December 2001 ECN-C--02-008

# SMART WORK PACKAGE 4.1: FINAL REPORT

## The SMART system and its test building: matching design logics

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## Acknowledgements
The SMART-project (Smart Building Multi-Agent InteRnet Technology) is sponsored by SENTER within the framework of its BTS-programme. This report is registered under ECN project number 7.6425.04.01.

The author wishes to thank all persons who have been interviewed for this project for their collaboration and patience.

## Abstract
Agent-based 'smart' systems for energy management in buildings are expected to enhance comfort of individual users together with their awareness about sustainability, to save energy and to improve cost effective building management. The study is part of a larger project to design, implement and test an experimental smart system in a recently finished office building at the ECN site near Petten, The Netherlands. The objective of this part is to investigate how the logic behind this experimental SMART-system fits to the properties of the test building in which it has to be installed. The approach chosen is to compare the design logic of the building with the logic of the SMART-system. For this purpose, the design logic is reconstructed on the basis of views of actors having been involved in the design process. These actor views are mapped by taking interviews and studying documents.

The main conclusion of the study is that there is a major discrepancy between the SMART-logic and the design logic of the building in which the system is to be implemented for testing. Both logic constructs their own end users but in different ways. While SMART-logic presupposes end users to practice sophisticated individual comfort management, the present building structures and provisions only presuppose a limited collective management by its end-users. This discrepancy in logic generates specific challenges for designing SMART, and requires considerable extra design efforts which can be avoided if smart systems are included in the design of buildings from the very beginning.

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# 1. INTRODUCTION

Existing control systems for public and commercial buildings under-utilise new technical opportunities emerging from computer networks which become increasingly fine-meshed. Especially access to distributed information and calculation capacity is generally organised in suboptimal ways. At the same time, information that is or can be made available through networks - such as the Internet and power lines - is seldom exploited fully to enhance the performance of such control systems.

The general objective of the SMART-project is to formulate requirements for a new generation of control systems to be used in the operation of public, commercial and residential buildings. The technology of these systems will be based on agent-mediated communication over the Internet and power lines. Such novel control systems should not only improve the performance of the building, but should also offer opportunities for users (i.e. building operators and inhabitants of the building) to link comfort management to energy saving and application of renewable energy. Together with energy saving, cost saving could be reached by automated selling and purchasing of energy through agent-mediated electronic marketplaces (Kamphuis et al., 2001).

One of the more specific goals of the SMART-project is gaining experience about implementation of a number of requirements for such a smart system in an experimental setting. In addition, user interaction with the system will be observed and analysed in order to collect data to evaluate and improve the original system design.

The SMART-project as a whole consists of a number of research and development activities divided over several work packages. For an elaborated project description and work-plan, we refer to the overall SMART-project proposal. The present report is the final report of work package 4.1. The complete list of work packages can be found in Appendix A of this report.

# 2. GOALS OF WORK PACKAGE 4.1

The objective of work package 4.1 is the reconstruction of the design logic underlying the lay-out of the relevant structural elements of the building in which the experimental SMART-system will be implemented and tested, i.e. building No. 42-1 on the ECN site.

The basic idea behind this objective is that the SMART-system can only function by using the structural provisions of the building in which it is implemented. Since building 42-1 was designed and constructed before it was selected as a test site for SMART, the functioning of the SMART-system is enabled and constrained by the existing building characteristics and provisions. This condition is to be reckoned with not only for the technical functioning of the SMART-system, but it may also shape its acceptance by users. Shortcomings of the SMART-system might appear later from studying its use (work package 4.2), but it is has certain advantages to anticipate possible limitations and shortcomings during the design stage of the system already. For such anticipation to be possible, one needs to understand not only the structure of the relevant building provisions and their operation (i.e. the functioning of the network of technical agents responsible for heating, cooling, lightning etc.), but also the logic underlying these material layouts. It is to this logic that the SMART-system has to relate in an optimal way.

By reconstructing the design logic of building 42-1 we hope to realise the following goals:

- To open the black box of building 42-1 with respect to the facilities relevant for SMART. That is, to make understandable to the designers of SMART how the provisions of the building are supposed to work and why.
- To reveal possible necessities of mutual adjustments in design -in the case of misfits- by comparing the logic of the building with the logic of SMART.
- To create an opportunity for learning, that is, to record relevant experiences that can be fed back into the design processes of new buildings in which SMART-like systems are integrated from the very beginning.

In short, the intention behind this work package is to inform and ameliorate the present as well as future design processes of smart systems for the intelligent operation of buildings.

# 3. APPROACH

We conceive of design as a process of tunnelling, in which the number of possible choices gradually decreases as the structural features of the object designed take shape. 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 non-human. 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 from the blueprints on the design board, form a network of enablers and constraints for the traffic of actors that is perceived as essential for the functioning of the object designed, in our case a building. These structural elements are the reification of scenario's the designers have in mind with respect to the working of the building. 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 (Jelsma, 2000).

Another pair of notions that we think to be useful is *design logic* and *use(r) logic*. Design logic is the shared logic underlying the design scenario's according to which the building is supposed to work. It is the 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: 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 want to realise)
- interests
- values, ideals
- professional views and approaches (paradigms)
- perceptions (e.g. of other actors) etc.

To design a building, the actors have to accommodate their different logics while developing a 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 its use of a product of design. Logic of users is expected to vary because of difference in sex, age, education, profession, culture, lifestyle, etc.

Depending on what happened during the design process, the resulting scripts of the building facilities 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 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 process 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 2.1.

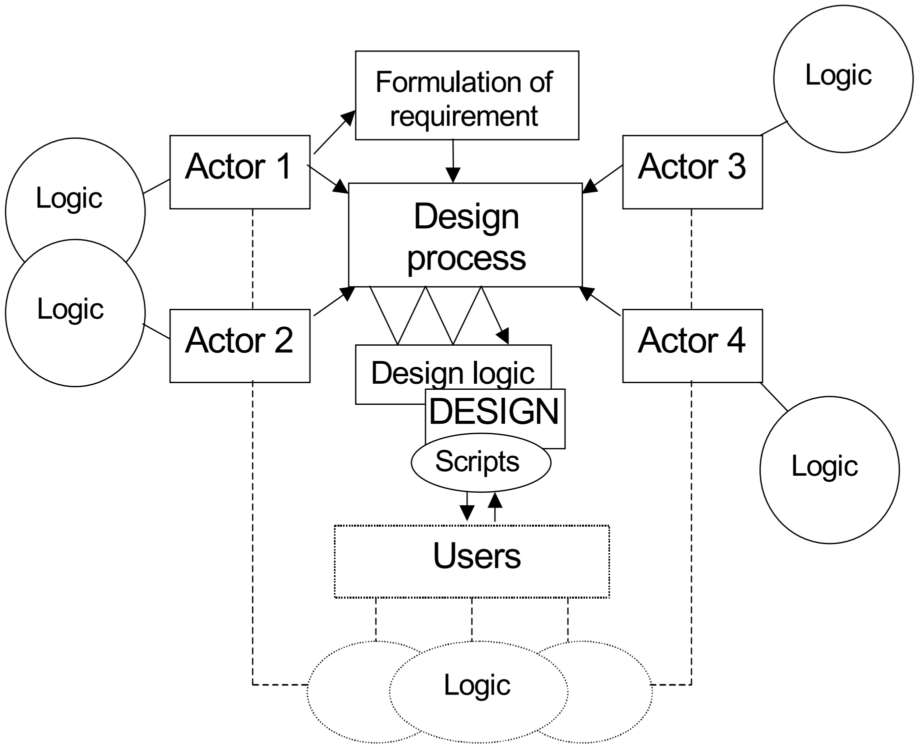


Figure 2.1 *Summary of the approach showing the relations between the concepts used. Users and their logics may be represented in the design process through other actors driving this process (see dotted lines)*

On the basis of this approach, the design logic underlying building 42-1 has been reconstructed. This reconstruction starts with first mapping the various logics of the actors participating in the design of the building. The mapping of the actor logics and the reconstruction of the design logic have been carried out on the basis of documents and face to face interviews with the actors mentioned in the next section.

# 4. ACTORS

The following actors were involved in the design process of building 42-1:

- *FAC/ECN*
  Within ECN, FAC is in charge of the operation and maintenance of the buildings. In doing so, FAC is expected to implement the ECN mission and policy in its own territory. In the past, FAC also designed ECN-buildings. In recent years, the design of buildings for ECN has been delegated to external contractors. FAC participated in the design team of building 42-1 by virtue of commissioning the building for ECN. In addition, FAC co-ordinated the construction process.
- *BEAR Architects*
  BEAR is the architect's firm involved in the design of building 42-1. The firm has an extended national and international experience in designing sustainable buildings and application of the latest energy technology such as solar energy.
- *DEGO*
  Duurzame Energie in Gebouwde Omgeving (Renewable Energy in Built Environment) is a recently established ECN department. Its mission is doing research and offering advice on new energy concepts for buildings, and on application of renewable energy, inside as well as outside ECN. In the design of building 42-1, DEGO was involved as advisor for energy efficiency and renewable energy.
- *Van Heugten*
  Van Heugten is an engineering firm advising on technical installations for buildings. They are, and have been, involved with prestigious construction projects implementing leading edge technology for energy saving. Their main task was to implement DEGO's energy concepts for building 42-1, i.e. to translate these ideas into the layout and dimensions of complete installations.

# 5. ACTOR LOGICS

*FAC/ECN*

FAC's logic rest on three pillars; its duty to operate and maintain the ECN buildings, ECN policy for housing of its employees, and ECN's energy policy.

- *Operation and maintenance*
  As an operator, FAC is a user of the facilities it builds. This duty fixes an important part of their logic that makes itself felt in informal requirements. New buildings such as 42-1 should be functional, reliable and should not generate high costs for operation and maintenance. Nor should they generate many complaints by users, since workload is a one of FAC's concerns.
- *Housing policy*
  In 1993, ECN developed a Housing Masterplan after a critical evaluation of its housing facilities. This plan provided for a drastic revision of the existing ECN facilities, and for the building of new ones (Mensinga, 1998). After a delay because of financial setbacks, the plan was updated and carried into effect in 1998. One of the demands made on new buildings was *flexibility in use*. That is, buildings should be easily adaptable to the shifting of tasks that characterises a dynamic, client-oriented organisation. Preferably, new estate should also contribute to ECN's image by eye-catching architecture. New buildings should not only be functional any more, but also aesthetically attractive.
- *Energy policy*
  Building 42-1 is meant to be an exemplar of ECN's strive for the development of sustainable and energy efficient construction technologies. New buildings on its own site offer ECN the opportunity to show that it is dedicated to its mission of developing and implementing new energy technologies. Buildings should not only be comfortable to work in, but at the same time be energy efficient and should cover their energy use with renewable resources for at least 3%. Another cornerstone of policy is the guideline that ECN allows no mechanical cooling (air conditioning) in its buildings. To keep rooms cool on hot summer days, more eco-friendly solutions have to be developed such as in building 31 housing the main laboratory facilities. In refurbishing this building, long rows of photovoltaic panels have been mounted across the façade above the windows. These solar panels convert the sunshine they keep off the windows into electricity. In this sense, ECN buildings are conceived as sites for experimenting with, and demonstrating new energy technology.

In summary, current ECN-policy aims at developing functional buildings that will attract international attention for combining sustainability and energy saving performance with remarkable, modern architecture and market-oriented prices.

The plan for building 42-1 implements these policy objectives quite clearly. Design requirements for the building were:

- Flexible operation and use, i.e. use as an office as well as a laboratory must be possible. Each floor would will form one room with clusters of desks, with tables and chairs for small meetings etceteras (open-plan office) Possible walls separating clusters should be 1.80 meters high at most. Nevertheless the option of making separate rooms in the future if needed should be kept open.
- Attractive architecture.
- Low energy use.
- Application of renewable energy.
- Good comfort for users while avoiding the need for mechanical cooling.

These requirements had to be materialised into a building under the supervision of FAC.

*BEAR Architects*
BEAR Architects are specialists in integrating renewable energy -especially solar energy- in residential buildings as well as in commercial buildings. They participated in a large range of national and international programs and projects for developing renewable energy for the housing sector such as IEA programs. Through these projects they have many contacts in the world of renewable energy, among others with leading solar energy experts within ECN. During the nineteen-nineties, BEAR urged contacts within ECN to start the integration of solar energy in its own buildings. The refurbishment of building 31 (see above) was a first opportunity to realise this intention and to collaborate in a joint project. This collaboration was extended in the design of building 42-1.

BEAR Architects conceived of their role in the design process mainly as to materialise the concepts for energy saving as advised by DEGO, and to find attractive architectural solutions for the installations stemming from these concepts. For instance, DEGO's concept of natural ventilation appealed to BEAR's philosophy. But BEAR also brought to the project decisive expertise of its own. In designing the huge, PV-panelled blue glass cover over the central corridor connecting the modules of the building and dominating its exterior appearance, their logic prevailed over that of ECN engineers. From experiences with sun porches elsewhere they knew that the cooling burden due to glass roofs could be reduced considerably by applying solar panels. These experiences were at odds with model calculations by ECN engineers, which the architects refused to believe. Their tenacity led to adaptation of the model.

Another aspect of BEAR's logic is their attitude towards users. According to this logic, user preferences are not simply there but have to be articulated and translated into a building design. Users handle certain images in which their wishes and desires are hidden; the architect has to interpret these images by translating and expressing them through structures. For a successful interpretation, frequent contacts with users are needed, otherwise there is a considerable chance of 'missing links' in the design for which the architect will be blamed afterwards. To the architects' regret, exchanges with the users of building 42-1 were impossible in practice because the ECN management continued to shift the destination of the building. Who would be the ultimate users remained unclear until the very last moment. On the other hand, abandoning user involvement can be seen as following from the management's wish to have a building being flexible in use.

*DEGO*
DEGO is one of the new business units that sprung from the re-organisation of ECN starting around 1995. It sees itself as a research department and consultant in the field of sustainable energy technologies for buildings. In its practice, DEGO distinguishes itself from traditional engineering and installation firms by emphasising its focus on the energy saving properties instead of on functionality of installations only. In addition, DEGO takes it as a challenge to defend its position in the race for the lowest EPC in buildings. When DEGO's own facility (building 40, designed by FAC in 1992) was finished (1994), it surprisingly turned out to have one of the lowest EPC's among Dutch office buildings, i.e. 1.4. This made DEGO (backed by the ECN management) keen to exceed this achievement in a new building and to beat competitors who had passed DEGO in the meantime. Building 42-1 became the target of this challenge. If its EPC was set on 0.9, DEGO might regain its number one position in the EPC battle at that time.

Over the years, DEGO has developed a kind of paradigm of its own for the design of buildings with low EPC's. In this paradigm, that is inspired and enriched by designs of a number of energy efficient office buildings which have been studied by DEGO engineers, principles and views on energy efficiency, on comfort and on use are integrated. We summarise the main traits of the paradigm as follows (for a more extended treatment, see Ligthart and Kaan, 2000).

*Energy: a ladder of measures*

- Avoid energy demand of the building as much as possible. Reduction of demand can be reached by:
  - A favourable volume/surface ratio of the building.
  - Reduced glass surfaces.
  - Optimal use of daylight.
  - Reduction of demand for cooling by using energy efficient devices (e.g. laptops instead of desktops).
  - High isolation properties of the building skin (outer walls).
  - Use of passive strategies for cooling. A prominent part of the DEGO paradigm is this respect is *summer night ventilation*. This is a system based on natural ventilation cooling the building during summer nights; the cooled mass of the building is used as a buffer that slows down the rise of internal temperature in the daytime. DEGO has imported this technique from the Mediterranean and studied and tested its mechanism in its own building.
- Meet energy demand by making use of sustainable energy sources such as passive solar energy.
- Meet remaining demand with energy efficient technologies, such as balanced ventilation with heat recovery, heat pumps, low temperature heating, CHP etc.

*Comfort*

The saving of energy should not be realised at the expense of comfort. In DEGO's logic, comfort is the leading goal in designing buildings. Comfort levels should be realised in accordance with standards set by governmental regulation, but against minimal energy costs.

*Use*

Concerning aspects of use, DEGO has logic too. DEGO emulates *flexible use*: adaptability of buildings is an important aspect of sustainability. When the destination of a building changes, demolition should be prevented. Further, on the basis of its experience, DEGO thinks for the user. DEGO engineers deliberately seek feedback by walking around frequently in buildings they have advised on, to observe use practice and gather user experiences. By such observations, DEGO has identified two functions to be most important for users, i.e. ventilation and warding off direct sunshine. DEGO learned that user acceptation of shut tight buildings generally is very low. People want to open windows and to close sun blinds if they feel the need to do so. This has led DEGO to develop a philosophy about use of buildings 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 controllable by the building operators. In accordance with this philosophy, building operation by users is tolerable as long as operators can correct it, since rational building operation cannot be entrusted to users.

*Van Heugten*

According to Van Heugten's philosophy, the technical installations of buildings are not engineering achievements as such. In a design for a building, installations, architecture and construction have to be integrated to guarantee optimal usability, i.e. a healthy and comfortable interior climate. Buildings should collaborate with their users. On the other hand, buildings are economic goods, they have to reckon with market needs. This means that buildings have to fit in with the demands of project developers and with the constraints of specific locations. Conflicting demands have to be reconciled, which requires a careful collaboration of all the parties in the construction process.

*Convergence/divergence of actor logics*
All actors emphasise that the design process of building 42-1 has been an iterative process. Ideas, options and unexpected problems were identified and debated within the design team, and solutions were discussed and decided upon in the same way. In working this way, the actors complemented each other's expertise. For instance, DEGO indicated how many channels they needed for the system of natural ventilation to be applied in the building. The architects integrated these channels in the construction as elegantly as possible, and the installation engineers designed the valves in these channels needed for fire prevention.

This example illustrates a typical hierarchy in the design process, i.e. that in it, the DEGO paradigm was leading. The building as it has been realised illustrates this dominance quite clearly (see below). Presumably, this dominance has to do with the fact that DEGO and BEAR had strongly overlapping visions on sustainable building. Between them there were frequent contacts. DEGO advised the selection of BEAR as the architect firm in charge. That is, their logics were already convergent before the start of the building of 42-1. This convergence probably helped the acceptance of DEGO's wish to set an ambitious EPC, and of its innovative concepts. Especially the application of DEGO's characteristic system of summer night ventilation in an office building was a novelty for the other parties. A quote from the interview with the installation firm -'the building has been designed around the ventilation system'- underlines the importance attributed to this aspect of the building's design. For this firm, designing the fittings for this system was an interesting new experience distinct from their normal design logic. This logic is based on mechanical cooling. The latter is the preferred system because it is perceived as offering better opportunities for control.

# 6. DESIGN LOGIC

We can now describe the design logic that has been guiding the construction of building 42-1. During construction, the design logic is being embodied in the structures and provisions of the building. During this process of construction, the design logic is further articulated and refined - and maybe is adapted- in all kinds of details. However, its core elements can be easily recognised in the real building as it stands now. These elements can be described as follows.

*Shape*
The building has been designed as a simple rectangular shape. The logic behind this shape is that it reduces the outer surface in comparison with more complicated shapes, and so minimises heat loss. In the centre of the building is a shaft (vide) around which three office floors are situated. This shaft increases the volume of the building but it brings daylight into the central part of the building and so reduces the need for electric light. The shaft also plays a crucial role in the logic of the ventilation system (see below). The idea of flexible use is behind the many ways in which the floors can be subdivided, guaranteed by a symmetric plan and as few columns as possible. If needed, each floor can be provided with rooms of different dimensions by placing separating walls. To maintain the option of making separate rooms, the layout of the provisions (electricity, heating) is grid-wise.

*Heating*
Heating is combined with winter ventilation in a joint system of balanced ventilation with recovery of heat. It should provide each floor with heated fresh air of a fixed temperature depending on the settings in the Building Operation System (BOS). The requirements of the heating system have been calculated using a model (TRNSYS) that predicts the heat demand of the building under different conditions. In addition, each floor has a second heating system consisting of a grid of small heating units in the ceiling (24 units per floor). The logic behind these units is that they can compensate for local heat losses on the floor (e.g. near windows). In the second place, the units support the goal of flexible use. Around the heating units, separate rooms can be hedged off the central floor by putting walls. As longs as no separate rooms are installed, the users can adjust the temperature on every floor by setting two thermostats, each of which checks 12 units. In addition, the building operator can control the heating units in clusters of 6-8 units by setting temperatures in BOS.

*Summer night ventilation*
Cooling of the building during hot summer periods is to be realised by a system of valves in all facades directly above the windows. Opening these valves during the night should generate draft between the valves and channels running around the central vide up to openings in the roof. In this way, cool night air is expected to stream from the valves between the ceilings and the next floor towards the central channels, and so to cool down the mass of the building. Each floor has a separate exhaust on to the roof in order to avoid disturbance of flow by a mixing up of air streams coming from separate floors. Research by DEGO has shown that such disturbance hampers the hot air to move upwards. The building mass, cooled during the night, is supposed to work as a buffer in the daytime. Windows cannot be opened, but the ventilation valves can be opened and closed manually by the users of the building, in summer as well as in winter. 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 servomotors. Sections of valves can be opened or closed by the building operator depending on the conditions inside and outside the building. This system of dual operation (by users and by operators) can be seen as a technical implementation of the principle of ‘corrected tolerance’ mentioned earlier.

*Lighting*
The electric lights on each floor are divided in two sections being served by pulse switches controlled by sensors. Interference by users is not possible.

*Renewable energy*
To connect building 42-1 to the adjacent building 31, a big hall has been designed. This hall is meant to give access also to the planned buildings 42-1-2 and 42-1-3. The hall is covered with a half transparent roof of photovoltaic cells. This means that the building will produce renewable energy that might be used by the building users. One of the options of the SMART-system is to make production of this energy visible and available to users and offer them software tools to plan their use of this renewable energy economically and efficiently.

# 7. USER CONSTRUCTION, SCRIPTS AND DIVISION OF AUTHORITY

The design logic of building 42-1 presupposes two types of users, the inhabitants of the building (end users) and the building operators. To both types of users certain needs, properties and authority are ascribed, embodied in the structural features of the building and its installations acting as scripts. That is, the scripts permit or invite certain types of user behaviour while constraining others:

- The inhabitants of the building are conceived as actors with certain needs (they want to open windows, adjust temperature of their work environment) but also as being careless (it must be possible to correct them).
- The starting point of the logic of using space flexibly is that there will be no separate rooms, the office workers sit in one large room per floor. This layout does not permit individual adjustments of user preferences, it prescribes negotiations about temperature settings, about opening and closing valves etc.
- The scripts of the installations introduce a division of authority between inhabitants and operators, which is summarised in Table 6.1 and pictured in Figure 6.1 As can be seen, individual users have no exclusive authority to regulate any provision in the building. The building operator has exclusive authority on some, and overruling authority on other provisions.
- The division of authority also works as a script for SMART, that is, it offers and constrains opportunities for the SMART-system and therefore influences the way this system has to be designed.

Table 6.1 *Division of operative authority between users, building operator and installations for realisation of conditions within the building*

| Mediating script | Building operator | User |
|---|---|---|
| Temp. setting of central heating | Yes | No |
| Thermostats for additional heating units | Sets temperature range | Negotiated management within range set |
| Valves for cooling & ventilation | Overruling users | Negotiated management |

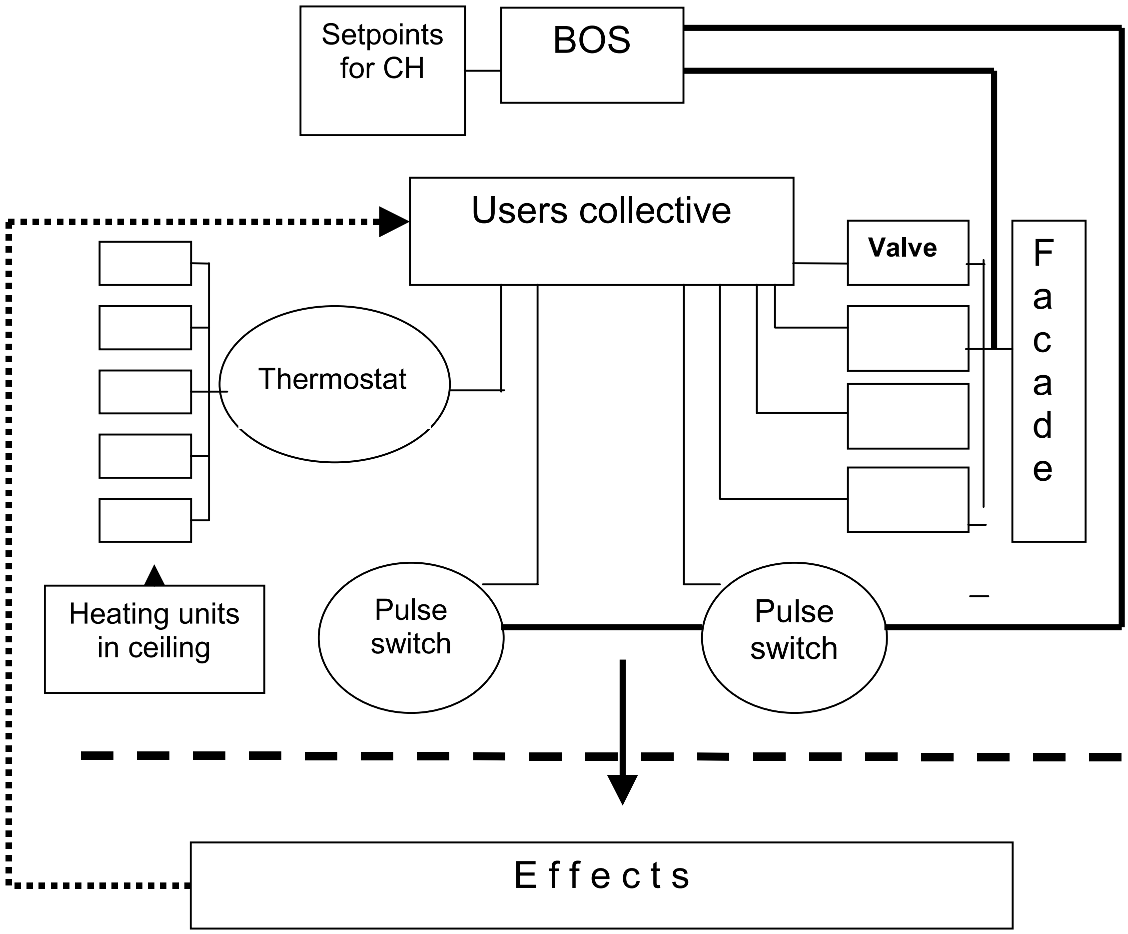


Figure 6.1 *Scheme showing division of authority to steer building provisions between end users and operators (operating BOS) according to the present design logic of building 42-1. Users on the office floor can operate thermostats, ventilation valves and light switches (see thin lines), but their settings can be overruled by the building operator (bold lines). CH = central heating*

Compared to the present logic, the SMART-logic is different. It constructs different relations and authorities between the actors and provisions involved (see Figure 6.2). According to SMART-logic, individual users have access, via the SMART agents and BOS, to the settings of all building provisions that influence comfort. That means that end-users have individual control of comfort provisions, they do not have to negotiate as a collective. The building operator (BO) has only authority to define the range within which comfort preferences can be entered into the system. In this sense, the SMART-logic leads to a system with less hierarchy.

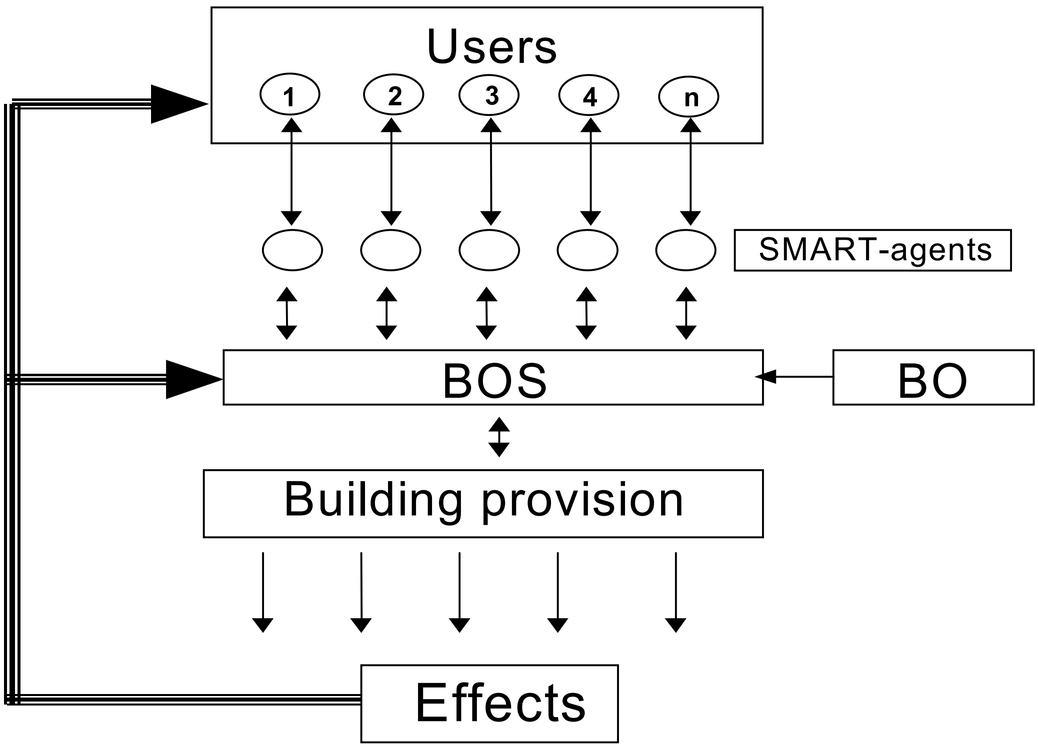


Figure 6.2 *Relationships between end-users (1 → n), operators, SMART agents and building provisions, in accordance with the logic of the SMART-system for comfort management*

According to this logic, all entities making up the system and its users are conceived as actors or agents negotiating with each other and exchanging information within limits set by the building operator (BO). Users creating and experiencing climatic effects are represented as individuals instead of as a collective (cf. Figure 6.1).

# 8. RELATIONSHIP BETWEEN DESIGN LOGIC AND SMART LOGIC

We can now compare the logic underlying the layout of the building with the logic of the SMART-system. It immediately appears that there is a discrepancy between both logics in the different ways they construct (or represent) users. This difference in user representation leads to different requirements for system representation (i.e. the capabilities of models for predicting relevant dynamics of the building), for steering (the capabilities of the building provisions to set and maintain preferred conditions) and for monitoring those conditions.

### *Differences in user representation*

The design logic underlying building 42-1 includes a conception of users as a *collective* that has to negotiate about the levels and quality of *common* comfort, which can be influenced by only a small number of mediators (two thermostats and the ventilation valves, see Figure 6.1). The ideal of SMART is the opposite, i.e. an *autonomous* user who sets comfort according to his own preferences through an extended number of agents controlling his environment with respect to all comfort parameters, and providing him/her with precise feedback about conditions realised, energy used and costs made on an *individual* level. The difference between these two user representations offers a challenge to the designers of the SMART-system.

### *Divergent requirements for system representation and steering*

The SMART-system presupposes a system representation that is precise enough to predict the outcome of each intervention in the climate system of the building by individual users at any moment, not only with respect to the physical parameters but also in terms of costs and energy use. This leads to the following requirements:

- *Precise modelling of the building as a system*
  The TRNSYS-model used to simulate properties of the building is not precise enough for SMART purposes. The model does not allow for predictions of climatic conditions at the level of individual working sites on the office floor. Especially, the natural ventilation of the building cannot be simulated by TRNSYS:
  - *At night*: at most, one can calculate the time span needed for cooling of the building under conditions of a given temperate difference and a given air velocity. Such an estimation is sufficient within a conception of ‘corrected tolerance’, which aims to cool the building at night when the users are out. The SMART-system, however, has to operate in the daytime, when the users are in. This difference in user representation means that a more sophisticated representation is needed of the physical processes in the building. Therefore, additional modelling effort is needed for design of the SMART-system.
  - *In the daytime:* because of the large amount of ventilation valves which can be opened in different combinations, all kinds of drafts may occur across the office floor which are impossible to simulate in a model.
- *Steering facilities to meet user preferences*
  The system must be able to react instantaneously to the setting of preferences by users, and to the information reported back by monitoring agents. This requires the presence of provisions that can immediately translate signals from the agents controlled by the SMART optimiser towards the physical conditions requested by the users of the system. There is serious doubt whether the present provisions are adequate in this respect. Especially the lack of a cooling facility in the daytime might be a concern for designers of SMART. When users prefer lower temperatures during a hot day and set SMART-levels accordingly, the system can do nothing to carry out this instruction. This limitation may apply even during warm winter days when the heating is switched off.

- *Setting and maintaining conditions*
  The present installations of the building limit the fine-tuning of comfort provisions. With respect to heating, the highest resolution of defining temperature zones on the office floors is determined by the lowest number of heating units in the ceiling that can be regulated by thermostats that report to the building operation system. In the current layout, on the ground floor 8 units are controlled by one thermostat. For the other floors, which are smaller, this number is 6. Thus, the current layout prescribes to the SMART-system a maximum resolution of a cluster of 6 to 8 heating units to be controlled separately. Further, because there are no separating walls between zones, interference between different temperature zones will unavoidably lead to deviations from the temperature set for a certain zone by the users in that zone.
- *High resolution monitoring of the system*
  SMART presupposes 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 needs this information (with a high time resolution) for calculating optimal settings. The current reporting to the building operation system by existing agents does not match this requirement. Especially the ventilation valves in the facades are a case in point. These valves do not report their status (open/closed) to the system, so there is no monitoring possible of individual valves. For the design of SMART this is a matter of concern because the status of the valves is expected to be important for the generation of drafts across the office floor (see above), especially under conditions of high wind pressure on the facades.

The differences between the design logic underlying building 42-1 and the Smart-logic are summarised in Table 7.1.

Table 7.1 *Comparison between the design logic of building 42-1 and Smart-logic*

| | Design logic 42-1 | SMART-logic |
|---|---|---|
| Comfort control | Common, negotiated | Individual |
| Use of renewable energy | Delegated to BO* | Managed by user |
| Energy cost management | Delegated to BO* | By user |
| System modelling | Rough | Precise |
| Steering of comfort conditions | Limited | Detailed |
| Monitoring | Low resolution | High resolution |

* BO= Building Operator

# 9. CONCLUSIONS

Building 42-1 has been selected because it was initially perceived as an attractive test facility and demonstration site for the SMART-system: the building has an eye-catching architecture and is a showcase of ECN's high ambitions to save energy. When design of the SMART-system got underway, however, it became gradually clear that building 42-1 harboured disadvantages for testing and demonstrating the SMART-system:

- It is a new building without a history, i.e. there are hardly any previous performance data against which performance of the SMART-system and satisfaction of its users can be compared.
- As a consequence of flexible housing policy, the user population of the test building has been shifting, and is expected to do so in the near future. This shift impairs the involvement of a stable user group in relevant aspects of the design process. It also burdens the performance of user studies, and may lower the robustness of the outcomes of such studies.
- The building was finished before the SMART-system came into the picture. That is, in the construction and the design of the building and its installations, the SMART-system was not reckoned with. This lack of tuning has led to discrepancies that interfered with the design of the SMART-system (see next).
- Building 42-1 has been designed and constructed mainly on the basis of a specific logic put forward by the energy advisor. As we have shown, this design logic is at odds with the logic of the SMART-system in several respects. The discrepancy between both logics expresses itself in the different ways in which users and systems are represented, in divergent requirements for model resolution and accuracy, and for monitoring. These discrepancies required considerable extra efforts in modelling, and they may harm the functionality of the SMART-system in the end. In any case it means that, for this particular test site, the original intentions of the project had to be adapted.
- On the other hand, the deviant design logic of the building and offers the opportunity to gain experience with developing a SMART variant for an environment that is interesting from the viewpoint of sustainable building, i.e. the flexible office. For instance, one could consider experiments with negotiated rearrangement of users on the office floor according to more or less shared comfort preferences derived from data gathered with SMART.

This study demonstrates 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 the smart system. For instance, for the proper working of such a smart system it is of crucial importance that all the technical installations and provisions of the building relevant for comfort management report their status back to the building operating system (BOS). In the case of building 42-1 for instance, ignorance of BOS about the state of the ventilation valves located in the facades added very much to the impossibility of reliable modelling of air movements through the building.

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.

# REFERENCES


Jelsma, J. (2000): *Verkeerd gebruikt of slecht ontworpen?* O2 Magazine voorjaar 2000, p. 2/3.

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

Lighthart, F.A.T.M. and H.F. Kaan (2000): *ECN-Nieuwbouw, Op weg naar nul-energie*, ECN-C-00-030, Petten.

Mensinga, R., et al. (1998): *Werk in uitvoering, ECN bouwt aan de 21ste eeuw*, FAC/ECN, Petten.

Reijenga, T.H. and M. Drok (1998): *Haalbaarheidsstudie ECN Gebouw 41*, BEAR Architecten, Gouda.

# APPENDIX A

List of work packages of the Smart project:

*WP. 1 Multi-agent framework*
WP 1.1 Agent rolls and utility functions
WP 1.2 Defining agent platform, optimising strategy and tasks
WP 1.3 Evaluation of electronic market mechanisms
WP 1.4 Final report multi-agent technology

*WP 2 Model-studies and scenarios*
WP 2.1 Energy and comfort scenario analyses
WP 2.2 Evaluation of comfort strategies and of concepts for building operation

*WP 3 Design of software application and field test*
WP 3.1 Mapping the local context
WP 3.2 Interface design
WP 3.3 Development of multi-agent software application
WP 3.4 Management and monitoring of field test

*WP 4 Study and evaluation of design and use*
WP 4.1 Comparing Smart-logic with design logic of test-building[1]
WP 4.2 User aspects of Smart

[1] This final report concerns WP4.1