INDIVIDUAL USER BEHAVIOR LEADING FACTOR IN COMFORT CONTROL

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ABSTRACT

With global warming effects and exploding energy prices it is necessary to further optimize the energy performance of buildings. Intelligent Agents technology for individual climate control for each user of a building in combination with feedback on the energy consumption (costs) leads to better acceptance of the individual comfort and a reduction of the energy consumption. Agents at room level with knowledge of the actual preferences of the occupants are used to improve the distribution of the available HVAC resources of the building and lead to better performance with less energy consumption and at lower costs. At building level an agent is used to optimize the settings of HVAC-controls and lead to peak reduction. The technology was tested in field tests in different office buildings in the Netherlands.

INTRODUCTION

In today's modern buildings employees may expect a comfortable work environment. The indoor environment is achieved by good integration of the technology for ventilation, heating and cooling in a building. Over the years the energy efficiency of buildings has increased. At first this was done by using better ways of construction, followed by applying better insulation and improved glazing. Also the introduction of more efficient building equipment has lead to further reduction of energy consumption of buildings. Building automation has become a crucial factor in order to reach the requested comfort for the occupants with the least energy demand.
The building to be designed takes a central place in thinking of the design team, see figure 1.

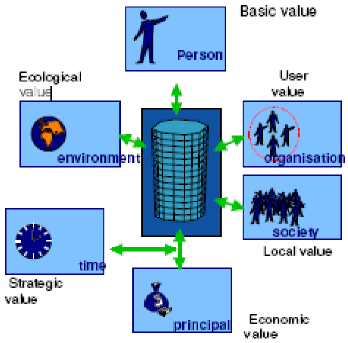

Figure1. Strategic design, the value aspect design approach by Paul Rutten (Hasselt et.al 1998)

Misunderstandings and wrong conceptions about indoor comfort and energy use are common. Most office users are not even aware of the fact that they can affect the energy use. The behavior of building occupants needs to be taken into account as it is responsible for almost half the outcome of planned energy reduction. Means and goal are often 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 are key aspects that have to be fulfilled, see figure 2.

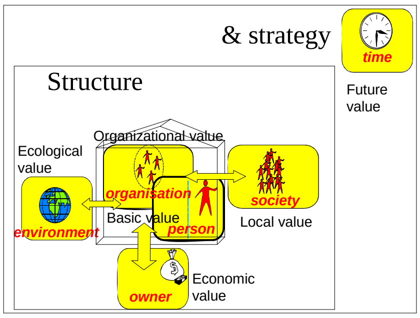

Figure 2. Integral design

METHODS

Integral Intelligent Process Control

Integration between end-user and building is the ultimate in the intelligent building concept. "Connecting" the end-user to a building is complex. User-connectivity, the combination of usability and user interface together, is studied and developed further. Information and communication technology connects people and helps them to communicate with the building. Clements-Croome emphasized transdisciplinarity and interaction: "Any consideration of intelligent buildings, whether learning, designing or managing them, requires a freedom of thinking which can embrace transdisciplinary ideas and systems. The word transdisciplinary, is a truly holistic and highly interactive concept. Intelligent building strategies are dealing with multiple criteria and attempting to integrate ideas over a wide range of issues (Clements-Croome 1997)."

When the comfort control system is not working adequately, a lot of energy is wasted by too much heating or cooling. As a result of this overshoot indoor temperature is the most common issue in occupants' complaints about thermal comfort .

THE HUMAN FOCUS

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 comfort control technology, such as individual control, offers new possibilities to further reduce energy consumption of office buildings. Dynamic online steering of individual comfort management and building management could save up to 20% of current energy consumption. Misunderstandings and wrong conceptions about indoor comfort and energy use are common. Most office users are not even aware of the fact that they can affect the energy use. The behaviour of building occupants needs to be taken into account as it is responsible for almost half the outcome of planned energy savings, see figure 3([Claeson-Jonsson 2005).

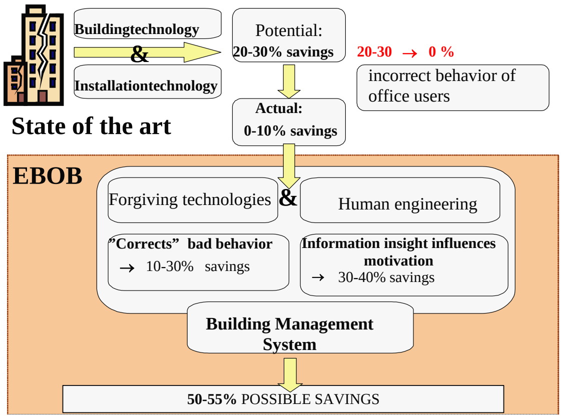

Figure 3. Influence behaviour of office users (Claeson-Jonsson 2005).

When the comfort control system is not working adequately, a lot of energy is wasted by too much heating or cooling. As a result of this overshoot indoor temperature is the most common issue in occupants' complaints about thermal comfort.
ASHRAE (2004) describes comfort as:

'The state of mind, which expresses satisfaction with the thermal environment'

It is possible to distinguish between deterministic and holistic factors concerning comfort. Determinist factors describe aspects that are definable and absolute: e.g. the physical properties of the building shell and the indoor and outdoor climate. Holistic factors are aspects that can not be determined: e.g. state of mind and influence on surroundings. For example if users can influence the indoor climate by opening windows they may not improve the indoor temperature or airspeed, still the user may find it more comfortable.

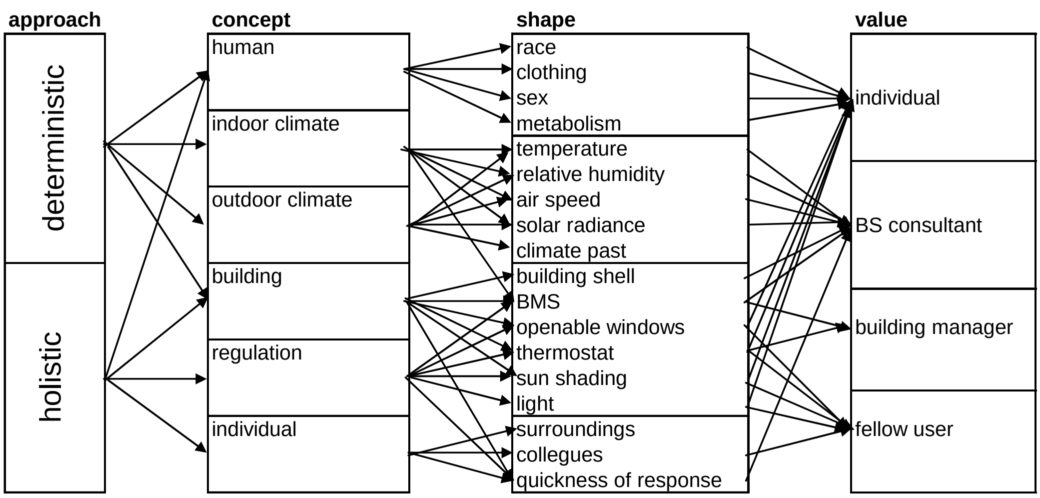

Figure 4. Conceptual map comfort (van Schijndel 2007)

The most important research on thermal comfort is done by P. Fanger (1970) and his Predicted Mean Vote model (PMV) is the basis of the indoor climate standards in Europe (ISO 7730-2005) and America (ASHRAE Standard 55-2004). This model includes thermo physiological properties of humans, such as sweat production and heat resistance of the skin. Based on what average people consider comfortable, the Predicted Mean Value (PMV) is translated into a percentage of people dissatisfied (PPD).

However, studies show that averaging comfort temperatures, clothing values and metabolisms is undermining the individual wish. Because of differences between people's individual levels of comfort and their individual differences in e.g. cloathing growing insight arises that the difference are too big to average. In order to explain the error on averaging people's comfort levels, a figure is taken from Fanger's thesis (1970). Figure 5 shows results of an experiment where people were asked when they were thermally comfortable at different metabolic rates. The evaporative heat loss per unit body surface area is measured. This figure shows a wide spread of heat loss, also at lower activity levels. This activity level is also expressed as metabolic rate or metabolism (Fanger 1970).

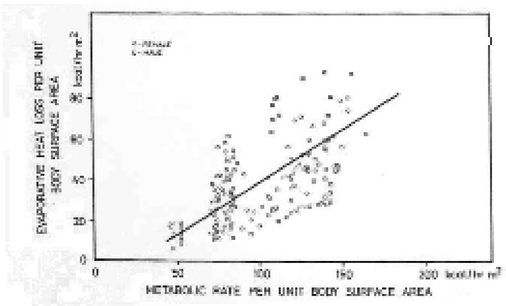

Figure 5. Evaporative heat loss per unit body surface area as a function of activity level for persons in thermal comfort. In order to maintain comfort the ambient temperature was lower the higher the activity level [Fanger, 1970]

Particularly at high metabolisms the spread in evaporative heat loss is big (>60 kcal/hr.m^2, which corresponds to 70 W/m^2). This research is limited to office buildings. The metabolic rate in office buildings on average is 65 W/m^2 (or 56 kcal/hr.m^2). The figure shows an average of 16 kcal/hr.m^2 (18.6 W/m^2). However, the measurement points show a spread between 6 and 26 kcal/hr.m^2(7 to 30 W/m^2). This results in a spread in PMV of 0.6 (both negative and positive), compared to an evaporative heat loss of 16 kcal/hr.m^2.

This example shows that averaging can be very helpful for determining guidelines for thermal comfort. However, the individual spread must not be neglected.

<u>Effect Personal Clothing</u>

While clothing of men in office buildings during the year only slightly changes, the women dress more according to the outdoor climate. Experiments show that the clo-value can even be 0.3 for women in summer (Darmawan, 2002). This experiment show that in one office, the clo-value can vary between 0.3 and 0.8 clo. Figure 6 shows the PMV as a function of metabolic rate and clothing value. It is shown that a large difference can be seen, especially at low metabolic rates.

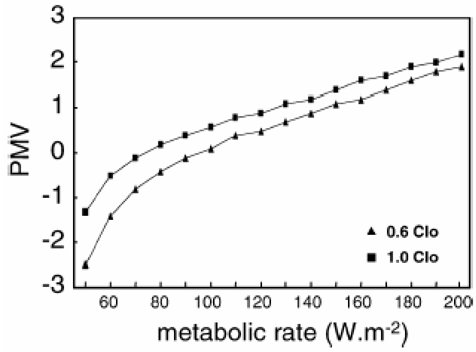

Figure 6: PMV as a function of metabolic rate (air temperature 22 ^oC, air speed 0.15 m/s, air pressure 1 kPa) (Havenith, 2002)

This figure emphasizes that difference in clothing results in a large spread in PMV-rating. In one office, comfort temperatures can vary from 21 to 26 ^oC, considering different clothing values. This is also shown in figure 7. The figure shows the dependence of dissatisfaction on the room temperature in relation to the type of clothing (Fröhlich, 2004).

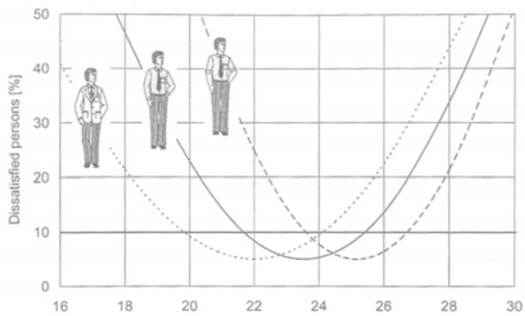

Figure 7: Dependence of dissatisfaction in relation to clothing (Fröhlich, 2004)

As until now the user has not been part of the building comfort system control strategy in offices, the energy consequences of the user behaviour are not accounted for. New technological development is needed to incorporate the behaviour of occupants of buildings. The energy supply on a system level should be dominated by trends in demands by the occupants of the buildings (Figure 3). Until now the user has not been part of the building comfort system control strategy in offices and the energy consequences of the user behaviour were not accounted for. Integration between end-user and building is the ultimate in the intelligent building concept. "Connecting" the end-user to a building is complex. User-connectivity, the combination of usability and user interface together, is studied and developed further. Information and communication technology connects people and helps them to communicate with the building. New technological development is needed to incorporate the behaviour of occupants of buildings. The energy supply on a system level should be dominated by trends in demands by the occupants of the buildings, see figure 8.

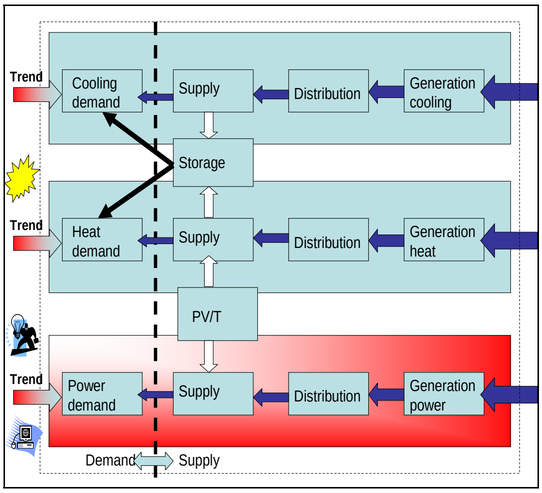

Figure 8. Demands and supply on system level

Such novel control systems should not only improve the energy performance of the building, but should also offer benefits to users (i.e. building operators as well as workers). Comfort management should be linked with improving energy efficiency. Individual comfort management makes it possible to optimize comfort, energy efficiency and costs. This combination would be beneficial for building operators as well as occupants. Therefore in commercial buildings, the inclusion of options for individual comfort management is an important feature to make such systems attractive to end users.

The making of the built environment has become complex. In the conceptual design phase, in order to create conditions to assure a better built environment, the ingenuity of the whole design team existing of different disciplines should be used, not only architecture.

Building automation (BA) has become a crucial factor in order to adjust the requested comfort with use of the least energy. BA started with simple thermostatic controls and has grown into a specialized field that uses the newest available techniques in data-communication and control algorithms. Crucial data concerning the status and performance of the equipment is gathered and used to optimize the comfort in the building. Further optimisation aims at the reduction of the energy consumption, without compromise on indoor comfort.

Present control systems for office buildings already make use of new technical possibilities offered by 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
- price level 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. However, the Web is far from ideal for the utilization of existing external potential.

This ICT architecture must be designed with in mind a specific system-wide optimal viewpoint, for example energy saving, but at the same hand look at the needs of local actors in the system. This demands a multi-actor coordination, which optimizes global system strategies, in connection with the local interests. The ICT-infrastructure needed to fulfill these requirements must be flexible, open and extensible and take into account stakes on the global level as well as those of individual actors in the system

Further integration of the available systems is needed. Intelligent Agents is a good concept in order to realise the further integration and optimization of building systems. Thanks to its autonomous operation, modular structure and abilities to communicate, software agents are a very flexible concept for integration of optimization at different levels.

Intelligent Agent concepts are developed over the last 20 years and have been applied to very different fields. The Intelligent Agents used by us can be best described as: *Intelligent Agents are autonomous pieces of software dedicated to certain tasks; an Intelligent Agent has access to resources and is able to communicate and negotiate with other Intelligent Agents in order to fulfil its tasks.* This definition suits the purposes for Intelligent Agents within our research, for further descriptions of the agent technology we refer to (Weiss 1999, Diane et al 2004).

The long term goal of this research project is to develop an Intelligent agent that can be used to optimize the building performance, but also can be used as a tool during the design phase. The Intelligent agent is used to specify's the needs and layout of the building systems.

METHODS

In the SMART/IIGO project the agent technology was developed for optimal setting of the comfort parameters. SMART stands for *Smart Multi Agent Technology* and IIGO is a Dutch acronym for *Intelligent Internet mediated control in the built Environment*. The, in SMART developed, technology was tested in an extended field test in the IIGO-project.

RESULTS

In this article the results are discussed of the two field experiments in office buildings.

EBOB-project.

The first experiment was part of the European EBOB-project (Energy efficient Behaviour in Office Buildings). In EBOB so called *Forgiving* Technology was developed, with this technology each user in the building was given control of his or her personal comfort in combination with feedback on the energy costs of the chosen setting.

In the EBOB-project the main topic was the interaction between energy use and individual comfort. This was done by giving each user a choice of 4 different modes. (1) a *Default setting*, where the system work with a default set point in the comfort band, (2) a *Comfort Zone*-setting, where the user can choose an offset of +/- 2K on the default setting, (3) an individual setting, where the user is able to choose a plus or minus offset to the standard comfort setting, and (4) an *Optimize Energy*-setting where the system operates within a wider comfort band is used to minimize energy costs. The users get feedback on the effects of their choice by information about the current outdoor weather conditions and by feedback based on the 'relative' energy consumption of the chosen mode.

The field-test in the already highly energy efficient Kropman building in Rijswijk showed a 10% reduction in energy consumption, due to a major choice for the *Optimize energy setting*. The field test learned the importance of a correct match of the offset-range to the actual ability of the HVAC-system. When the system is at is max. offset it should not 'promise' a cooler temperature than actual achievable. For a room with more occupants, the feedback of *the room temperature* is not representative for each individual user. For example a person near an air-outlet can perceive a cooler temperature; in fact the feedback should be made possible per workplace.

SMART/IIGO

In the first part of the project, the agent-software for climate control was developed and tested at ECN research Centre. The SMART comfort control is based on the PMV-index. In more conventional building management systems (BMA) the local comfort control is based on a fixed temperature set-point, as shown in figure 9 the same level of satisfaction can be achieved al lower costs. When applied to a set of users in a building, the individual preference can be stored and used to modify the personal comfort level. The preferences (adjustments) over a day can be used to maintain the comfort level at the least costs.

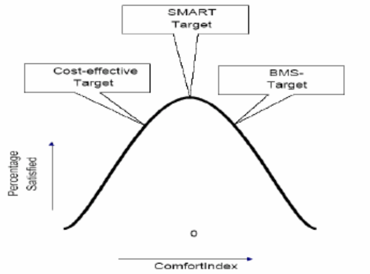

Figure 9. Smart control lead to the same level of satisfaction, BMS with fixed temperature set point, compared to cost-effective setting of comfort parameters. Percentage satisfaction= 100% - PPD according to Fanger (1970)

The SMART-technology combined with the communication and control system developed in the IIGO led to the configuration of figure 10 and was used in the field test. In the test the ISA-platform was implemented as a top layer on the existing BMS.

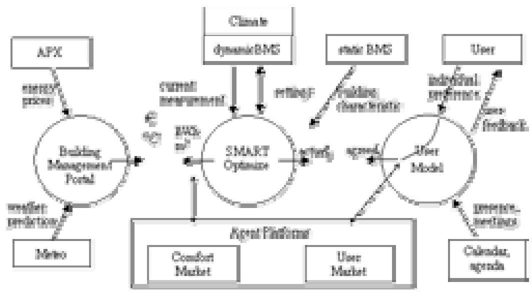

Figure 10. The ISA-layout as used in the SMART IIGO field test at the Kropman Office building in Nijmegen (Hommelberg 2005)

In figure 11 is the detailed structure of the user model given. This model of the user agent is connected to the other agents by the agent structure which project on the different levels of a building the needed functional relation to the physical parameters of the building level itself, see figure 12. Due to the size of the building and the lay-out of the HVAC-system, *Floor*- and *Workplace Agents* had no real function. In the implemented lay-out the User Agents directly negotiated with the *Room agents* and the *Room-agents* had direct access to the *Building Agents*.

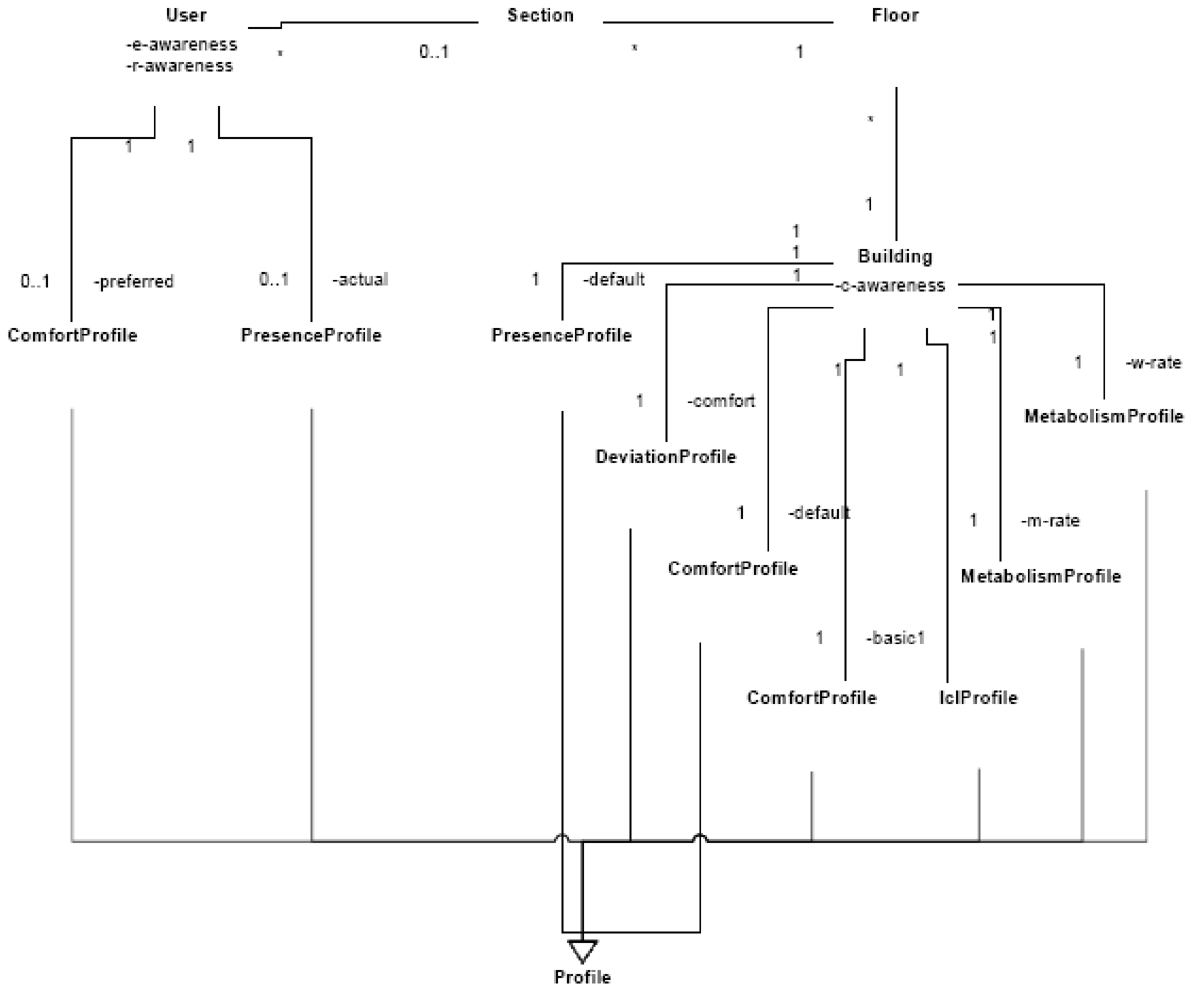

Figure 11. Detail structure of object model user basis for the agent profiles

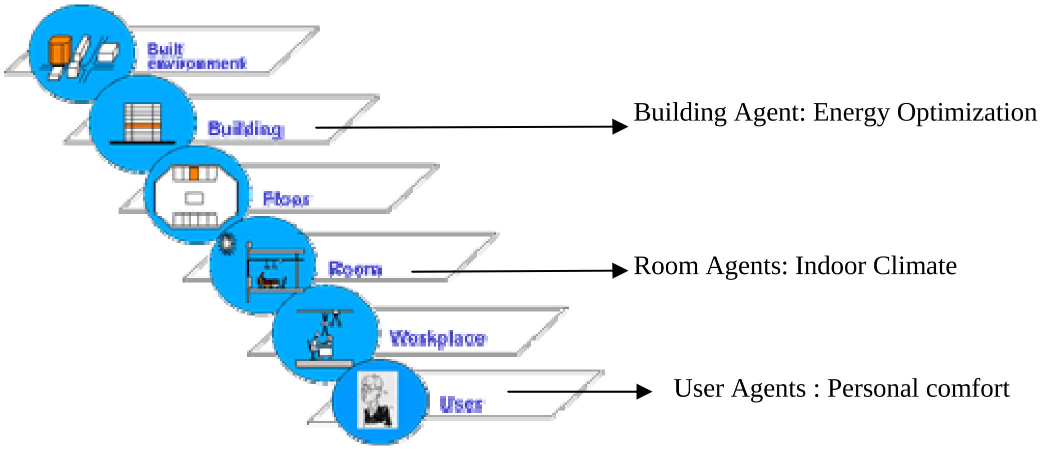

Figure 12. At 3 levels agents are implemented: User agents for employees, Room agents for climate control of each room, and a Building agent for energy optimization.

The U*ser agents* adjust the room conditions to the needs of the user; it creates a comfort profile over time, and uses this profile to negotiate set-point adjustments with the Room-agent.

The *Room-agent* controls on basis of the SMART-set-point of figure 9, the set-point is amended by an average 'vote' of the connected User-agents, a simple 2-node room model is used to predict the actual need for heating or cooling. The

2-node model uses weather predictions, orientation on the sun and the thermal mass of the building to predict the air- and radiant-temperatures. The prediction is used to negotiate the air-supply temperature of the building. The different settings can be seen on the computer screen, see figure 13.

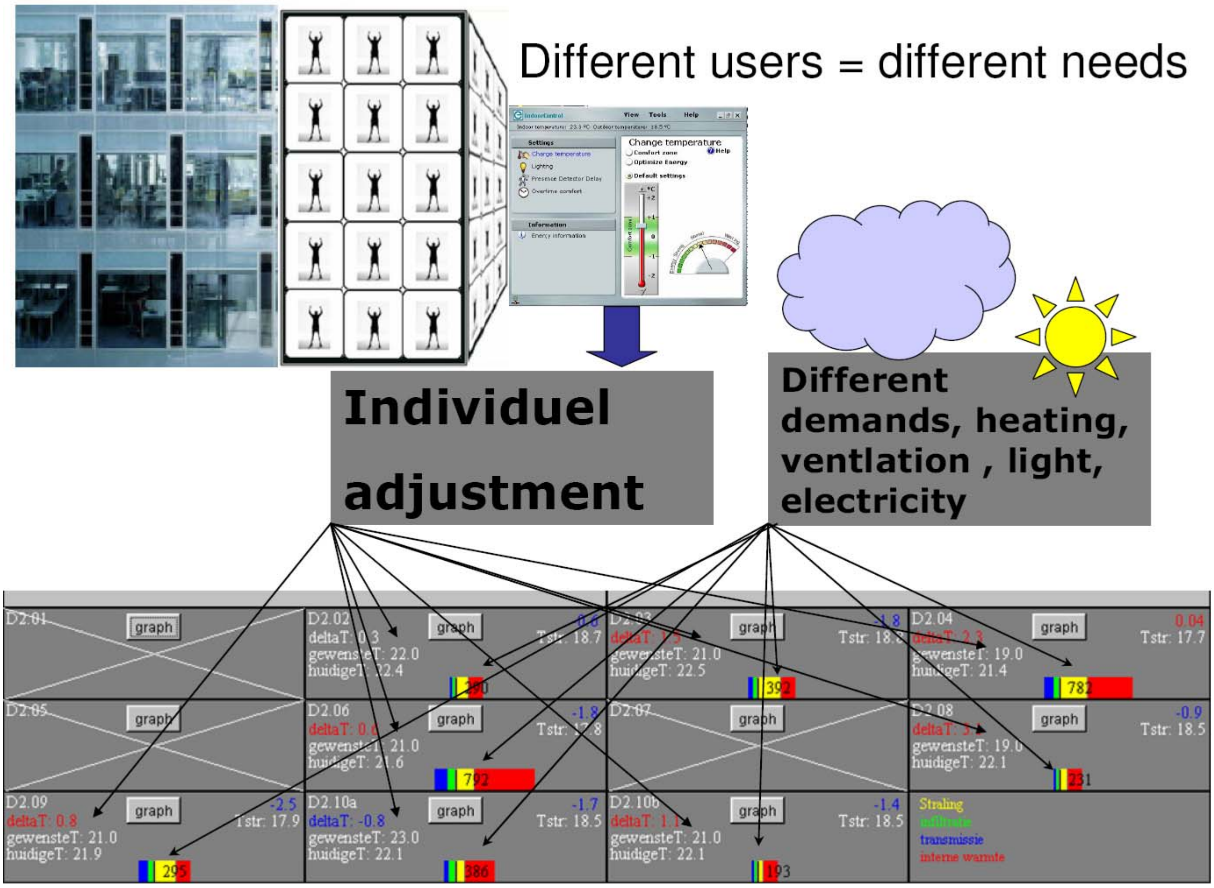

Figure 13. Individual adjustments and different energy demands for each office room is shown on the computer screen (Hommelberg 2005)

DISCUSSION

The concepts developed in EBOB and SMART-IIGO have shown to be applicable in an actual building configuration. In the field test no stability problems occurred, although in a multi-agents systems the same problems can occur as in multi-control configurations as shown by Akkermans and Ygge (Akkermans, Ygge 1999). When the agents, operating at Floor, Work-place-level are incorporated in the system, this could possibly lead to stability problems.

The *intelligence* of each agent can be further enhanced, for example more complex building models for use in the *Room-agents* give better predictions, and extended comfort-models in the *User-agents* can lead to better performance. An increase in the complexity of the system balances better performance against risk of stability problems. In further research each addition to the system will be weighted to performance and robustness of the total system.

In the experiment the Intelligent Agent system was implemented as a top layer on an existing HVAC-control system. When during the design of HVAC and BA are developed with Intelligent Agents in mind better performance could be achieved.

In order to optimize the comfort/energy ratio of each user, further research is needed in the translation of the user needs to the optimal setting of the system. Individual controls at the workplace should be incorporated in the *workplace-agent.*

CONCLUSIONS AND FURTHER RESEARCH

Building automation based on Intelligent Software agents are a flexible and promising technology for efficient operation of building.

To further optimize the performance of these systems, further research is needed into the possibilities and use of system for individual comfort control (*Workplace-agent).*

The lessons learned in these projects are further used in the Flexergy project. In this project SMART control of the building is combined with agent technology for energy purchase on an open market. This technology was developed at ECN in the POWERMATCHER-project (PM). The PM-technology combines local demand and supply of electricity and efficiently incorporates distributed generation into the network (ECN 2006).

ACKNOWLEDGEMENT

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