypes and combined experiments we...
became aware that a new design approach was needed to implement user based preference indoor climate control. A new integral design methodology has been developed and used to develop a concept for further development and implementation of the new design and control strategy.

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