Agents to improve Individual Comfort and Save Energy

Wim Zeiler, Paul Noom, Gert Boxem, Rinus van Houten
TU/e, Technische Universiteit Eindhoven.

Joep van der Velden, JanFokko Haan, Willem Wortel
Kropman Building Services Contracting

Maarten Hommelberg, Rene Kamphuis,
ECN, Energy research Centre Netherlands.

Henk Broekhuizen
Installect Energy consultancy

ABSTRACT

In order to further improve energy performance of buildings, intelligent building control is needed which integrates individual demands and behavior of occupants. Intelligent Agent technology is suited to be implemented at different levels of building automation. Individual agents control the climate for each user of the building in combination with feedback on the energy consumption can lead to better individual comfort and a reduction of energy consumption. Agents at room level with knowledge of the actual weather and orientation of the windows are used to improve distribution of available HVAC resources within the building and this can lead to better performance at lower costs. At building level agents can be used to optimize the settings of central HVAC-controls and lead to peak reduction.
Intelligent Agent technology was tested in field tests at different office buildings in the Netherlands.

1. INTRODUCTION

In today's modern buildings occupants may expect a comfortable indoor environment. This indoor environment is achieved by good integration of 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.

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.
As until now the user has not been part of the building comfort system control strategy in offices, the energy consequences of the user behavior are not accounted for. New technological development is needed to incorporate the behavior of occupants of buildings. Central in this approach is the user focus 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.

2. METHOD

Building automation started with simple thermostatic controls and has grown in to 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. Intelligent Agent process control 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 very different fields. The Intelligent Agent process control used in this article can be best described as: *Intelligent agents are autonomous pieces of software dedicated to certain process control tasks; an Intelligent agent has access to resources and is able to communicate and negotiate with other Intelligent agents in order to fulfil its task and achieve the 'best' results for the occupant which the agent represents.* This definition suits the purposes within this paper, for further descriptions of the agent technology we refer to (Wooldridge and Jennings 1995, Weiss 1999, Diane et al 2004). 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 (Akkermans 2002). The long term goal of this research project is to develop intelligent agents framework that can be used to optimize the building performance, but also can be used as a tool during the design phase based on the specification of user needs and layout of the building systems. In this article the results are briefly discussed of the two earlier field experiments with intelligent agent technology in office buildings.

3. RESULT: SMART/IIGO

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*. In the first part of the project, the agent-software for climate control was developed and tested at ECN research Centre. The, in SMART developed, technology was tested in an extended field test in the IIGO-project in the building of Kropman Nijmegen.

The SMART comfort control is based on the PMV-index. The most important research on thermal comfort is done by P. Fanger (1970). The Predicted Mean Vote model (PMV) is the basis of the most important indoor climate standards in Europe, ISO 7730 (ISO 2005) and America, ANSI/ ASHRAE Standard 55 (ANSI/ASHRAE 2004, Olesen and Brager 2004). This model includes thermo physiological properties of the human, such as sweat production and heat resistance of the skin (Fanger 1970).

In more conventional building management system the local comfort control is based on a fixed temperature set-point, as shown in figure 1 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.

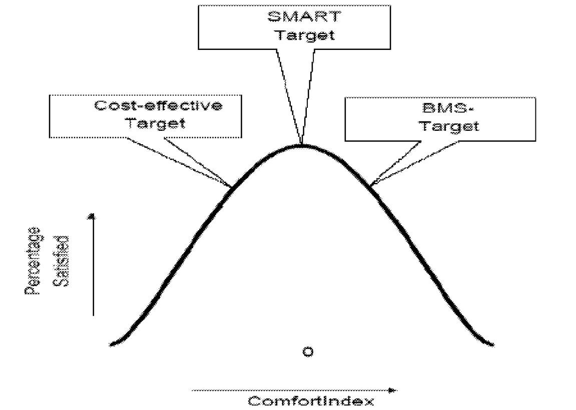

Figure 1. Smart control lead to the same level of satisfaction compared to cost-effective setting of comfort parameters (Jelsma et al. 2002).

The SMART-technology combined with the communication and control system developed in the IIGO led to the configuration of figure 3 and was used in the field test. In the test the Intelligent agent-platform was implemented as a top layer on the existing building management system.

In figure 3 is the agent structure projected on different levels of a building. 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*.

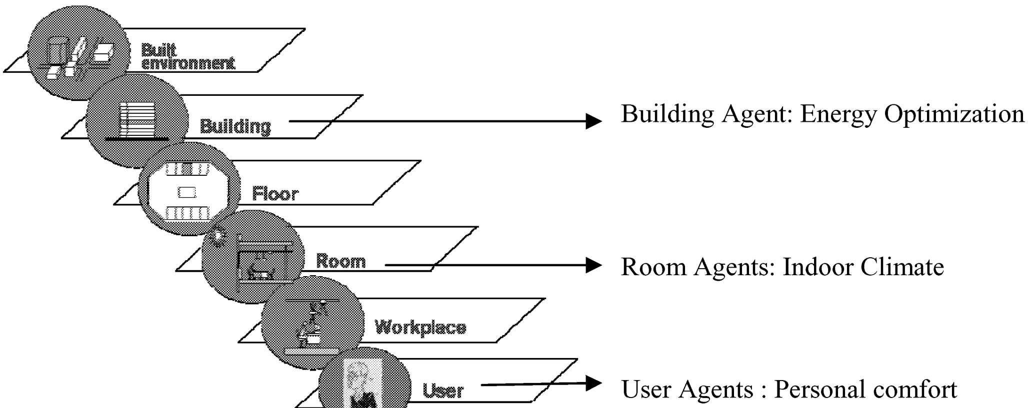

Figure 2. At 3 levels agents are implemented: User agents for employees, Room agents for climate control of each room, and a Building agent for energy optimization.

The *User 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 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 (Fanger 1970) model predicts user's evaluations of the indoor climate in buildings.

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.

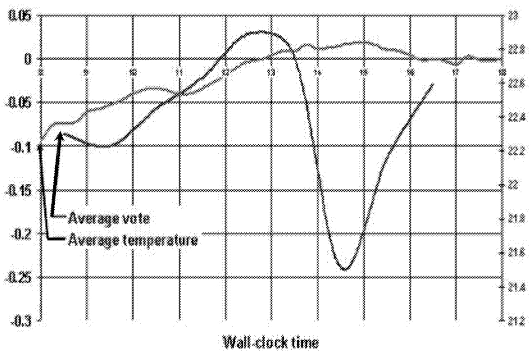

Figure 3. Average vote for adjusting the optimal Fanger comort room temperature and average room temperature during a summer day, with the present room temperature right and the resulting temperature adjustment left (Jelsma et al. 2002).

SEBOS optimization applies a pre-emptive, forward looking strategy using intelligent agent technology. A complete description can be found in (Kamphuis et al. 2002). In figure 4 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.

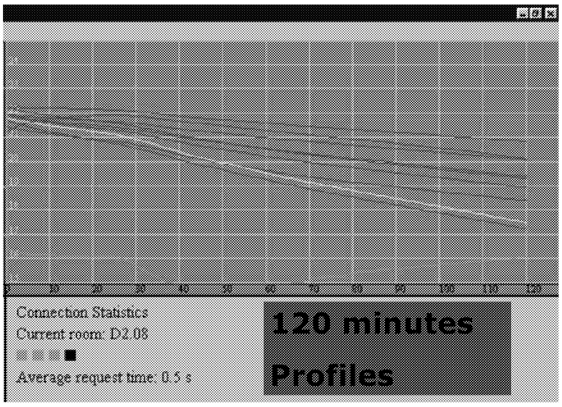

Figure 4. Different individual temperature comfort profile predictions for the next 120 minutes with different current individual setting.s

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 temperature levels beyond the really desired levels. So small adjustments have to be made again and energy is lost.

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 5 shows the new user interface and the integrated user-agent. It allows personal control through individual setting, information and individual feedback. The *Room-agent* controls on basis of the SMART-set-point of figure 5, 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.

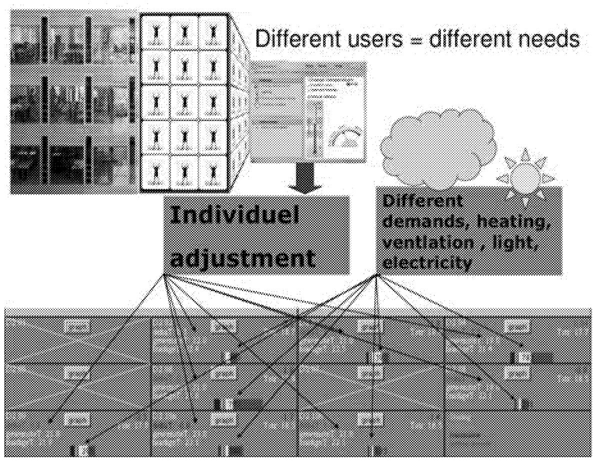

Figure 5. Individual adjustments and different energy demands for each office room is shown on the computer screen (Hommelberg 2005)

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 6.

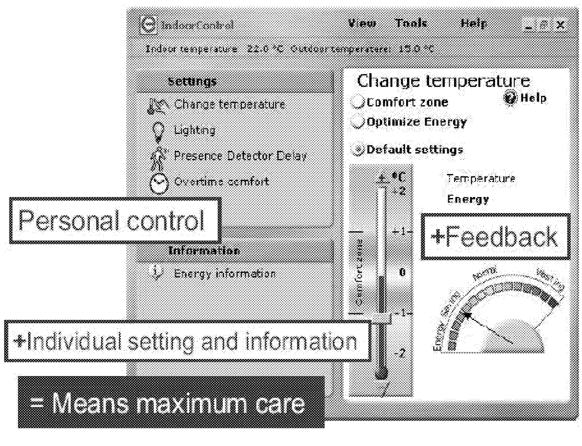

Figure 6. User interface on Personal Computer

4. PRESENT RESEARCH

After the EBOB and SMART/IIGO research a new project was started with the focus on structuring comfort and energy demands on all the different levels of abstraction in the built environment from building to user.

During this project individual comfort profiles were determined based on questionnaires which were filled in each hour by the occupants of the Kropman Utrecht office building. All answers were scaled on a scale from 1 till 7 according to the ASHRAE scale for comfort (Humphreys and Hancock 2007). Figure 7 shows the results of the comfort questionnaires. In total 18 persons were asked to fill in the questionnaires every hour during one full working day.

		Temperature preference								
		8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00
1	BG	0	0	0	0	0	-1	0	-1	1
2	BG	-1	-1	0	-1	-1	0	0	0	0
3	BG	0	0	-1	0	0	-1	0	0	0
4	BG	0	1	0	0	0	2	0	2	2
5	1e Zuid	0	0	0	0	0	0	0	0	0
6	1e Zuid	2	1	0	0	0	0	0	1	1
7	1e Zuid	0	0	0	1	0	-1	0	0	0
8	1e Zuid	0	-1	0	0	0	0	0	0	0
9	1e Zuid	0	0	1	-1	0	2	0	0	0
10	2e Noord	1	1	0	1	1	1	0	0	0
11	2e Noord	0	0	1	0	0	0	0	0	0
12	2e Noord	0	0	0	0	-1	1	0	1	1
13	2e Noord	-1	0	0	0	1	1	1	1	1
14	2e Noord	0	0	0	0	0	1	0	0	0
15	2e Zuid	0	0	0	0	0	1	1	1	1
16	2e Zuid	2	1	1	0	0	0	0	2	2
17	2e Zuid	-1	-2	-3	-2	-2	-1	-1	-1	-1
18	2e Zuid	1	0	0	0	0	0	0	0	0

Figure 7. Results questionnaires personal preferences to temperature comfort (Noom 2008)

The results of the questionnaires can be used to make comfort profiles of the individual occupant, see figure 8. Clearly it can be seen that there are large individual differences. An important factor connected to the individual differences is the different clothing of persons. Correcting the preset temperature setting to the actual average clothing factor, leads to a much better perceived comfort, see figure 9.
The optimized preset temperature setting combined with the individual comfort profiles for the users leads to an energy saving of around 5%.

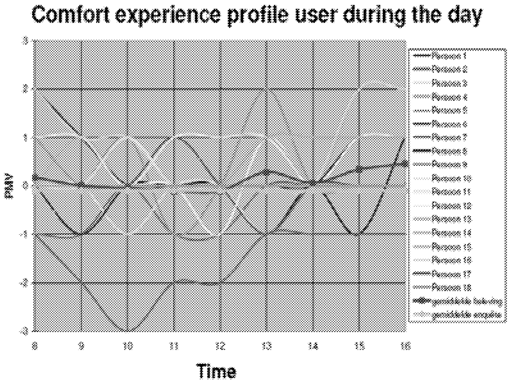

Figure 8. Individual comfort profile users during the day (Noom 2008)

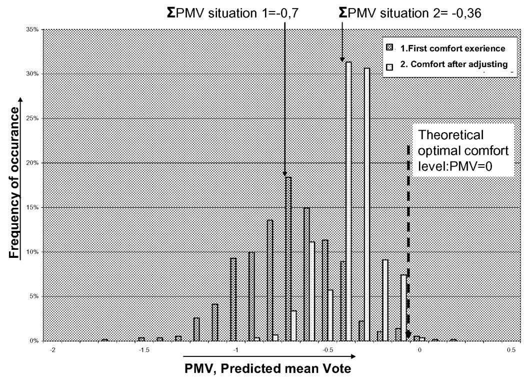

Figure 9. Result of adjusting the overall comfort control strategy(Noom 2008)

5. DISCUSSION

Users opinion is central in this research;

- perception of indoor climate is important for determining whether users are comfortable.
- it is important to look at possible gains from the interaction with the intelligent agent system.

The number of questionnaires completed in the office building is far too low to have significance and produces only semi-quantitative results. Still these results show remarkable individual differences between the occupants during the day. These individual comfort 'profiles' can be used to model the agent behaviour representing the individual occupant accordingly.
At present the Individual Comfort application is only partly tested. It will be further developed within the follow-up project **Flex**(ible en)**ergy**.

6. CONCLUSIONS

The concepts developed in SMART-IIGO have shown to be applicable in an actual building configuration. Individual controls at the workplace should be incorporated in the *workplace-agent.*

The *intelligence* of each agent can be further enhanced, for example more complex building models for use in the *Room-agents* gives better predictions.

Present energy efficient technology is not sufficient to further reduce the energy use of buildings. The individual comfort profiles of occupants during the working day can be determined and used to improve modelling of individual differences. New comfort control technology, such as intelligent agent process control, offers possibilities to implement these comfort profiles to further reduce energy consumption of office buildings while improving comfort at the same time. In order to optimize the comfort/energy ratio of each user, further research is needed into translation of user needs to the optimal setting of the overall comfort system. This will be one of the main topics of the Flexergy (Kamphuis & Warmer 2008) in which different solutions will be developed for the different levels of conditioning of user, room and building

ACKNOWLEDGEMENT

SMART, IIGO and Flexergy were financially supported by SenterNovem.

REFERENCES

Akkermans H. (2002). *Being Smart In Information Processing. Technological And Social Challenges And Opportunities*, Proceedings IFIP IIP2002

ANSI/ASHRAE (2004). *Standard 55-2004*, Thermal Environment conditions for Human Occupancy.

CRISP (2002). Distribute Intelligence in Critical Infrastructures for Sustainable Power, *rapport ENK5-LT-2002-00673*, Energy Research Center The Netherlands, Petten.

Diane J. et al (2004). *Smart Environments: Technology, Protocols and Applications, ISBN 0-4715-448-5*, John Wiley & Sons, New Jersey

Fanger P.O. (1970). *Thermal Comfort*. Copenhagen: Danish Technical Press.

Hommelberg M. (2005). Careful Building, Master thesis, Technical University Eindhoven, Eindhoven.

Humphreys M.A., Hancock M. (2007). *Do people like to feel 'neutral'? Exploring the variation of the desired thermal sensation on the ASHRAE scale*, Energy and Buildings 39 (2007) 867-874

ISO (2005). *Standard 7730:2005*, Ergonomics of the thermal environment, analytical determination and interpretation of thermal comfort using calculations of the PMV and PPD indices and local thermal comfort criteria

Jelsma J., Kets A. , Kamphuis I.G., Wortel W.(2002). *SMART work package Final Report*, Energy Research Center The Netherlands, Petten

Kamphuis I.G., Warmer C.J. and Dok, D.H. van , (2002). *SEBOS, A SMART Enhanced scope Building Optimiser Shell, Functional and architectural description*, research report ECN-CX—02-102, ECN Petten.

Kamphuis I.G. et al (2006). *IIGO: Intelligent Internet mediated control in the built Environment: Description of a large-scale experiment in a utility building setting*, Energy Research Center the Netherlands, Petten

Kamphuis I.G., Warmer C.J., 2008, *Flexergie, Agent based optimalization of energy use in buildings; Inventory of existing project approaches, functional requirements and preliminary field-test implementation mechanisms*, rapport Energy research Center the Netherlands ECN-1-08-000.

Noom P. (2008). *Het individu leidend; Een omgekeerde benadering van het thermisch comfort ten behoeve van de gebruiker*, (Dutch), MSc thesis TU Eindhoven

Olesen B.W., Brager G.S. (2004). *A Better Way to predict Comfort, The new ASHRAE Standard 55*, ASHRAE Journal August 2004, pp. 20-26

Weiss G. editor (1999). *Multi-agent Systems, a Modern Approach to Distributed Artificial Intelligence*. ISBN 0-262-2320-0, Cambridge Massachusetts, MIT press

Wooldridge M., Jennings N.R.(1995). *Agent theories, architectures and languages: A survey,* Intelligent agents, series Lecture Notes in AI Vol. 890, Springer Verlag Berlin