Agent Technology to Improve Building Energy Efficiency and Occupant Comfort

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Abstract: Global warming, caused largely by energy consumption, has become a major problem. During the last decades the introduction of energy saving technologies has strongly reduced energy consumption of buildings. Users' preferences and behavior have become central to building services control strategies. Achieving synergy between end users and buildings is the ultimate in intelligent comfort control. This new comfort control technology, based on use of the latest ICT development in agent technology, can further reduce energy consumption of buildings. This paper reviews Multi-Agent Intelligent Internet-mediated control strategies and combines the most useful insights into a new technology called Forgiving Agent Comfort Technology (FACT). The University of Technology Eindhoven is developing this FACT technology further into a new concept .

Keywords: energy, comfort, agent technology

1. INTRODUCTION

Over the last years the average global temperatures has risen. Global warming, caused largely by CO_2 emissions as a result of energy consumption, shows an increasing effect. Climate change is becoming a major problem. Office buildings have a relatively high-energy consumption and as such are responsible for a major share of the 40% of the energy consumption of the built environment. Therefore it is important to look at energy reduction especially for this type of building. In office buildings most of the energy is needed for thermal comfort; heating and 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 [4].

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 emphased 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 [2]."

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 .

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 reduction.

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. 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 optimise 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 seen as an important feature to make such systems attractive to end users.

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 [4]. 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 utilisation 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 fulfil these requirements must [5];

- be flexible, open and extensible
- take into account stakes on the global level as well as those of individual actors in the system

1.1 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 [6].

Multi-agent systems provide the essential technology for this ICT-infrastructure[6];

- 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 decisionmaking bu 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' behaviour with information sources from the Internet [4]. However, the question of how behavioural aspects of building occupants could be best represented remains.

There are two major scalability problems:

-the number of participants in the system representation

- the interdependency in the participant's demand over time

To solve these problems the user representation and the optimization strategy used in such a system is of great importance. To cope with the different users and their different needs the system wide information by agents is the basis.

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 1.The different agents dynamically and continuously exchange information and negotiate with each other to get the best conditions for their representative. Through this mechanisme 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.

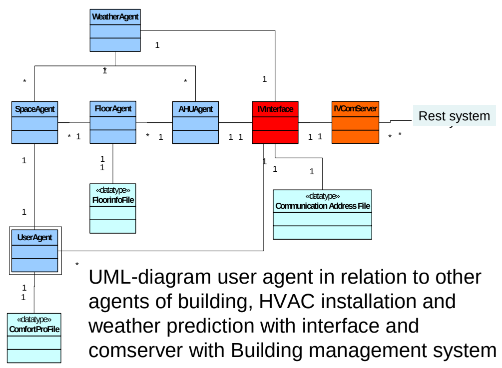

Fig.1: System wide information exchange by hierarchical structuring of the agents platform

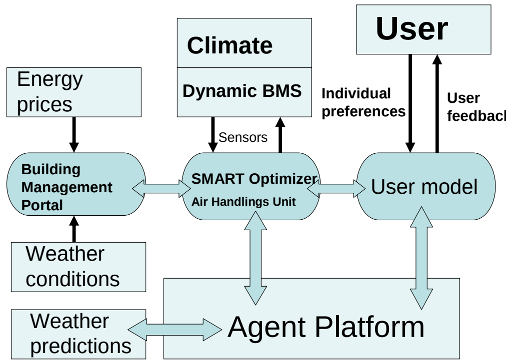

Fig.2: All around system information exchange by the dynamic operation of the agents in relation to the other parts of the system.

2. PREVIOUS WORK

Kropman, one of the major Dutch building services contractors, has participated in various research projects the field of building management systems with Energy research Centre of the Netherlands (ECN) and TNO Building and infrastructure. Each research project had its own focus to incorporate user behaviour aspects into the comfort control systems strategy.

2.1.1 SMART (Smart Multi Agent inteRnet Technology) / IIGO (Intelligent Internet mediated control in the built environment)

From 2000 until 2002, the SMART project was carried out at the site of the Energy Research Centre of the Netherlands (ECN) near Petten, [6]. The general objective of this project was to formulate requirements for the optimization of new climate control systems. It was important to gain experience in the implementation of such climate control systems in different settings. A second, extended field-test with the SMART technology was done within the IIGO project at Kropman's office in Nijmegen.

2.1.2 EBOB (Energy efficient Behaviour in Office Buildings)

A different type of technology to incorporate user behaviour, Forgiving Technology, was developed in another project, EBOB, Energy Efficient Behaviour in Office Buildings. 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. 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.

2.2 Explanation of techniques used

The techniques used within SMART/IIGO and EBOB were different: there was a major difference in user representation and optimalization techniques. First the user representation will be explained within the projects;

2.2.1 User representation SMART/IIGO

The representation of end-users was realized by developing an individual voting system for SMART; some results are shown in Figure 3. End-users were represented in the design of the SMART system by Fanger's comfort model [7]. Fanger's 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.

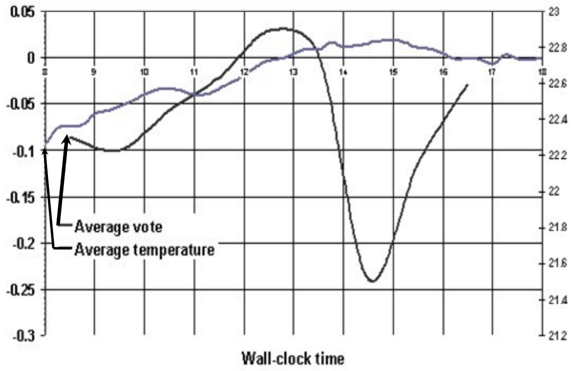

Fig.3: Average vote for adjusting the optimal Fanger comort room temperature and average room temperature during a summer day, with the present room temperature right and the resulting temperature adjustment left [6] .

The users comfort needs dominate this control strategy. The control strategy is based on the prescription of the user behaviour 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.

In the IIGO test-experiment a learning curve was built from the user voting behaviour. With the new interface on the computer, the response of the user is interpreted differently depending on the overall trend of the comfort level in the building. Overall voting behaviour 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.

2.2.2 User representation in EBOB

The control technology of the EBOB project is based on the behaviour of users. First, the behaviour of users was studied and described. Secondly, the description of the actual behaviour of the occupants of the building was then implemented in the control strategy to predict the user behaviour. The EBOB control strategy is descriptive. This was achieved by starting from the human perspective and using available and new technology (including IT, smart control, user interfacing). The combination of human engineering and corrective actions makes it possible to positively influence motivation positively and to correct "bad" behaviour, see figure 4. Complete descriptions can be found in [3].

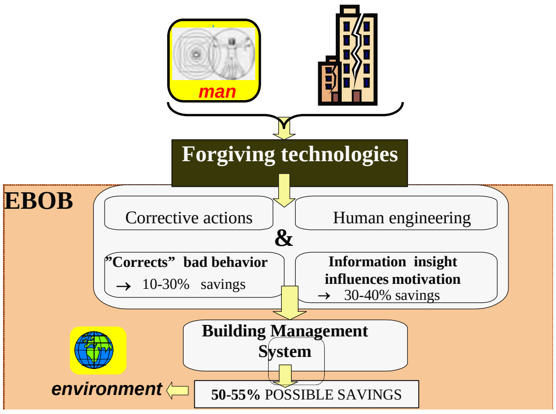

Fig.4: Potential possible savings EBOB's by using Forgiving Technology based on corrective actions and human engineering [3]

2.2.3 Optimisation strategy SMART/IIGO

The SEBOS (SMART Enhances scope Building Optimiser Shell) optimiser determines an optimal strategy for controlling the thermal comfort in a building [8]. The optimalisation by SEBOS is based on user preferred comfort, cost weather conditions and energy use. Figure 5 shows an complete overview 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

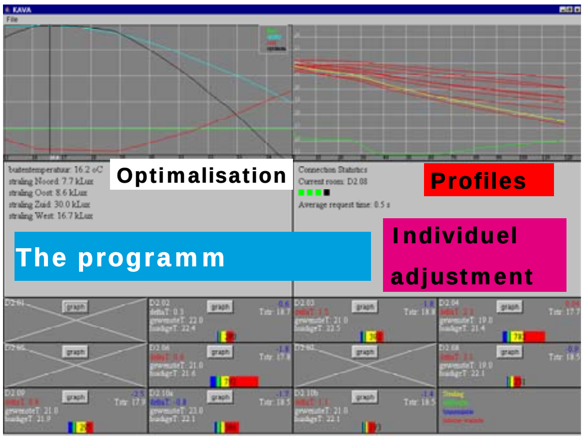

Fig.5: Central utilization function, ventilation inlet temperature prediction and actual voting of individual users, shown on the functional screen of the SMART system [9].

In figure 6 the representation of the adjustments of the different users is shown

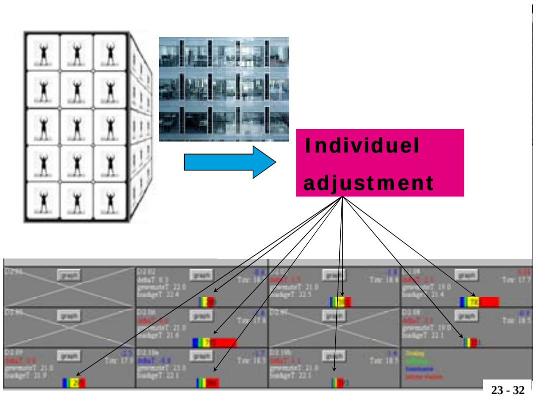

Fig.6: Individual adjustments shown in the screen

SEBOS optimization applies a pre-emptive, forward looking strategy using intelligent agent technology. A complete description can be found in [8]. In figure 9 the different profiles for the next 120 minutes are shown based on the individual comfort settings and the weather forecast.

SEBOS multi-goal optimization is done by weighing the comfort deviation with respect to the preferred comfort against cost and energy use within a utility function, shown in figure 8.

In the IIGO test-experiment the optimisation 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 emperature levels beyond the really desied levels. So small adjustments have to be made again and energy is lost.

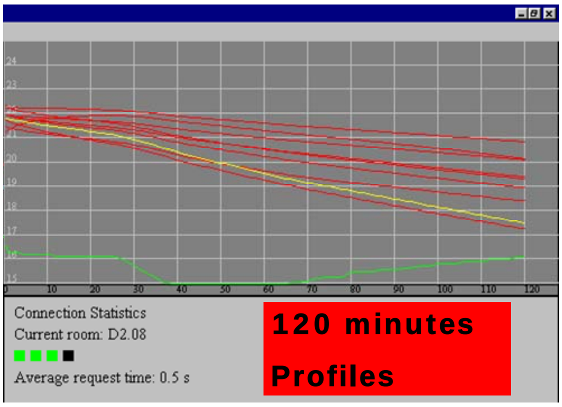

Fig.7: Different individual comfort profile demands for the next 120 minutes

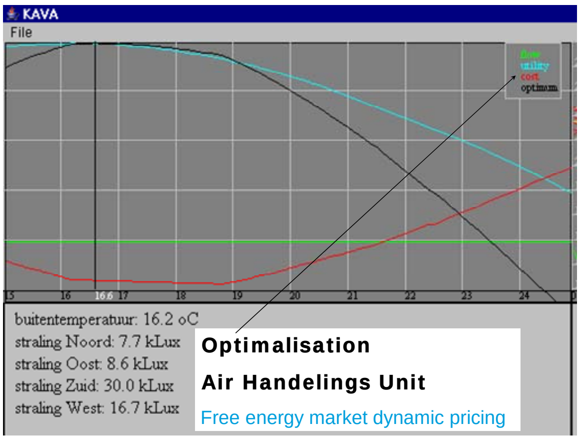

Fig.8: Utility optimalization function to costs

2.2.4 Optimisation strategy EBOB

Improvements of energy saving behaviour in office buildings can be achieved either by changing the user's behaviour or by overriding the user. Information is presumed in the EBOB project to be an important factor in motivating the occupants to use the forgiving technology. Within EBOB the term forgiving technology is utilized. The aim of Forgiving technology is two-sided;

- to influence or stimulate humans towards more conscious behaviour resulting in more energy efficient behaviour and better indoor conditions.
- to correct undesired human behaviour such as leaving the light on after leaving the room for longer periods.

3. EVALUATION

3.1 SMART/IIGO

In the IIGO field test of the SMART 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 SMART 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 influenced by a few mechanical climate systems. As a result the users could not actively influence their immediate comfort level. The building response took longer than the occupants expected.

To analyse the findings gained during the field test, the concept of design logic and use logic was introduced. The mismatch between these logics caused a loss of control of SMART agents and introduced ambivalence for users. From this analysis it is concluded that it was not the design of SMART proper that explains its poor performance. The clash of logics, design logic versus use 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. More elaborate accounts of the project and its results can be found in [10].

3.2 EBOB

It has been a constant observation during the EBOB research that all common temperature controllers are difficult to use and understand correctly because there is too little information on them. It is important to present facts and explain in an easily understandable way how office users can affect the indoor environment and thus the energy use. By doing so the office users will be tempted to behave in ways that save energy. Also, the new control systems have ways to reduce the effect of spoiling behaviour and so forgive 'bad' behaviour of the building occupants.

4. DISCUSSION AND FUTURE WORK

The SMART/ IIGO and EBOB-tests differ from systems developed for in-home comfort management systems such as early applications of COMFY [1]. Within the home, the roles of user and manager/operator coincide. In an office building, these roles are separate. Therefore, the new systems have to deal with two types of users: (i) building managers operating the building management system, and (ii) end-users instructing the building management system through SMART. This clash of logics explains the system's lack of functionality, which discouraged use during the field test. 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 [10].

The final result of SMART/IIGO and EBOB was the combination of the insights from the projects. Agent technology and forgiving technology were combined into FACT, Forgiving Agent Comfort Technology. As a result of the clash of logic in SMART/ IIGO and EBOB, the design logic of the new comfort control system includes a conception of users as a collective. This user collective negotiates through agent technology about the levels and quality of common comfort. Figure 9 shows the new user interface and the integrated user-agent. It allows personal control through individual setting, information and individual feedback. The user-agent, shown in figure 10, interprets the user behaviour and takes care of giving feedback to the user.

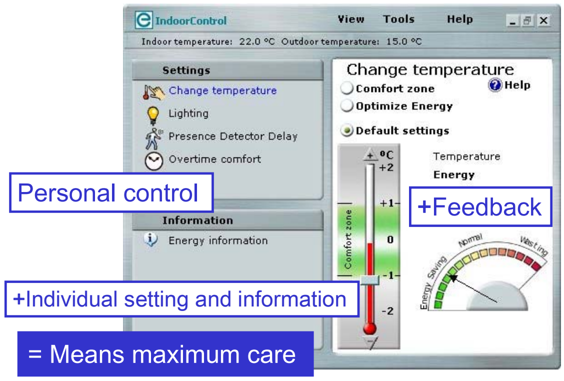

Fig.9: User interface on his or her Personal Computer

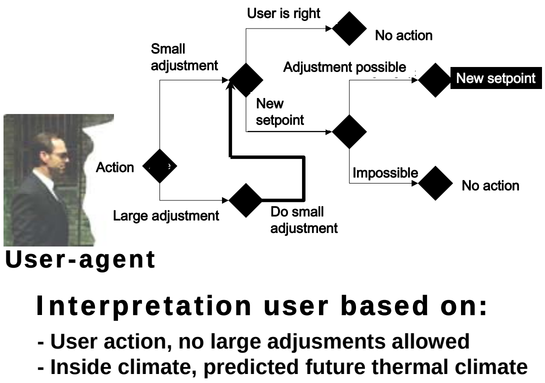

Fig.10 : User interpretation agent [9]

5. CONCLUSIONS

The goal of SMART/ IIGO and EBOB was to create practical solutions for a new generation of control technology in which the end-user behaviour is integrated. By using Agent Technology and Forgiving Technology it was possible to integrate user behaviour into the climate control system and to improve energy efficiency of buildings. The results were prototypes that were implemented in the Kropman office.

From these prototypes a combined technology emerged, FACT, Forgiving Agent Comfort Technology. The TU/e [9] developed FACT further into a concept for CB (Caring Buildings). In this CB concept building control is based on the individual requirements and preferences of the occupants of buildings. As the building and its climate control system really take care of the occupant, technology transforms to care. The building becomes a Caring Building.

ACKNOWLEDGEMENTS

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