Chapter 6

Intelligent Buildings: Energy Saving and Value Added Services

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6.1 Executive Summary

In a de-regulated market the distribution utilities will compete with added value for the customer in addition to the delivery of energy. We describe a system consisting of a collection of software agents that monitor and control an office building. It uses the existing power lines for communication between the agents and the electrical devices of the building, such as, sensors and actuators for lights, heating, and ventilation. The objectives are both energy saving, and increasing customer satisfaction through value added services. Energy saving is realized, e.g., by lights being automatically switched off and room temperature being lowered in empty rooms. Increased customer satisfaction is realized, e.g., by adapting temperature and light intensity according to each person's personal preferences. We present initial results from simulation experiments of an office building and its staff. Different user profiles are modeled in terms of their energy consuming behavior, e.g., their tendency to put out the light when leaving a room, and to adjust the temperature when leaving and entering the building. The energy consumption when using the system is compared to that of not using the system. Our simulations indicate that significant savings, up to 40 per cent, can be achieved.

6.2 Introduction

In a de-regulated market the distribution utilities will compete with added value for the customer in addition to the delivery of energy. We will here describe a system consisting of a collection of software agents that monitor and control an office building in order to provide value added services. In our terminology, an agent is an independent piece of software often implemented as a separate process capable of communicating with other agents, and typically having well-defined internal states, behaviors, and goals. The concept of software agents, as well as the communication languages used by such agents, is becoming a standard concept in software engineering [4].

The system uses the existing power lines for communication between the agents and the electrical devices of the building, i.e., sensors and actuators for lights, heating, ventilation, etc. The objectives are both energy saving, and increasing customer satisfaction through value added services. Energy saving is realized, e.g., by lights being automatically switched off, and room temperature being lowered in empty rooms. Increased customer satisfaction is realized, e.g., by adapting temperature and light intensity according to each person's personal preferences. We present initial results from simulation experiments of an office and its staff. The energy consumption when using the system is compared to that of not using the system. Our simulations indicate that significant savings, up to 40 per cent, can be achieved. We plan to soon start field experiments at our test site, the Villa Wega building, Ronneby Sweden.

A collection of software agents that cooperates and / or competes in a common environment is often called a Multi-Agent System (MAS). In the MAS described below, different agents control different parts of the building, as well as different aspects of the environmental conditions of the building. Other agents represent the persons in the building in order maintain their preferences concerning temperature, light intensity, etc. The goal is to make the system transparent to the people in the building in the sense that they do not have to interact with the system in any laborious manner. By using an active badge system, the MAS automatically detects in which room each person is at any moment and adapts the conditions in the room according to that person's preferences.

6.3 The Building Infrastructure

A building contains a number of electrical devices that constitute an important part its infrastructure of the building. At the Villa Wega test site, the interaction with the devices at the hardware level is facilitated by an infrastructure based on LonWorks technology (cf. www.echelon.com). Its conceptual structure is depicted in figure 1. Each electrical device in the system is connected via special purpose hardware nodes to the LonWorks system, allowing the exchange of information over the electrical grid. All the information received from the devices is recorded on a control panel. This information reflects the state of the devices (and therefore the state of the environment) and is stored in a special attribute-value table.

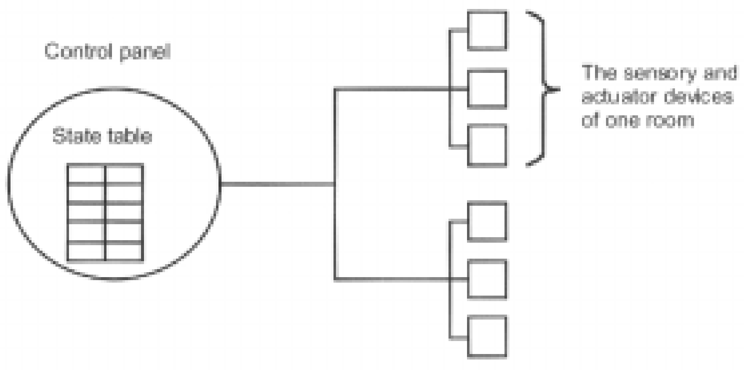

Figure 6:1. The hardware infrastructure.

The devices are either sensors or actuators. The sensory devices we use are: temperature, light intensity, presence (detects whether there is activity in a room or not), and an active badge system. It is of course possible to include also other types of sensors, e.g., fire detectors. The active badge system [6] makes it possible to know which persons are in each room at any moment. The actuator devices differ from the sensory devices in that it is possible, besides reading the state of the device, to change the state of the device (in order to change the state of the building). The actuator devices in the current application are lamps, radiators, and generic mobile devices (ARIGO Switch Stations, see www.arigo.de) that can be connected to an arbitrary electrical device, e.g., a coffee machine, or a personal computer. It is possible to switch on and off the device connected to the generic mobile device and to read its state.

These devices interact with, and are controlled by, the MAS. The devices provide input to the MAS (the sensory devices) and occasionally receive instructions from it (the actuator devices). The interaction is mediated by the control panel and its state table using an interface that translates messages originated from the MAS to commands understood by the LonWorks system and vice versa. The language used to implement the MAS is April [8] together with its extension April++.

Currently, a simulation of the building environment is provided including a simulation of the control panel functionality. Thus, the MAS and the interface communicate with the simulated building through the simulated control panel. This design will simplify the integration of the MAS with the actual LonWorks system of Villa Wega. The only modification necessary concerns the part in the interface that communicates with the control panel.

In addition, a graphical user interface (GUI) visualizing the building environment (and a simulation scenario editor and executor) has been implemented. figure 6:2 shows a snapshot of this GUI that visualizes the state of the building in terms of temperature, light intensity of the rooms and the persons present in the rooms.

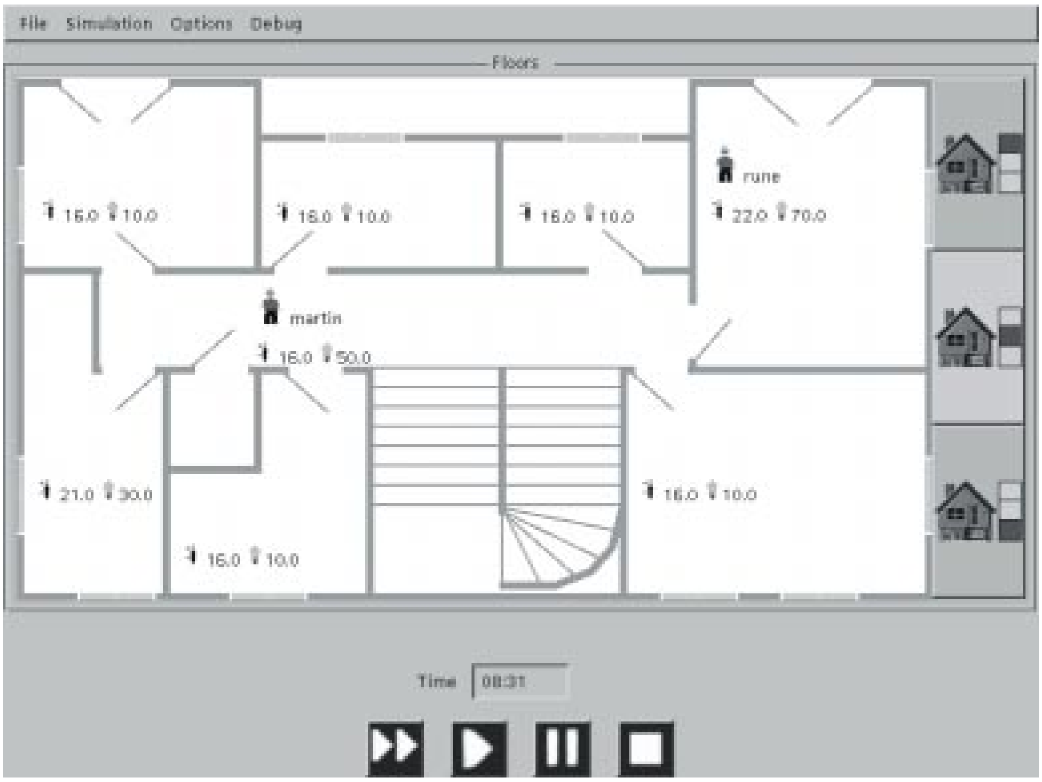

Figure 6:2. A snapshot of the environment visualization GUI.

6.4 The Multi-Agent System

As mentioned earlier, a multi-agent approach was adopted during the design and implementation of the software. Each agent corresponds to a particular entity of the building, e.g., office, meeting room, corridor, person, or electrical device. The behavior of each agent is determined by a number of rules that express the desired control policies of the building conditions. The occurrence of certain events inside the building (e.g., a person moving from one room to another) will generate messages to some of the agents that will trigger some appropriate rule(s). The agents execute the rule(s), with the purpose to adjust the environmental conditions to some preferred set of values. The rule will cause a sequence of actions to be executed, which will involve communication between the agents of the system. For the format of the messages a KQML-like [3] approach was adopted.

The agent-based approach allows for a structure preserving mapping of the design entities of the application and the distributed smart equipment of the implementation. This methodology has advantages extending those of traditional object-oriented modeling and programming [5]. It also provides the advantage of an open architecture in the given context, i.e., agents can be easily configured and even dynamically reconfigured. Furthermore, it is possible to add new agents at run-time without the need of interrupting the normal operation of the system. Such changes reflect changes in the infrastructure of the building or in the staff. Finally, in contrast to traditional object-oriented approaches that are limited to reactive behavior, the MAS approach provides a straight-forward way of modeling and implementing pro-active behavior.

6.4.1 Types of Agents

There are four main categories of agents in the MAS:

- *Personal Comfort (PC) agents,* which each corresponds to a particular person. It contains personal preferences and acts on that person's behalf in the MAS trying to maximize customer value. Thus, the agent does not model the behavior of a person, rather it tries to act in that person's interest.

- *Room agents,* which each corresponds to and controls a particular room with the goal of saving as much energy as possible. Taking into account the preferences of the persons currently in the room, it decides what values of the environmental parameters, e.g., temperature and light, are appropriate.
- *Environmental Parameter (EP) agents,* which each monitors and controls a particular environmental parameter in a particular room. They have access to sensor and actuator devices for reading and changing the parameter. For instance, a temperature agent can read the temperature sensor and control the radiators in a room. The goal of an EP agent is to achieve and then keep the value of the parameter decided by the Room agent.
- *Badge System Agent (BSA),* which keeps track of where in the building each person (i.e., badge) is situated and maintains a data base of the PC agents and their associations to persons (badges).

For conceptual and administrational purposes the agents have been divided into groups corresponding to theses categories (see figure 3). However, we make no assumptions about the agents' locations in the network. For instance, the PC agents may reside on the individuals' desktop computers and interact locally with the corresponding person, e.g., in order to change the preferences. Normally, the preferences are set when the agent is initiated, i.e., when the person visits the building for the first time, and rarely changed.

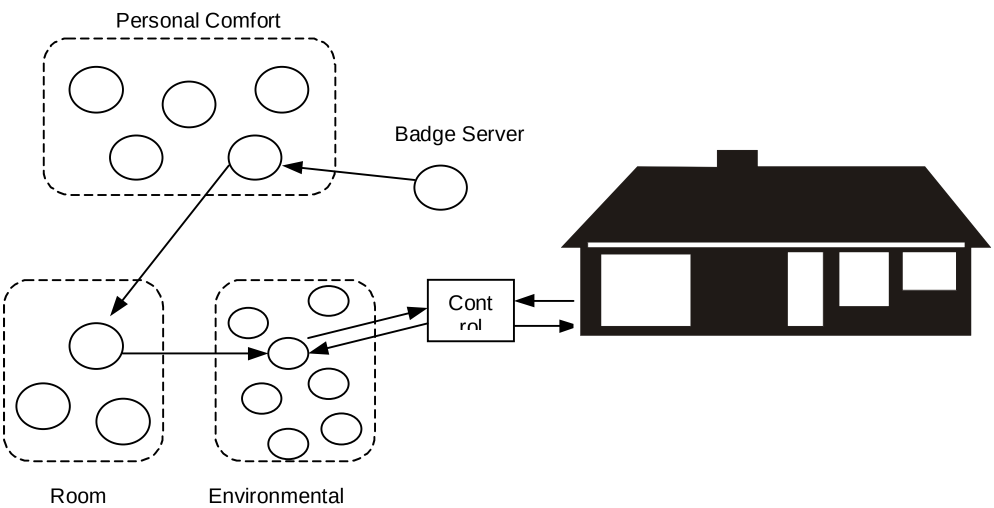

Figure 6:3. The structure of the multi-agent system

As an example of the working of the MAS, we describe what happens when a person moves from one room to another. When the person movement is detected by a badge sensor and forwarded to the BSA via the control panel, the BSA informs the appropriate PC agent about this. The PC agent informs the appropriate room agents, i.e., the agent of the room the person is leaving and the agent of the room the person is entering. The PC agent also provides the rooms agent with the personal preferences. The room agent decides, based on these preferences and on energy saving considerations, the new desired environmental conditions and passes them on to the EP agents. The EP agents then try to achieve and keep the values decided by the room agent by monitoring the relevant sensors and sending commands to the relevant actuators via the control panel. More details about the MAS software can be found in [1].

6.4.2 System Constraints

The system conforms to a number of general rules (constraints or decision policies) that are fed to the agents. Some examples are listed below:

- Every room with no persons in it must maintain some default environmental conditions.
- For common rooms, like corridors, the temperature remains steady regardless of the persons in the room. The light is turned on only when at least one person is in the room, otherwise it is turned off.
- When a particular person is in her office, the room agent must adapt temperature, light, etc. to her preferences, otherwise the default conditions are maintained. If an “irrelevant” person (i.e., another person than the ones that normally work in the office) enters that office, this does not affect the environmental conditions (except for that the light is turned on if the room was empty).
- For meeting rooms, the temperature condition is adjusted to the mean value of all the meeting participants, and the light intensity to the highest preference value.
- It must always be possible to over-rule the decisions of the agents in the MAS by physical interaction with the electrical equipment. For instance, even if an EP agent has decided that the light in a room should be on, it must be possible for a person to turn off the light using the switch in the actual room.

- The persons are also allowed to provide the PC agents with different preferences depending on the activities they are undertaking. For example, it is possible to specify different light or temperature conditions for working activities different from those for meeting activities.

These constraints are, of course, not hard-wired into the MAS and can be changed easily.

Usually, the goals of the room agents and the PC agents are conflicting: the room agents maximizing energy saving and the PC agents maximizing customer value. Another type of a conflicting goal situation would be the adjustment of temperature in a meeting room in which people with different preferences regarding temperature will meet. We are currently investigating the use of *decision modules* to address this problem with possible extensions of using the notions of group utility and norms for dealing with problems arising from agent negotiations [2].

6.5 Evaluation of the MAS approach

In this section we present the results from some basic simulations of the building environment. The MAS approach is compared in terms of energy consumption to the current method of controlling the environmental parameters of the building (i.e., manually by the people working in the building).

6.5.1 Thermodynamical model

We use the thermodynamical models described by Incropera and Witt [7]. However, they have been discretized according to standard procedures described by Ogata [9] and used by, e.g., Ygge and Akkermans [10]. In all simulations below we use the sample time 1 minute.

All the thermodynamical characteristics of a room are described by two constants: the thermal resistance, *R*, which captures the heat losses to the environment, and the thermal capacitance, *C*, which captures the inertia when heating up/cooling down the entities in the room.

6.5.2 The simulations

In this first stage we have made the following simplifications:

- only energy used for heating is taken into account, not for lighting etc.
- constant outdoor temperature is assumed (10°C)
- negligible radiation from the sun (i.e., cloudy weather)
- the heat produced by persons in the room is ignored
- the heat produced by computers, lamps and other electrical devices is ignored

Note that if we were to take into account any of these aspects in the simulations, the results would have been even better.

The building has five small offices (each used by one person), two large offices (3-5 persons), and one meeting room, and one corridor at each of the three floors. However, we will not include the energy consumption by the radiators in the corridors in these first simulations. Since they will have the temperature 18°C at all times, both with the MAS and without, the influence of the corridors on the energy consumption in the two scenarios will be negligible.

We use R = 0.1 and C = 3000 for the small offices in the building, R = 0.05 and C = 5000 for the large offices, and R = 0.05 and C = 3000 for the meeting room. (Larger rooms have greater losses to the environment than smaller rooms and there are less entities to heat up/cool down in the meeting room.) In the small offices there is one 1000W radiator, whereas in the large offices and the meeting room there are two.

There are 12 persons working in the building who share the following characteristics:

- prefer 22°C both at their office and when in the meeting room
- the working day is normally nine hours with one hour lunch, i.e., on average eight hours are spent in the building. However, there is a 20% probability that a person does not show up at all during a day (because of meetings in another city, illness etc.)
- on average there are five meetings in the meeting room each week
- the length of a meeting is two hours on average

When the person "belonging" to an office is not in the building, the temperature of that office is set to 16°C. Similarly, when the meeting room is empty, the temperature is set to 16°C.

In the simulations the radiators use a simplified temperature control algorithm: To raise the temperature, they use the maximal effect (i.e., 1000W) to heat up the room to the desired temperature. To maintain the desired temperature, they produce just the right amount of heating power. Finally, to lower the temperature, the radiators are turned off.

6.5.3 The results

We will now compare the energy consumption when using the MAS with that of not using it. In the latter case the temperature is always 22°C in the offices and in the meeting room.

According to our simulations this approach will consume 221.8 kWh an average week, whereas the approach using the MAS only consumes 136.2 kWh. That is, we save almost 40% energy by using the MAS approach.

We can also make use of the electronic diaries in order to heat up the rooms to the preferred temperature in advance. Our simulations shows that this is only slightly more energy consuming, 137.0 kWh, but will probably lead to greater customer satisfaction (on the other hand, it requires that the individuals keep their electronic diaries updated).

Above we have only evaluated the energy saving performance. At least as important is the evaluation of customer satisfaction. However, it is difficult to make such evaluation based only on computer simulations; it is necessary to let real persons use the system.

6.6 Conclusions and Future Work

We have given a high-level description of a current project aimed at investigating the usefulness of the agent metaphor and the notion of multi-agent systems for the design of control systems for intelligent buildings. The use of the agent approach was initially motivated by the close mapping that it offered between the entities of the application domain and the entities of the software. The concurrent non-deterministic nature of the activities inside the building was another factor that led to the development of concurrent autonomous entities. Moreover, the agent system, as it was designed, allowed for the dynamic re-configuration of the agents without any disruptions of the operation of the system. This is a useful feature when changes in the building infrastructure or of the staff in the building occur. Finally, we evaluated the approach by means of computer simulations. The simulations indicate that the approach is viable and that energy savings of up to 40% are possible.

The simulations described above are very rudimentary, more sophisticated simulations will be carried out before the system is actually implemented in the real building. These simulations will take into account all or most of the following aspects: lighting power, sun radiation, variable outdoor temperature, heating power produced by other entities than radiators such as humans, computers, and lamps. As mentioned above, we argue that taking into account these aspects will provide even better results for the MAS approach. Other aspects that we consider adding to the simulations (which may not favor the MAS approach) are: more realistic radiator control algorithm, taking into account that the price of energy is not constant, and simulating persons with individual characteristics (i.e., preferences, habits etc.).

When the simulations have been fully evaluated and the MAS optimized accordingly, the next step of the project will be to make the actual transition from simulation environment to physical implementation. This is also necessary in order to evaluate the value-added services from the customers' perspective in terms of increased satisfaction. As pointed out earlier, it is difficult to make such evaluation based on computer simulations only; we need a real implementation of the system with real persons using the system.

A further step would be to combine the services of our system with the load balancing system described in a previous chapter. We then have to design the interface between the multi agent systems and the physical devices of the building to use and reuse the same data from the control panel, but for different services. In addition, we are experimenting with more complex functionalities, e.g., when a person enters the building in the morning, her monitor is switched on and the coffee machine starts making coffee.

6.6.1 Acknowledgements

The author would like to thank Dr. Magnus Boman (DSV, Stockholm Universtity) who has co-authored most of the texts from which this chapter was complied, Christoffer Dahlblom, Martin Fredriksson and Mikael Svahnberg who implemented the simulation environment and Marko Krejic for helping us with hardware-related issues (all M.Sc. students at the University of Karlskrona / Ronneby), Dr. Nikolaos Skarmeas and Professor Keith L. Clark (Imperial Collage, London / Agent Solutions Partnership, UK) who helped us with the implementation of the MAS, Stefan Johansson (Ph.D. student at the University of Karlskrona / Ronneby) for comments on a draft version of this text, and Dr. Fredrik Ygge (EnerSearch AB) for the help with the thermodynamical modeling.

6.7 References

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