Learning about smart systems for comfort management and energy saving in office buildings

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Abstract

Implementing innovative agent technology-based smart systems in office buildings show promise for combining the saving of energy and cost-effective building management with enhanced comfort of individual office workers. We studied a field test of such a system in an office building in which users were offered opportunities to optimise their comfort together with an option for saving energy by an interface on their personal office computer. Design of the building, design of the Smart system, together with attitudes, actions and experiences of test users were studied by combining different methods. Our research carried out before and during the test revealed that initial expectations were not met. The frequency of Smart use for comfort management appeared to be low and users did not understand the energy saving option. Users could not detect any improvement of comfort.

For analysing the findings gained during the field test we introduce the concept of *design logic* and *use logic*. We demonstrate that the mismatch between these logics caused loss of control of Smart agents and introduced ambivalence for users. On the basis of this analysis we conclude that – despite having some minor shortcomings – it was not the design of Smart proper that explains its poor performance, but the clash of logics. Implementation of smart climate systems for buildings can be improved, and unwelcome outcomes avoided, by analysing and comparing such logics early on, i.e. in the design stage.

Introduction

Existing control systems for public and commercial buildings under-utilise new technical opportunities that emerge from computer networks which become increasingly fine-meshed. Especially in organising access to distributed generation and calculation capacity, the utilisation of existing potential is generally far from being optimal. At the same time, information that is or can be made available through networks- such as Internet and power lines - is seldom exploited fully to enhance the performance of such systems in terms of optimising comfort, energy efficiency and costs.

To improve this situation, a new generation of control systems is being developed for use in the operation of public, commercial and residential buildings. The technology of these systems will be based on agent mediated communication over local networks, the Internet and power lines. Though there is no agreed upon definition, agents most commonly are described as autonomous and intentional pieces of software capable of searching and sorting information to carry out certain tasks for the users they represent (see e.g. Wooldridge and Jennings 1995). In a multi-agent system, agents communicate and negotiate with each other by a shared communication language. In a setting of a multi-agent comfort management system, agents should know the comfort preferences of the users they represent, and they must be able on their own to gain the information needed to realise these preferences in negotiations with other agents representing other users and energy consuming devices and processes. Such novel control systems not only should improve the performance of the building, but should also offer opportunities to users (i.e. building operators as well as residents and workers) for linking comfort management with improving energy efficiency and the application of renewable energy. Along with energy saving, cost saving could be reached by automated selling and purchasing of energy through agent-mediated electronic marketplaces (Kamphuis et al., 2001). Promotors of such systems claim that dynamic online steering of building management could save up to 20% of energy (Broertjes et al., 2000). For application in utility buildings, the inclusion of options for individual comfort management is seen as an important feature to make such systems attractive for end users, i.e. as a guarantee that optimising in terms of energy efficiency and costs is being made dependent on the comfort preferences of occupants.

From 2000 until 2002, an explorative project called Smart has been carried out at the site of the Energy Research Centre of the Netherlands (ECN) near Petten, The Netherlands. The general objective of this project was to formulate requirements for such new control systems, and to gain experience about implementation of such requirements in an experimental setting. The experience to be gained was not restricted to technical matters only. In fact, a salient characteristic of the project was its reflexivity towards 'wider' aspects and an eagerness for experimenting and learning. Awareness of the project's sociotechnical character was shared by its participants, and reflected by the diversity of backgrounds represented in the design team. It was also baked into the project plan, part of which was directed at analysing design questions *per se*. In addition, right from the start, aspects of use were explicitly included in the development of system requirements to be explored in the field test. In enrolling users, the Smart system had to compete with provisions for climate control that were already present in the building in which the system was tested. These provisions had been shaped according to a logic that differed much from the logic behind Smart, and were entrenched already in the practice of users. In this situation, the Smart project had little chance to prove the system' s strengths. Just in this quality, however, the project offered a unexpected and unintended setting for studying the implementation of a new technology in a hostile environment. For this study we choose to try out, within a new empirical domain, the capabilities of a theoretical vocabulary inspired by semiotics of explaining what happened[1]. Seminal articles and books in which this vocabulary is introduced can be found in the bibliography (see Akrich 1992, Akrich and Latour 1992, Jelsma 2000, Rommes 2002).

In the present paper we can only highlight the most salient outcomes. Elaborate accounts of the project and its outcomes have been published elsewhere (Jelsma 2001, Jelsma et al. 2002).

Approach

Semiotics conceives of designing as a process of tunnelling, in which the number of possible choices gradually decreases as the structural features of the object designed take shape along a ladder of ‘translations’. The resulting material structures can be seen as actors or agents having the task to guide the behaviour of other actors, human as well as nonhuman. For instance, chimneys and shafts have to lead air molecules in directions meant by the designers, wires and switches have to guide electrons etc. That is, the structural elements translated into hardware or software form a network of enablers and constraints for configuring the traffic of actors that is perceived as essential for the functioning of the object designed, such as a building or a smart optimiser. These structural elements are the reification of scenario’s the designers have in mind with respect to the working of the object or system. Thus design can be conceived as a gradual process of *inscription* of ideas, views and ideals of designers into a coherent material order consisting of a great number of structures that act out *scripts*. A script is a thought-out material construct intended to exert specific forces on the actors who use it. For instance, a curve in a corridor forces you to change the direction in which you walk in accordance with the intentions of the building designers. These scripted structures do the real work after the designers have retreated. Scripts *prescribe* –with more or less force- the actions of other actors who pass through them by enabling certain behaviour while constraining other (see Jelsma 2000).

We developed another pair of notions we estimate to be useful for the analysis of design and use processes, i.e. *design logic* and *use(r) logic*. We define design logic as the shared logic underlying design scenarios according to which the resulting object or system is supposed to work as intended by the designers. It is the inscribed texture of reasons why the design is as it is. Design logic is a mental and a social thing at the same time. It is the outcome of a social process, of the negotiations between different actor logics brought to the design team by its members. In the case of a building these are architects, client, energy advisor, engineering consultants etc. These actor logics consists of a more or less consistent framework of different elements, such as:

- goals (the actor wants to realise);
- interests;
- values, ideals;
- professional views and approaches (paradigms);
- perceptions (e.g., of other actors) etc.

In designing a building, the actors have to accommodate their different logics while developing shared design logic. If there is convergence between actor logics from the beginning, this will help the process of accommodation.

Use(r) logic is the patchwork of conscious and unconscious intentions, interests, values, rules, habits, attitudes etc. that guides the user in the practice of using a product of design. Logic of users is expected to vary by difference in sex, age, education, profession, culture, lifestyle, the setting of use etceteras.

Depending on what happened during the design process, the scripts coming out of a building design may, deliberately or unintentionally, support or counteract the logic of the users of the building. To give an example, the design logic of construction engineers often results in the construction of

1. Semiotics, the theory of signs, has been further developed and applied within science and technology studies to describe and understand the building of order and paths out of an indefinite number of possibilites; i.e., how a particular technological trajectory becomes priviliged (Akrich and Latour 1992).

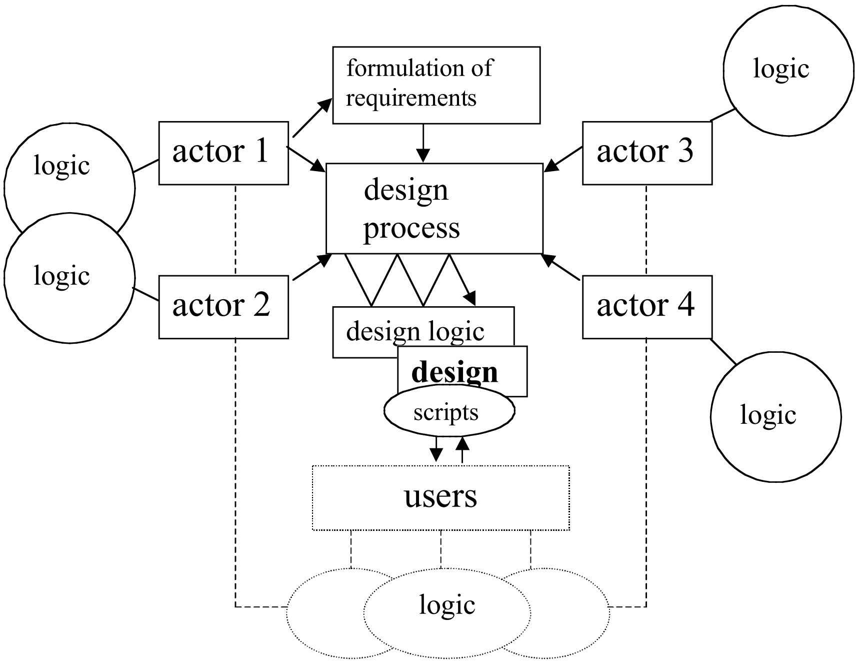

Figure 1. Summary of the approach showing the relations between the concepts used. *Users and their logics may be represented in the design process through other actors driving this process (see dotted lines).*

buildings that are shut tight to control internal conditions. However, such buildings counteract use logic, since a solid body of research in buildings demonstrates that users want to be able to open windows. In such cases, there is a conflict between design and use logic that can lead to trials of strength between users and building operators. A good design practice is alert to anticipate such conflicts. That is, in a good design process there is influence by users, either by direct participation or consultation of users, or by representation. In the latter case, the designers think for the users, i.e. they apply conscious or unconscious *user representations*. They construct users on the basis of their own expectations which can be more or less empirically informed.

The approach is pictured in Figure 1.

On the basis of this approach, the design logic underlying building 42-1 has been reconstructed in the first part of the project. This reconstruction started by first mapping the separate logics of the actors participating in the design of the building, followed by the actual reconstruction of the accommodation of these logics in a shared design logic (for details, see Jelsma 2001). The mapping of the actor logics, and the reconstruction of the design logic has been carried out on the basis of documents and face to face interviews with the actors involved in the design process.

Research questions and methods

Taking into account the foregoing approach, the following questions were formulated at the outset for leading the study in the second part addressing the field test of the Smart system:

- How were users represented by designers, which assumptions did the designers make about the logic (preferences, views, attitudes, values) of users, and how were these translated into the design of the Smart system?
- How did interactions develop between the test users and the provisions for comfort management (Smart system and the existing building provisions)? Did any new practice or routine develop, and how was it being shaped? How did the use of Smart relate to the use of other provisions for comfort management?
- Which forms of user logic underlie relevant user preferences, attitudes and actions?
- How did users assess the Smart system in terms of visibility, reliability and performance?
- Were there any misfits between the logic of the system and the logic of the users than should be repaired in the next version of the Smart system?
- To find answers to these questions a varied set of research methods and instruments was used including questionnaires, personal interview, group interview (a weak version of a focus group), contextual interviews, participant observation and a brainstorming. Findings from the group interview and contextual interviews were cross-checked by questionnaires and vice versa. By this broad approach we gathered a large amount of various data of which we can only highlight a limited set in this paper (for details, see Jelsma et al. 2002). The research was carried out in two phases, i.e. a preliminary investigation before the introduction of Smart (serving mainly as a reference) and the study of the use aspects proper[2].

2. For practical reasons, it was impossible to work with a control group.

System, test site and test users

The original objective of the Smart system was to provide technical possibilities for delivering optimal comfort to individual users in an office building while taking into consideration user awareness about sustainability and energy saving, and to improve cost effective building management by selling and buying energy in electronic marketplaces. The technology of the system was based on agent-mediated communication schemes. Heart of the system was the software of an optimiser shell around the existing building management system. By using algorithms this shell processes information coming from outer sources (such as the Internet: energy prices, weather forecasts) and inner sources (comfort preferences entered by users, data from sensors reporting about equipment). In this optimising process software agents negotiate for the real actors to calculate an optimal comfort against optimal prices. Users can give way for saving of energy by allowing the system a wider bandwidth for optimising comfort (for details, see Kamphuis et al. 2002).

Mainly for reasons of public relations, Smart was implemented and tested on the second floor of a new and innovative multi-purpose building at the ECN site. Designed as a showcase of sustainability, the building has leading edge energy technology well integrated in its architecture. For instance, a huge curved roof consisting of steelblue solar energy panels covers the central hall and dominates the building' s appearance. Further, to avoid mechanical cooling, the principle of summer night ventilation has been applied. This implies that the building mass -which is larger than usual to act as a buffer- is cooled after a hot sunny day by passive ventilation during the night. For this purpose, various ventilation shafts have been included in the building design. Cool night air enters the building through ventilation valves above the windows. These valves can also be used for additional ventilation during the day (the windows can not be opened). The decision to choose this building as the test side for a new high tech comfort management system was taken while the construction of the building was nearing completion.

Blowing in air, which is being heated on cold days, centrally ventilates the building in the daytime. Due to the fact that the building is very well insulated, the central heating is only in operation a few hours a day during autumn, winter and springtime[3]. Electric convection heaters in the ceiling can adjust local heating levels in places that are too cold (close to windows and corridors). Before the introduction of Smart, the building operators set the temperature of the blown-in air as well as the local heaters' temperature. By setting a room thermostat, workers on the office floor could adjust the temperature per block of 8 ceiling heaters within the range set by the operators (plus or minus three degrees). They also had the possibility to open the valves above the windows to increase the ventilation level within the building (for a more extended description of the design of the building and its provisions, see Jelsma 2001).

During the fall of 2001 this new building came into use. About thirty employees of the Shared Service Centre, the central administration unit of ECN, moved into the building and started their work on the first floor. The floor was laid out as an open-plan office space, with clusters of desks separated by low fences. The Smart system was introduced about six months later (in April 2002) when the office workers were well accustomed to the building and its provisions. The field test with the system lasted from the end of April until early in June 2002. Since Smart interferes with the heating system the test was originally scheduled in the winter season but because of technical problems (see below), the test had to be delayed.

The Smart system was briefly introduced to the unit's employees by an e-mail announcing the preliminary investigation. In this e-mail the employees were invited to join as test users and to collaborate in the test. Handing out the questionnaire for the first phase was used as an occasion for some further explanation of the system and its test. About two months later, a next e-mail announced the actual introduction of Smart indicating how the employees could log in on the Smart screen by using their desktop computers. This screen supplied the interface by which test users could interact with Smart, mainly to enter comfort preferences (see below). Only at the end of the test it appeared that a few employees had not been able to get access to Smart. However, the large majority of them (about 25 persons) used the system and participated in different parts of the investigation.

It is important to emphasise here that Smart was offered to test users as an additional, electronic option for handling comfort in their work environment. The mechanical equipment already present -such as the thermostat and the ventilation valves- remained available to them during the test.

User representation in design

For a long time, it remained unclear which department would move into the new building in which Smart was to be installed and tested. This undermined the aspiration of the design team to involve end-users from the very start. Nevertheless, designing Smart needed an image of its future user to be made explicit and to be fed back into design decisions. We focus on four design issues to give an impression how the design team developed user representations to be inscribed into the Smart system.

USER HETEROGENEITY AND DISTRIBUTION OF AUTHORITY

The use context of the Smart-test differs from systems developed for in-home comfort management systems such as early applications of COMFY (Boertjes et al., 2000). Within the home the roles of user and manager/operator coincide. In an office building, these roles are separated. Therefore, the Smart system had 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. Only the first user group was represented personally in the design team. In view of the

3. The temperature of the air blown into the building is set according to a water heating curve in which seasonal variations are included. Above a certain level of complaining by occupants of the building, operators may deviate from the temperatures the heating curve prescribes.

small size of the test population, further heterogeneity among the end-users was not explored. The distribution of authority and competence between both user types had to be inscribed in the software of the Smart system, so it needed attention to be given in the design process. The distribution inscribed had to reckon with the authorities, responsibilities and interests of both user groups. As a result of the deliberations within the design team, the system's design was subordinated to the existing management logic. I.e., the building operators should control all aspects of cost management (such as energy trading), and would set bounds to the comfort preferences that end-users were able to enter into the system. Since energy efficiency is an aspect of sustainability that users might want to promote, but also one of cost saving for the employer, the team's general opinion was that saving energy should be an option that users could choose to use or to neglect.

End-users were represented in the design of the Smart system in the first place by a standard derived from the Fanger doctrine. Fanger, a Danish researcher, developed a complicated formula relating empirically derived parameters of perceived thermal comfort in buildings such as air temperature, humidity, draft and clothing of test persons. Using this formula, the percentage of dissatisfied users can be predicted for a given set of comfort parameters (Fanger, 1970). Buildings are designed such that they are capable of providing a comfort level at which no more than 10% of all users will complain about the comfort they perceive. This 10% comfort level - called predicted mean vote, PMV- is a standard value laid down in the ISO standard EN 7730 (Fanger, 1996). The Smart designers inscribed this standard into the Smart system, i.e. Smart determined the comfort level in a given period by comparing the actual comfort (calculated on the basis of measured values of the Fanger comfort parameters, see above) with the PMV. Thus there was a chained representation here: one could say that the designers acted as spokespersons for Fanger who acted as a spokesman for the end-users.

ENROLLING END-USERS

The first thing the Smart system must achieve is recruiting users. The system's force to enrol end-users can be dosed by varying the openness of its script:

- *Open script*: users have to activate the system themselves.
- *Half-open script*: the system offers it service to users automatically (for instance, with regular intervals the Smart interface pops up) but users may switch it off unused.
- *Closed script*: the Smart interface pop-up screen will only disappear after the user has entered preferences[4].
- The definitive choice between these options was postponed to a later stage. Due to heavy time constraints in the last stages of the design trajectory, the first option was implemented for pragmatic reasons. The weakness of this script contributed strongly to the relative invisibility of the system to users (see below).

SERVING INDIVIDUAL USERS BY SHARED EQUIPMENT

Especially the open-plan character of the office room was an issue of concern, i.e. finding solutions for serving *individuals* within the constraints of the present script of the building, i.e. in an environment of *shared* technical equipment for creating comfort in an open-plan office environment. The solution sought was to define five thermal or comfort zones in which the temperature could be regulated more or less by bringing the settings of the ceiling heat convection units in each zone under the control of Smart. In the kind of hybrid environment present, three options for representation of end-users in the design of the system were distinguished:

- *As a group* in a climate zone. After negotiations the group enters its preferences into the system. That is, negotiations about preferences are delegated to the group.
- *As individuals*. Individuals enter their preferences into the system, which then calculates and implements an averaged solution. In this case, negotiation between individual preferences is delegated to the system and is invisible to the users.
- *As individuals in a group*, i.e. a combination of option 1 and 2. End-users are conceived as individual group members who must be enabled by Smart to consider the choice made by other group members in making their own, and so influence the outcomes of the choice process in terms of thermal comfort acquired. This requires the system to make the choice process transparent to the group members.

After appraising the merits of all options the design team came to the following conclusion. Option 1 would water down the goal of Smart too much. Moreover, negotiation within the group might lead to conflicts. Option 2 kept the suggestion of individual comfort management alive for end-users, but in reality the preferences entered individually are thrown into an electronic melting pot hidden to the users. This might undermine the confidence of users in the system. Therefore, from a user perspective, option 3 was to be preferred, but probably was the most complicated option to realise technically. Inspired by a pilot study with a similar system (the DUCOZT system, see Oseland et al., 1997), the team decided to realise option 3 by developing an individual voting system for Smart. The voting system implied that every user in a thermal zone could 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. A user interface materialising this idea would look like this (cf. Oseland et al.):

Previous requests in your zone:	
warmer	63%
no change	13%
cooler	25%
time to next vote:	15 mins
current time	10.15

4. A pilot study with the smart DUCOZT system revealed that a majority of the end-users (69%) preferred option 2 (Oseland et al., 1997).

ENERGY EFFICIENCY

To generate ideas about the design question how Smart could promote the saving of energy by changing behaviour of users, a brainstorm session with internal experts was held. The discussion at this meeting revealed the following opportunities and constraints for an energy saving feature to be effective:

- Considerable saving of energy is delegated to the building itself, i.e. the building is energy efficient by design (see below and Jelsma, 2001). This implies that little opportunity for saving energy is left to users, which may undermine efforts to do so.
- In a utility environment, the saving of energy does not reward users but the employer. Users loose nothing by neglecting energy efficiency.
- Experience in the home environment demonstrates that support for extra behavioural effort to save energy is low; only 10% of residents are motivated to do so.
- Energy is only a small share of the costs faced by the employer. Due to productivity loss, dissatisfaction about comfort is a much more costly risk run by increasing energy efficiency.
- Giving feedback, i.e. confronting users with long-term developments in energy consumption generally increases awareness, which generates incentives for saving energy by changing behaviour. Goal setting may help consumers to maintain incentives over a longer period. Here again the question arose whether results found in a setting of households would apply in a work environment.

Part of the experts' low expectations about the potential for energy saving in the office stemmed from the realisation that comfort levels were already tuned to user needs by the Fanger criteria on which the building's central comfort management was based. Complaints by office workers more or less forced a further fine-tuning of the system to user needs. During the session, the building manager present indicated that, for an operator, the easiest way to satisfy complaints about cold is to raise the building temperature. Those who are getting too warm then may open the window. In this way, an optimum comfort is realised which users will not give up easily, he thought. However, this practice leads to an average temperature in ECN buildings close to 23 degrees C, a temperature considerably higher than most workers were expected to have at home. The experts agreed that in this temperature difference a considerable potential for saving energy is looming, since a 1-degree decrease in room temperature implies a 10% saving of energy consumption. Behavioural change supported by Smart could support an ECN-wide policy setting targets for bringing down office temperature. Smart could help in giving feedback to users about their contribution in catching these targets, some experts argued. This approach could be successful only if the employees could be convinced to participate, and such participation would be voluntary. The latter condition is difficult to realise in an open-plan office setting. It was decided that the participants in the Smart-test would be consulted about such an initiative.

Smart field test: main outcomes

During the field test, logging with 15 minutes intervals took place of data relating to voting behaviour and the behaviour of the building (room temperature, switching of sensors etc.). Comfort perception and routines of the test users relating to comfort management and the possible changes therein after the introduction of Smart, were investigated by questionnaires and interviews. The test users were also questioned about their attitude toward the Smart system and about the comprehensibility of the system and the interface.

The logged voting behaviour of the population in the different climate zones is shown in the following table.

The trend in the votes averaged over all days of the week, and the average temperature curve are depicted in Figure 2 for one climate zone (north). The latter curve indicates that the building has no constant air temperature over the day, but heats up gradually in the course of the day reaching its highest temperature in the early afternoon. This up-going trend in the daytime temperature more or less explains the average voting pattern. Starting from 9.30 a.m. on, a trend of voting for a warmer climate can be discerned (i.e., for an increasing number of voters the comfort perception is 'too cold'), though in the early morning the building is perceived as too warm (in the early hours, the majority of voters votes for 'colder'). From around 13.00 p.m. this trend turns into the opposite, i.e. during the afternoon hours the voting pattern indicates that the comfort perception of an increasing number of test users is 'too warm'. In Figure 3 the average voting patterns are split into patterns for separate days of the week (Monday until Friday). The Monday-pattern is exceptional in showing a strong tendency in the voting behaviour expressing a preferred increase in temperature in the early morning. The afternoon-peak in votes for 'colder' appears to be delayed on Monday. These outcomes suggest that there is not only a pattern of rising temperature over the day, but also over the week. The week pattern indicates that the building is not cooling down during the night toward the

Table 1. Distribution of votes per climate zone during the test period.

Climate Zone	Possible Voters	Actual Voters	Votes	Too Warm	Equal	Too Cold
West	2	2	2	0	1	1
East	7	5	18	13	1	4
North-West	2	2	10	3	2	5
North-East	5	2	5	3	0	2
North	7	7	63	38	10	15

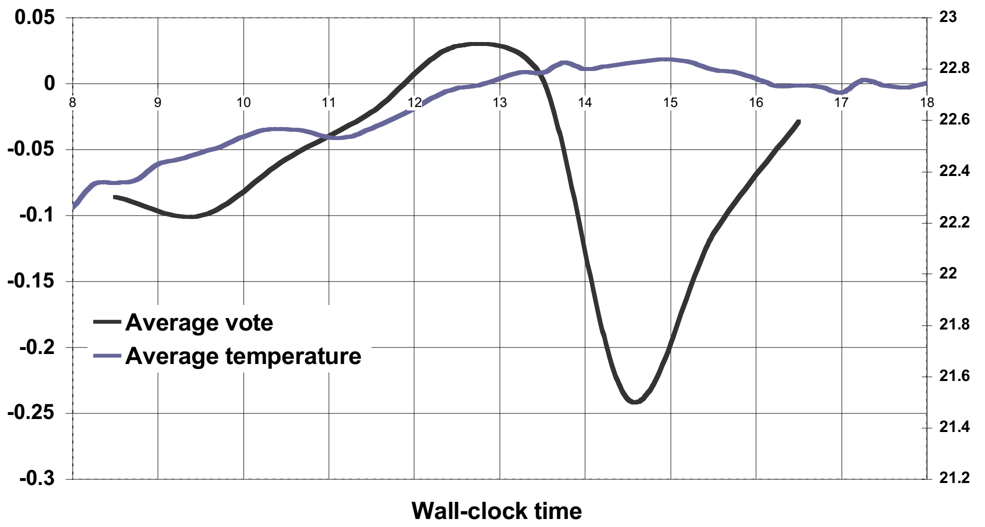

Figure 2. Average voting behavior north segment and average temperature. L*evel 0 (left-hand scale) means that the number of votes for 'cooler' equals the number of votes for ' warmer' at a certain moment in time. The right-hand scale indicates the ambient air temperature in degrees Celsius.*

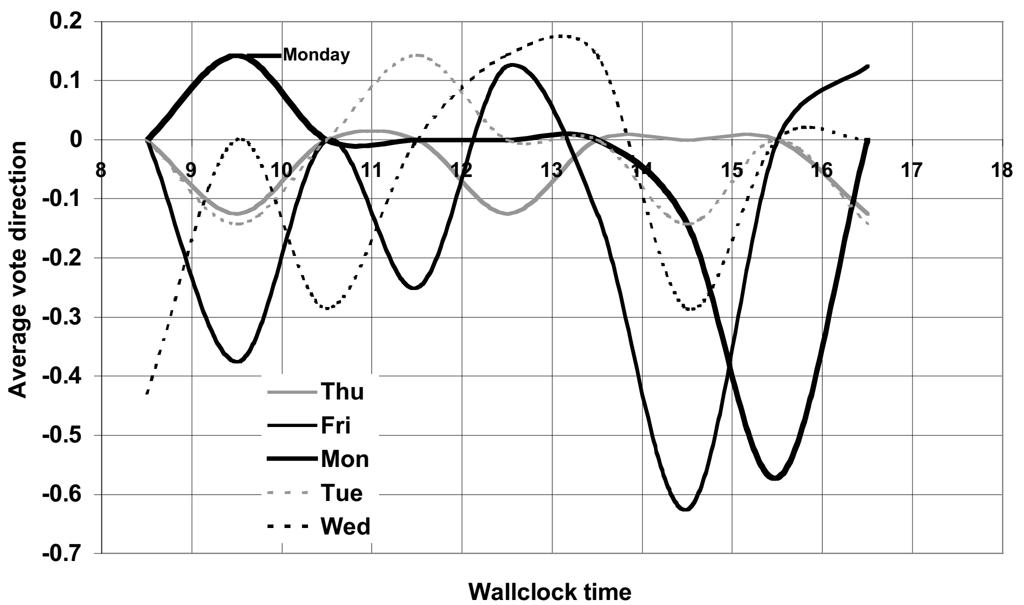

***Figure 3.** Average voting behaviour per weekday.*

same level as the one it starts from in the early morning when the heating is switched on. Only on Monday, after being cooled through the weekend, the building has reached a temperature that is generally perceived as too cold in the morning. The voting patterns of the other weekdays are not completely consistent with a gradual heating up of the building in the course of the week, however.

For the eastern zone, with fewer voters, comparable trends were observed. The Monday pattern, with its characteristic morning 'too cold' peak and its shift of the 'too warm' peak in the afternoon was seen here as well. The data on the overall voting behaviour and the temperature measurements is consistent with the responses of users to the questionnaires. The ambient air temperature indicated by respondents as the preferred one (19 ± 0.8 degree Celsius) differed considerably from the measured temperature in the office room (22.8 degree C in the early afternoon, see Figure 2, T-average curve). This difference was consistent with (i) respondents' reported perception of the building's climate being rather too hot than too cold, (ii) this perception becoming stronger during the day, and (iii) the fact that about a quarter of the respondents indicated that they used to wear less clothes in the office than they did at home.

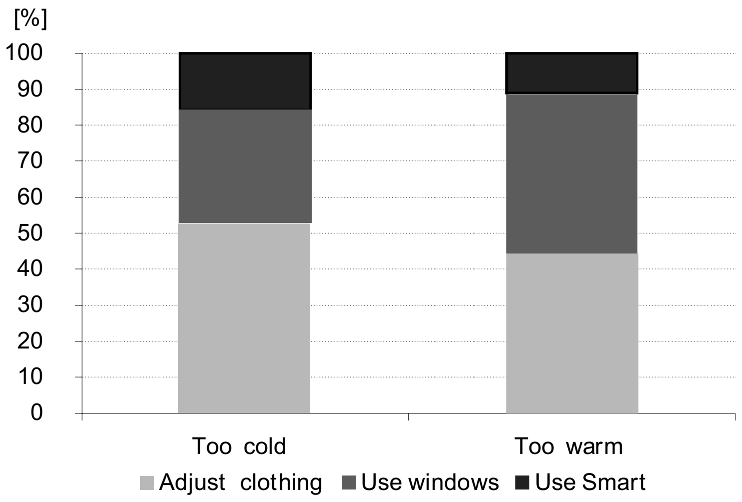

Figure 4. *Actions taken first for adjusting thermal comfort.*

Table 1 makes clear that Smart use was low: 18 out of 23 test users voted only 98 times during the 1.5-month test period. In other words, there was considerable *non-use* of Smart. During the group interview test users made clear that, in most cases, Smart was not the first option they turned to for adjusting thermal comfort. This observation was validated for the larger group of test users by the questionnaire, through questioning about preferences for different routes of comfort management. Route preferences were measured as the regulatory option used first to adjust thermal comfort. That is, test users were asked what they did first if they wanted to adjust thermal comfort in two situations, i.e. when they perceived the climate in the office as too hot or as too cold. The answers given are plotted in Figure 4.

The results indicate that most respondents, when feeling uncomfortable, first adjusted their clothing before they took action to adjust the temperature by manipulating the ventilation valves or turning to the Smart system. These priorities are confirmed by answers to a question on the route preferences being followed in the situation in which the ventilation valves could not be operated [5]. Even in this situation, only 21% of the users indicated that Smart was the first route chosen for managing comfort. When inquired about reasons for neglecting Smart in the first instance, a considerable part of the respondents answered that they deemed the other routes more effective, whereas they also attributed considerable influence to routines for comfort management already established before the introduction of Smart. The data further indicated that almost half of the respondents who did use Smart to regulate thermal comfort did not notice any effect of such action.

While entering their comfort preferences by the Smart screen the test users could indicate that energy should be saved by ticking the box 'energy efficient'. The group interview made clear that not any of the interviewees ever used this option. This outcome was confirmed by answers in the questionnaire: more than 80% of the users said they did not tick the option 'energy efficient' while entering their comfort preferences. The group interview revealed further that test users were puzzled not only about the way the option 'energy efficiency' might work, but also were wondering what happened when several users within the same segment entered different comfort preferences into Smart within a certain voting period. By taking up questions in the questionnaire we checked both observations. Thus respondents were asked whether they understood what happened when they ticked the box 'energy efficient'. A large majority of the respondents (76%) gave a negative answer to this question. Second, the question was asked whether it was clear to respondents what happened when more than one person voted during a certain voting period in a certain zone. The share of the test population stating either to be unsure or to have no idea about what happened under this circumstance was 38% and 33% respectively, while 27% of the respondents who answered this question indicated to be sure about what happened. In the group interview, participants sketched several tentative scenarios about the way the voting system was supposed to work

Clashing logics

We argue that the disappointing results of the field test can be explained by a triadic clash between the logic of the users, the design logic of the building and the design logic of the Smart system. This argument is based on the following observations.

As reconstructed elsewhere (Jelsma 2000), three principles stand out in the design logic of the building, *flexible use, corrected tolerance* and *no mechanical cooling in ECN buildings*. Flexible use, i.e. adaptability of the building, is an important aspect of sustainability. According to the logic of the designers, demolition should be prevented when the destination of a building changes. Absence of separate rooms was a consequence of this flexibility principle. A second aspect of the design logic is based on learning by doing. After advising on many building designs and by monitoring practice, the designers of the building in which Smart was tested had learned that user acceptation of shut tight building is generally very low. People want to open windows if they feel the need to do so. This inspired these designers to develop a philosophy about building use that could be characterised as being based on a principle of 'corrected tolerance'. That is, users of a building should be offered opportunities to fulfil their needs, e.g. whimsically opening windows, but cannot be relied upon for responsible operation, e.g. closing windows while leaving. Thus provisions such as windows should also be under the control of building operators. Accordance to this philosophy, building operation by users is tolerable as long as the operators can correct it, since rational building operation cannot be entrusted to users.

The 'no mechanical cooling' principle is an element of ECN-wide logic; it stems from ECN's mission to promote

5. Within the test period, the ventilation valves did not work during about a week because of a failure in the electric controls.

energy saving and renewable energy. Thus instead of air conditioning, the concept of 'summer night ventilation' has been implemented in the building. Cooling during hot summer periods is delegated to a system of valves in all facades directly above the windows (see earlier description above). Since the valves are small, they are supposed to cause only small heat loss (in winter) or heat gain (in summer). The valves can also be operated at a distance by activating servo-motors. Sections of valves can be opened or closed by the building operator. This system of dual operation (by users and by operators) can be seen as a technical implementation of the principle of 'corrected tolerance' mentioned above.

In summary, the design logic underlying the layout of the building in which the Smart test was carried out included a conception of users as a *collective* that has to negotiate about the levels and quality of *common* comfort, to be influenced by a few mechanical mediators (two thermostats and the ventilation valves). The rest of the comfort management is delegated to the building itself: its large mass, the ventilation channels etc.. The original logic of Smart is the opposite, i.e. an *autonomous* user who sets comfort deliberately according to his own preferences through an extended number of agents controlling his environment with respect to all comfort parameters, and providing him with precise feedback about conditions realised, energy used and costs made on an *individual* level. In other words, the basic idea underlying the Smart-system constructed a completely different user and neglected the sustainability script which had been already inscribed by the building designers. This clash of logics explains the system's lack of functionality which discouraged use during the field test. For instance, Smart presupposed all structural elements of the building that contribute to climatic comfort to behave as agents reporting to the system about their status. This is because the Smart-system needed this information (with a high time resolution) for calculating optimal settings. The present building design fell short of facilities for such sophisticated reporting to the building operation system. Especially the ventilation valves in the facades were a case in point. These valves did not report their status (open/closed) to the system, so neither monitoring nor manipulation of individual valves was possible by the system. However, the status of the valves was of crucial importance for the generation of drafts across the office floor and thus for comfort perception of users, especially under conditions of high wind pressure on the facades. That is, the Smart logic required a much tighter control of all the agents acting in the system than the building could offer. Further, to keep trusted by users, the system should react quickly and noticeably to comfort preferences entered. The heating units in the ceiling were to slow for this purpose, while the inertia of the building (caused by its large mass) counteracted quick adjustments as can be seen form the air temperature loggings. When cooling was requested (in the early afternoon, as the logging data show), the system could do nothing.

In the design of the building, user logic based on learning was accommodated with a demand for sustainable operation that stemmed from the ECN mission. As explained, 'corrected tolerance' can be seen as a vehicle of such accommodation. From the outset, Smart design was sensitive to user issues too, but failed to take into account that among the test users a comfort management practice (with an underlying logic) already had been developed and shaped that was fundamentally different from its own. Consequently, the Smart system had to compete with a system of agents that was already in place and was perceived by the test-users as functional and controllable (at the cost of a high energy consumption though, as we have shown). Smart was doomed to loose this trial of strength crippled as it was by the incompatibility of its logic with the building logic, the lack of transparency of its own logic to the test users (test users did not understand how the system worked) and its invisibility. Whether the Smart system, with its particular logic of control, can still enrol end users and stimulate them to save energy under more favourable test conditions remains to be seen. The present field test, by its particular setting, was unsuitable to prove this.

Evaluation

Prototype testing of technical systems is generally considered as a technical enterprise that can be handled straightforwardly. What stands out in our case in the first place is the path dependency and the contingency of testing and its outcomes. The first step in this test trajectory, the choice of the location of the test, was very influential for the steps that followed but was not at all taken in view of such consequences. The choice of the test location had political overtones. For the ECN management, it was quite clear that a revolutionary new climate control system should be linked to the shiny office building that just had been finished. This building dominates the site by its eye-catching architecture in which leading edge energy technologies has been integrated elegantly, to reach one of the lowest energy needs among office buildings in the country at that time. A specific drawback of the novelty of the building that no one realised at the moment of choice as a test location was its lack of history. That is the lack of performance data which can be taken as a reference against which possible changes can be demonstrated (e.g. decreased energy consumption) as a result of the introduction of Smart.

After this test site had been chosen, design difficulties quickly started to accrue. Especially the modelling of air streams through the building and calculating the parameters controlling the climate zones required a lot of brain racking. This took a lot of extra time of money. As design advanced, ambitions had to be given up or perished under time pressure. Development of the technical functionality of the system soon prevailed (i.e., getting the system work), and user-friendliness suffered. At the end of the design trajectory, in the early spring of 2002, there was hardly any time left for designing the user interface (the test should take place during the heating season). As a consequence of its poor design, the incomprehensibility –and thus the non-use- of the energy saving option was predictable; in fact this option was given up.

Contingency manifests itself in the occurrence of valuable outcomes that were not sought but came to the fore gradually and unexpectedly. For instance, the finding that the inertia of the building causes heat accumulation during the day (which can only cooled away by opening windows, which is not very sustainable) had nothing to do with Smart but was an outcome of the temperature logging during the test. The unfavourable heat curve of the building that came out started speculation about possibilities to generate a flatter curve during the day by using the Smart system. Reconstruction of the operators' logic underlying the heating regime of the building was another unintended but valuable deliverable of the Smart test. This subject popped up during the brainstorm session which actually had quite another focus, i.e. how to elaborate Smart's energy saving option. It appeared that interactions between the operators and office workers complaining about the building temperature drive up considerably the heating temperature of ECN buildings[6]. Awareness of this high ambient air temperature inspired us to include a question in one of the questionnaires about the room temperature test users prefer. The responses showed a considerable discrepancy (more than 2 degrees C) between the preferred and the real air temperature in the building. This is an important outcome since it may be used to support an ECN-wide policy to bring down temperature in its buildings. If such a policy –to which Smart systems can contribute if matched better to building scripts- succeeds it will deliver considerable savings, in money as well in CO_2 emissions.

Looking back, we can say that the basic objective of the field test, to be an experiment to learn from, has delivered, be it in unintended and unexpected ways. The most important lesson is that design of Smart systems for comfort management in buildings will be easier and more straightforward if the design of such a system is included in the design of the building from the very beginning. In that case, the situation is much more flexible for tuning the logic of the building to that of the Smart system in the design of the technical layout. In those cases in which one chooses to install a Smart system for comfort management in an existing building, we advise to compare the design logics beforehand in accordance with the approach developed in this study. In doing so, designers can make a better estimation of necessary efforts and investments to be made for the development of the system for the building in question. For the selection of test buildings, the presence of a well recorded data-set of past settings and performance of the building's climate system is crucial.

A drawback of the limited functionality of the system and its consequential low frequency of use in the test was that we had scant opportunity to observe and reconstruct user logic in interaction with the system. This hampered our intention to learn about this concept by doing. That is, to test our conceptual and methodological toolkit Smart was not an ideal case. Only the group interview revealed some items to be important for end-users with respect to comfort management systems, i.e. visibility or 'avoidability' of the system , its performance in giving feedback on end-users' actions, its consistency (single instead of multiple routes), its transparency (the voting system), control on and trust in what the systems is doing, and fun in working with it. An intended, but interesting outcome in this respect was the co-production of a heating logic in interaction between operators and complaining users, leading to temperature settings on the expensive side of the PMV bell curve. For a more systematic comparison of design and use logic in terms of related encoding and decoding actions more work needs to be done, however. Nevertheless, we estimate this work to be an encouraging first attempt demonstrating that a semiotic vocabulary holds promise for describing and elucidating the coherence of design and use processes in the technical mediation of comfort management by ICT in buildings.

References

Akrich, M. (1992), *The de-scription of technical objects, in: Shaping Technology, Building Society* (W.E. Bijker and J. Law. eds.), The MIT Press, Cambridge Mass., pp. 205, 225.

Akrich, M. and B. Latour (1992), *A summary of a convenient vocabulary for the semiotics of human and nonhuman assemblies*, ibid, pp. 259-265.

Broertjes, E., H. Akkermans, R. Gustavsson, I.G. Kamphuis (2000): *Agents to achieve customer satisfaction: The COMFY comfort management system*, paper submitted to PAAM-2000, 1-12 April, Manchester.

Fanger, P. O. (1970), *Thermal comfort*, McGraw-Hill Book Company, New York.

Fanger, P.O. (1996), *Moderate thermal environments. Determination of the PMV and PPD indices and specification of conditions for thermal comfort (ISO 7730: 1994)* (see www.annova.dk).

Jelsma, J. (1999), *Domestic energy use, from better behaviour to a better design: an onset to integrated approach*, Novem Utrecht 1999 (in Dutch).

Jelsma, J. (2001), *Smart work package 4.1 final report; The Smart system and its test building: matching design logics*, research report ECN-C—02—008, ECN, Petten.

Jelsma, J., A. Kets, I.G. Kamphuis and W. Wortel (2002), *Smart work package 2002 final report; Smart field test: experience of users and technical aspects, research report* ECN-C—02-094, ECN, Petten.

Kamphuis, I.G., C. J. Warmer, and H. Akkermans (2001), *Smart: Innovative e-Services for Smart Buildings*, paper for ISPLC Conference, Birmingham.

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

Oseland, N.A., R. Fargus, D.K. brown, A.D. Charnier, and A.J. Leaman (1997): *DUCOZT, A prototype system for democratic user control of zonal temperature in air-conditioned offices*, CIBSE 97 Virtual Conference 'Quality for People, pp. 1-15.

Rommes, E.W.M. (2002), *Gender scripts and the internet*, Thesis, University of Twente.

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

6. Ironically the driving force behind this trend is heterogeneity in user comfort preferences for which the Smart system is designed to deal with.