ECN-C--05-084

IIGO: Intelligent Internet mediated control in the built environment

Description of a large-scale experiment in a utility building setting

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OCTOBER 2005

Acknowledgement/Preface

This document is prepared as a deliverable in the IIGO-project [IIGO, 2001] (ECN project number 7.4910). It describes of the modelling of the building and its users, as used in the field-test, the monitoring of parameters in the building, and the preparatory actions for the field test. The IIGO project is partly funded by the Dutch organisation for energy and the environment (NOVEM) in the DEMOS-programme with registration number 0140-01-01-01-0021 and order number 4800000735. This document is the first deliverable. In the second deliverable of the project experiences in the field test with applying SMART-building technology will be discussed.
Special thanks are attributed to Frans Koene, who has extensively reviewed the document and made a large number of constructive suggestions.

Abstract

An innovative strategy for managing the thermal comfort in utility buildings has been developed in the SMART-project. A pre-emptive, forward-looking strategy based optimisation using the intelligent agent metaphor is used, as it is available in the SEBOS-shell. The "SMART"-building software shell so far has only been tested in a very short experimental field test.
In this document, the preparatory activities to cast the building, in which a two-year experiment will take place, into the SMART-software shell are described. First, the construction and validation of a physical model of the building is discussed; then, the experimental data collected in an 8-month data-monitoring trajectory are treated and conclusions are drawn as to the performance of the building. Interesting findings are, that the central and local proportions of cooling and heating in individual rooms are not as expected from the design. The central heating and cooling system has the largest effect on realising the inner comfort. This leads to a smaller impact of user actions on the realised comfort than users might expect. This especially holds for the process of cooling in summer.
In the last part, the SMART-alterations in the strategy of building operation are discussed. These include introduction of a user voting procedure per room for obtaining a comfort preference profile over a day, the introduction of building model physical data and information of persistent signals in calculating the effect of control actions on the building and its segments on 24-hours and 4-hour timescales ahead and implementation of an improved strategy of shutting the window blinds to minimize heat-loss by radiation in winter.
The document forms the basis for a rollout in a two-year practical experiment, the set-up of which is described.

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Summary

The results aimed at for phase I of the IIGO-project are described. These pertain to:

- Building simulations and model calculations, showing the energy efficiency potential for intelligent Internet-enabled, dynamic control of building installations. These also provide the essential input for the SEBOS-shell implementation.
- Design and installation of the SEBOS-shell related entities at the location of the practical experiment. Modifications and extensions to the existing building management system to the InsiteView package.
- Design and implementation of a logging strategy for user actions and the response of SEBOS and a collection and interpretation of a preliminary set data, that direct to a number of improvements in the operation of the building management system.

Learning from the results of an 8-month pre-monitoring trajectory, the way the new control strategy is implemented in the SEBOS-shell is described. The implementation uses the existing infrastructure as much as possible. Strategy modifications of central installation parts as well as local, user influenced control algorithmic parameters are described.
Finally a staged implementation plan is depicted with individual phases to tune the SEBOS software, to perform shadow operation and full operation.

1. Introduction

This document describes the first phase of an experiment done to embed the building management system of a commercial office building in Nijmegen within SEBOS [SEBOS-FA, 2003, SEBOS-UM, 2003]. SEBOS (a Smart Enhanced scope Building Optimiser Shell) was developed in 2001-2002 as a result of a joint effort of ECN and Kropman Research and Development in Rijswijk. Using the SEBOS package, the strategy of operating a central building installation on the central level and on the room (segment[1]) level (maintaining a satisfactory level of thermal inner comfort in a room) is optimised. Furthermore, the context of this optimisation is much broader than used in conventional building management systems and the computational and communication possibilities of current ICT is utilised extensively. Finally, SEBOS optimises the building's installation looking forward to expected trends in the building's environment. This context includes meteorological conditions, the reaction of the building on the exerted control actions, user actions and activities and energy market price information. Thus, the user model, the building model and the external model can be seen as three more or less independent views, that have to be defined and configured before SEBOS can be deployed in a building.

SEBOS was deployed during a short introductory period at the ECN, Petten facility [ICEEE, 2003]. The aim in this second field test at the Kropman building in Nijmegen [IIGO, 2001] is to use SEBOS for an extended period covering all seasons and to determine the energy and cost saving potential. This document describes phase I of the IIGO-project. The targets of phase I of IIGO were:

- A number of building simulations and model calculations to determine the energy-efficiency potential of intelligent dynamic control using Internet technology. These simulations also provide SEBOS with essential input about the building physics.
- Design and implementation of the practical experiment. Extension of the existing building management system with the necessary additional hardware and software interfaces.
- Design of a logging strategy of the experiment to verify and analyse operation with and without SMART control over a period of a number of years. Apart from logging by the InsiteView package, a logging procedure has been defined for the user actions.

In IIGO there are number of energy and cost saving objectives. In a well-insulated, high mass building as the building in Nijmegen, that has been established recently according to high standards with an Energy Performance Coefficient of 1.6, this poses a number of challenges. After a number of discussions, possibilities for further energy efficiency improvements considered for this building were threefold:

- On the user level. In the current design of the building management system, the user has the opportunity to have a direct influence on the realised temperature in a room by adjusting the local set-point of the local heating and cooling control system. On the room level, a better understanding of the patterns of individual user preferences is sought by applying the SMART voting procedure. Thus, with SEBOS, a composite desired comfort profile over a day is built up using a voting procedure for all users in a room. Furthermore, the aggregated comfort profile is based on the Fanger model, which not only takes into account the air temperature for defining the comfort level, but also factors like the contribution of the radiation temperature to the comfort feeling, of physical activity, clothing level and relative humidity.
- On the central comfort installation level. Possibilities to better control the temperature of in blown air (either heated or cooled) and water temperature of the heating and cooling elements in the rooms are to be considered.

[1] The term real-world term 'room' and building physics term 'segment' are intermixed in this document but have the same meaning

- On the building level. Instead of using empirical trial-and-error coefficients to account for the thermal behaviour of the building, in this implementation data from a complete, validated building physics model and measured external data are used to simulate control actions over different time periods. In these calculations a persistence mechanism covering periods of a day[2] or a week[3] is used to tune, constrain and stabilise the numerical computations.

This document is targeted researchers in building HVAC and engineers doing research in energy efficient building management systems.

[2] To cover day-night rhythms
[3] To cover working day patterns in a week

2. The experimental setting

A picture of the building is shown in Figure 2-1. In the building the first and the second floor were taken as part of the context of SEBOS.

Figure 2-1 The Kropman building in Nijmegen

Building management is facilitated using the InsiteView supervisory building management visualisation and control package [InsiteView, 2001]. The layout of the two floors, involved in the experiment, is shown in Figure 2-2. The first floor contains a small number of large rooms and the second a large number of small rooms. There are about 50 inhabitants residing on the two floors. Comfort control is present as indicated by the thermometer icons and sun icons in the Figure. The thermometer icon denotes the temperature control possibilities using user manageable set-points for heating and cooling. The sun icon pertains to the possibility of user control on the operation of the sunblinds. During working hours the user has control on the level of the sunblinds; in off-working hours a building manager's predefined strategy is followed. User interaction is possible through a display as shown in Figure 2-3. When a user enters or leaves a room, a presence-button is pressed. With this action, the operating mode of the room thermal comfort control changes it's strategy. Strategies are *standby, comfort, ventilation, pre-heating, frost-prevention* and *off*. Upon first presence in the morning, comfort control changes from standby to comfort operation mode. On leaving, control changes from comfort to standby. A general sweeping mechanism, triggered by the night porter, assures that, at the end of the day, all strategies return to a common setting. In a few rooms control of the sunblind angle is possible as well to save energy by adjusting the lighting level. The user is able to influence the temperature set point according to his individual preference. In most rooms this is realised using one control-box for all inhabitants of the segment. In addition, a few users have access to the InsiteView interface, closely mimicking the wall control, on their personal computer to control their environment. From the climate control point of view the control possibilities are the same. There is one difference in the presentation: on the InsiteView mediated computer display the currently measured temperature can be seen; on the wall displays, this is not possible.

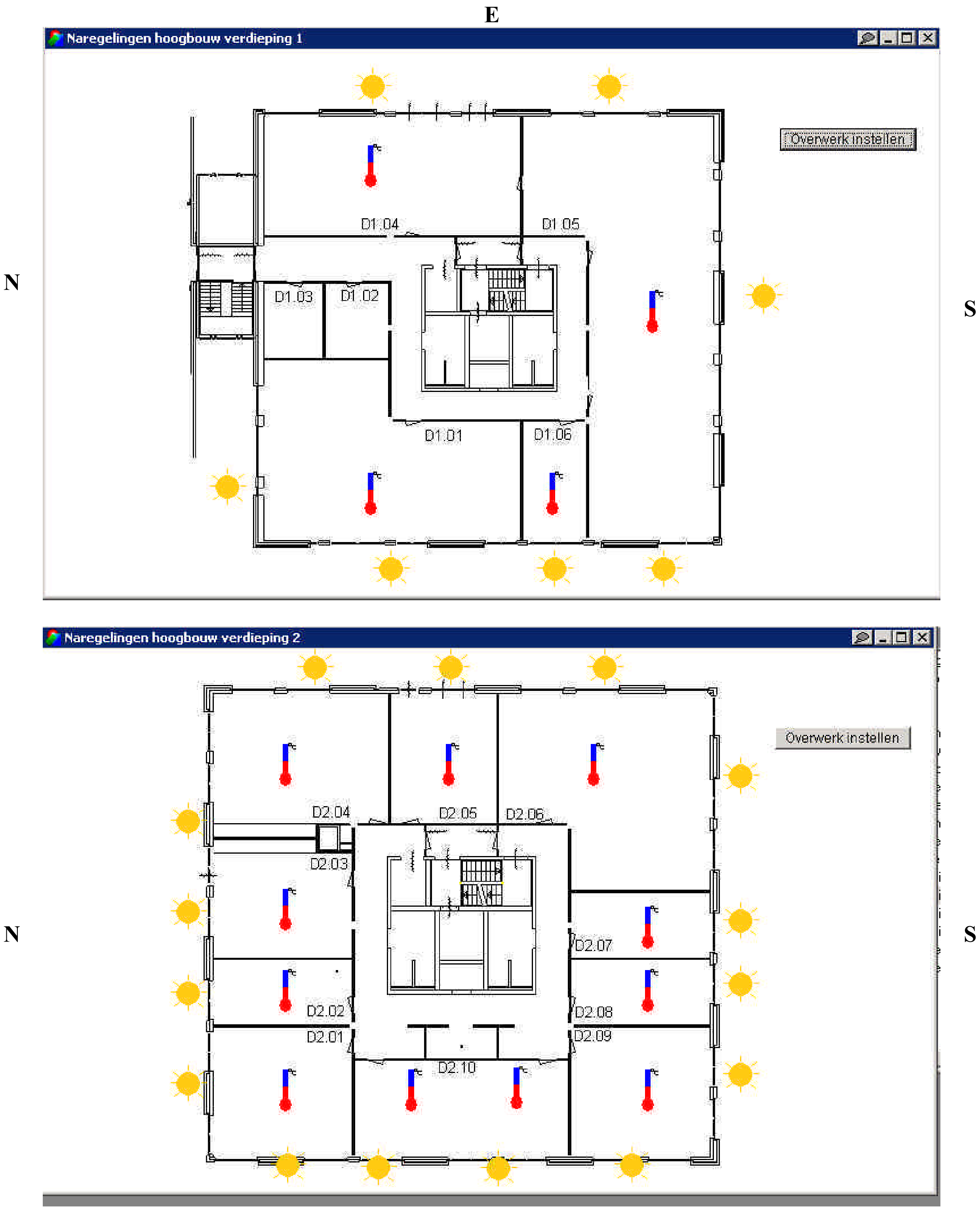


Figure 2-2 Lay-out of the 1st floor (top figure) and 2nd floor (bottom figure) N and S denote the orientation (North and South)

In the following discussion the room numbers as shown in the figure are used extended with an orientation (E,N,S or W) suffix if needed. For instance D2.01 becomes D1.01NW and D2.10 becomes D2.10W.

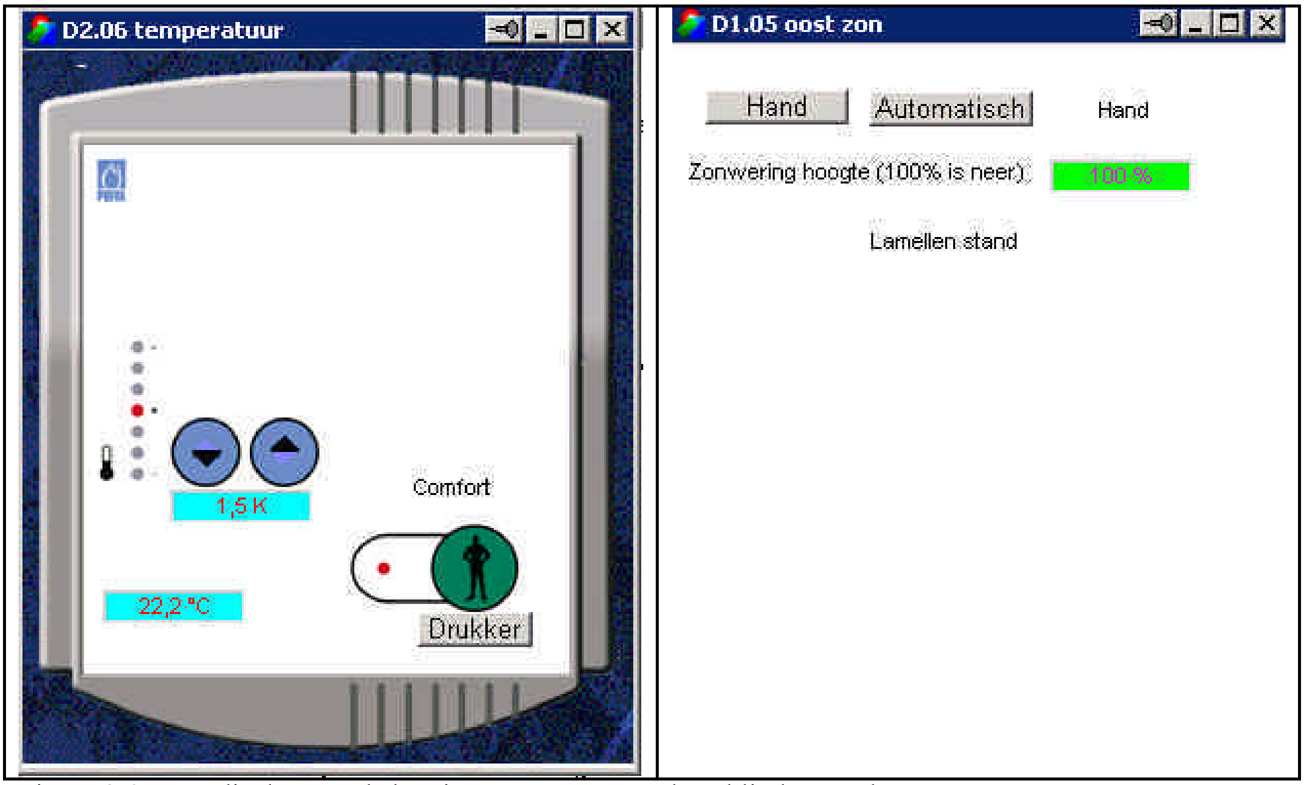


Figure 2-3 User display panel showing temperature and sunblind control

The display on the user interface, shown above, allows a user to indicate presence (the "Drukker"-button) and an installable set-point correction of up to 3.0 degrees C up and down. The right screen enables the user to manually control the sunblinds.

3. Building simulation calculations

The SMART software performs real-time calculations to account for the effects of control operations on the behaviour of the building. SMART has a built-in physical model of the total building and each of the individual building segments and of the installation. An elaborate, commercial building physics package, TRNSYS [TRNSYS,2001], is used to model the building extensively over the time-span of a complete reference year. The TRNSYS runs yield a number of tables describing the behaviour of the building over a period of one year in a number of standard, reference conditions. The SMART shell makes a mapping of these data to a particular run of the optimisation kernel under actual conditions for doing a certain optimisation at a certain time with a certain time-horizon. In this chapter, the assumptions made with respect to the building physics and the installation model is described.

The first and the second floor of the Kropman building are simulated in TRNSYS. TRNSYS is a thermal simulation program for buildings. In this program, a lot of data of the office is entered. The model needs data about construction materials (area, specific gravity, heat transfer coefficient, specific heat, absorption and reflection coefficients), desired room temperatures, ventilation fold, infiltration fold, orientation of the walls of the office and the internal heat production.

The outputs of the simulation are for example the heating demand and cooling demands of the thermal zones and the temperature in these thermal zones for each timestep of the simulation.

3.1 Thermal zones in the building

In TRNSYS the first and second floor of the building are divided into 22 thermal zones. A characteristic of a zone is correspondence in room temperature, ventilationfold, infiltrationfold and internal heat production. From these 22 zones, 16 zones are office rooms (each office room is a thermal zone) and the other 6 zones are corridors, a stairwell and the space between the false ceilings and the architectural ceilings.

3.2 Architectural information

On the basis of drawings of the office, all wall areas of all thermal zones have been determined. The outside walls consist of calcium silicate brick, mineral wool, an air cavity and brickwork construction. The insulation value of the outside walls is 3.8 m2 K/W. The insulation value of the windows is 1.7 W/m2 K. The architectural ceiling is made of concrete and the false ceiling is made of insulation material with an insulation value of 0.7 m2K/W.

The building is provided with outdoor sunblinds. These sunblinds will go down automatically during working hours. The people in the office can manually adjust the angle of the lamellas of the sunblinds. In a simulation it is difficult to simulate the behaviour of the people working in the office. In the model, the sunblinds go down (with open lamellas) during working hours (on working days between 8:00 AM and 5:00 PM). During this period, 15 % of all incident radiation on the windows will be reflected. When the lamellas of the sunblinds are closed, 75 % of all radiation will be reflected. The criteria for closing the lamellas of the sunblinds in the model are:

- Beam radiation on the window > 70 W/m2
- Temperature in the office > 22 °C

Hourly weather data of the Test Reference Year (TRY) of KNMI in the Netherlands (de Bilt) were used for the simulations. The TRY is based on measurements during the years 1971 – 1980.

3.3 Internal heat loads

The internal heat load for each thermal zone is calculated as a function of time during one working week. The assumptions about the usage of the equipment and the presence of persons in the office rooms are the following:

- There will only be an internal heat load during working hours.
- The working hours are from 8:00 AM till 5:00 PM, from Monday till Friday.
- Heat load per person 75 W
- Heat load per Computer 96 W
- Heat load per fluorescent tube 42 W
- Heat load per spotlight 52 W

For each thermal zone in the building the number of persons, computers and lightning is known. With the heat dissipation above, the total internal heat production for each thermal zone is determined and fed into the model. With a total number of 26 people, 26 computers, 95 fluorescent tubes and 12 spotlights on the first floor, the total internal heat load (for the whole floor) is app. 9.0 kW. With a total number of 18 people, 18 computers, 91 fluorescent tubes and 12 spotlights on the second floor, the total internal heat load is app. 7.5 kW.

3.4 Ventilation

The office building is provided with a HVAC unit. The air quantities of each office room are determined from the construction drawings of the office. In these drawings, the number of ventilation air inlets is indicated. With a fresh airflow rate of 140 m3/hr per grid, the total inlet air quantity is known. With these air quantities, the ventilation fold can be calculated. The ventilation folds of the office rooms vary from 1.7 to 2.8.

The incoming ventilation air is preheated (or cooled) before entering office rooms. The air inlet temperature will be heated (or cooled) according to a heating curve. The graph in Figure 3-1 shows the relation between the outside temperature and the air inlet temperature.

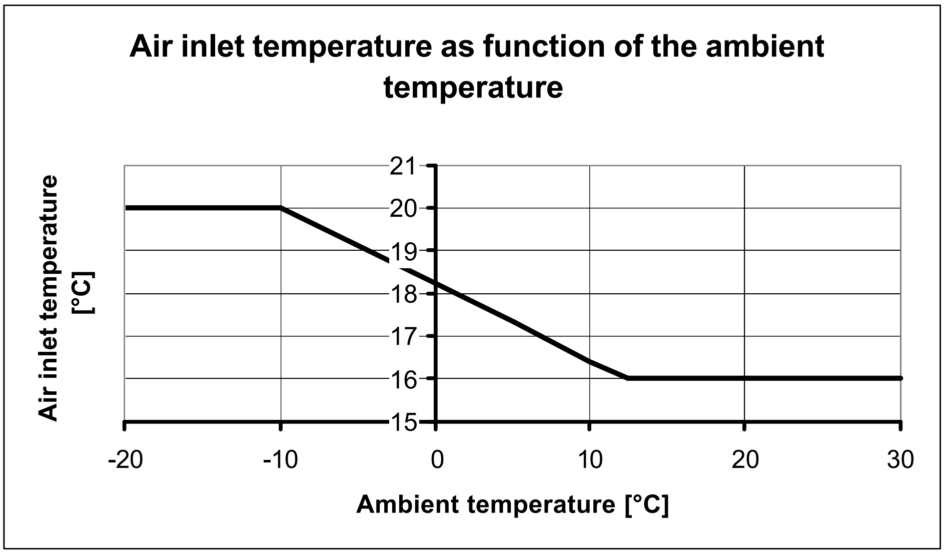


Figure 3-1 Air inlet temperature as function of ambient temperature

The ventilation air is heated by 2 heat exchangers. One heat exchanger is connected to a heat exchanger in the exhaust air. In this way, heat is recovered from the exhaust air. The second heat exchanger is connected to the hot water system.

In reality, the control strategy for using heat recovery is rather complex. Moreover it is difficult to determine the efficiency of the heat recovery system. Because of these reasons, the heat recovery is modelled in a simpler way. It is to be assumed that the heat exchanger for heat recovery has a temperature efficiency of 50 %. If the ambient temperature is higher than 14 °C, the heat recovery system is switched off.

All ventilation air will enter through ventilation inlets, fixed in the false ceiling of each office room. The exhaust pipes for the ventilation air are installed in the space between the false and the architectural ceiling. Because from a model perspective, the space between the false and the architectural ceiling is a different zone than the office zones below, there will be a coupling airflow between these zones.

3.5 Room heating

All office rooms are provided with radiators, connected with the central heating system. The temperature set-point for room heating is adjustable by the user. The user has the possibility to adjust the set-point by 3 °C. In the model, a fixed set-point of 20 °C is used during working hours and 16 °C outside working hours. In a model, it is not possible to simulate the behaviour of the people and that is, why a fixed temperature set-point for room heating is used.

In the model, the central heating system is not modelled. Instead of the heating input of the radiators in the room, the heat demand is calculated. The heat demand is the amount of energy that is needed to keep the room at the desired room temperature, and depends on the ambient temperature, solar radiation, ventilation, infiltration, transmission and internal heat production. In fact, it is the energy quantity that is supplied with a heating system with an ideal control system.

3.6 Room cooling

The office is provided with a central air conditioner to cool the office in summertime. Blowing in cold air will cool the office. The air will be cooled in two ways: centrally and locally. The inlet air will be cooled centrally in the HVAC unit. In this unit there is a heat exchanger for cooling. With this heat exchanger, the air will be cooled down to 16 °C at the least, depending on the ambient temperature (see Figure 3-1).

The temperature set-point for cooling is adjustable, just as it is for heating. The user has the possibility to adjust the set-point by 3 °C. In the model, the temperature set-point for cooling is 22 °C. In a model it is not possible to simulate the behaviour of the people and that is why a fixed temperature set-point for cooling is used.

All false ceilings of the office rooms are provided with a ventilation grid with integrated air circulation. This grid supplies not only the ventilation air, but also a substantial part of room air (recirculation air). The ratio between the ventilation air and the recirculation air is app. 1:3. This total air quantity is cooled before it is blown in. To cool the total air quantity, all grids are connected to a cold water circuit.

The water flow to these grids is controlled to reach the desired air temperature in the office. In the model, it is not possible to simulate this, because the cold-water flow rates through the collector are not known. It is hardly impossible to calculate these flow rates, because these flow rates are dependent on the total resistance in the pipes and this resistance changes constantly (by opening and closing valves for cooling).

For this reason, a simplification is used in the model. It is assumed that all cooling grids have a fixed cooling power. This cooling power will be used maximal if the temperature in the room is 1.5 °C or more higher than the temperature set-point for cooling (22 °C). In the model, a proportional controller is used. Determining the cooling power of the cooling grid is not very easy, because this depends on the cold-water flow, the cold water supply temperature and the room temperature. In the model a fixed cooling power per meter grid is used.

Results of the simulation

The simulation is run for a period of one year. The main results of the simulation are as discussed below.

3.7 Heat demand

In the following figure the heat demand of the central heating system and the heat demand for the ventilation air is shown.

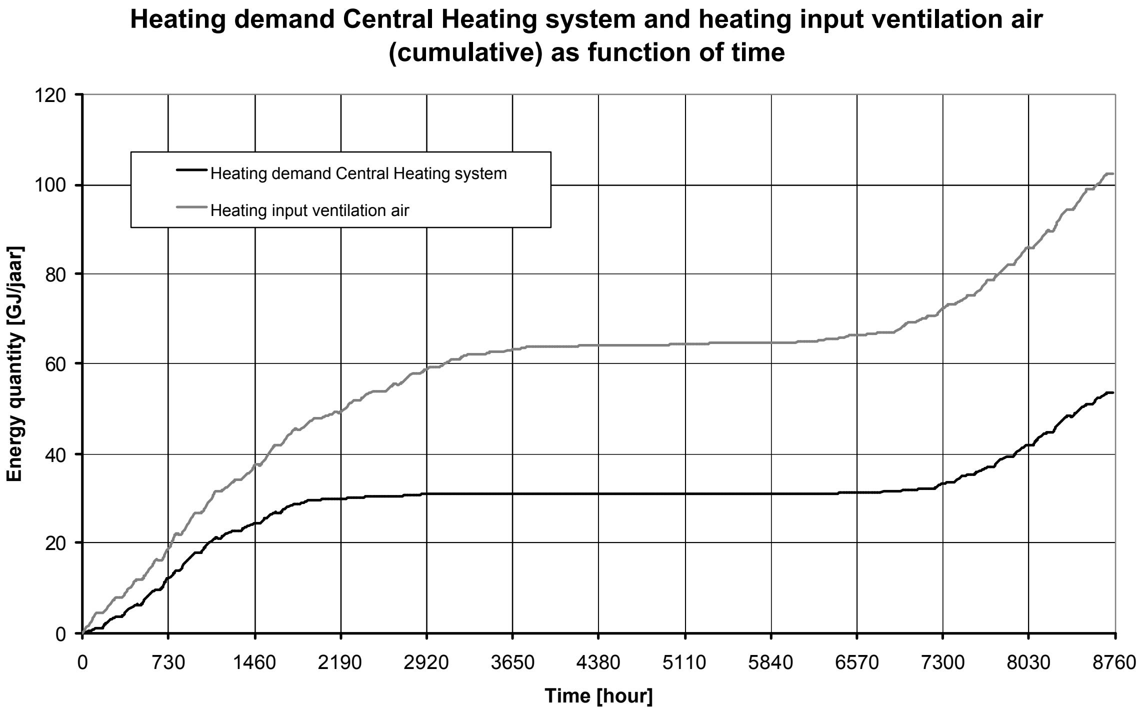


Figure 3-2 Heating energy quantities as a function of time

The graph shows the cumulative energy required for central room heating and for heating ventilation air. The energy quantity for heating the ventilation air is the energy quantity that is needed excluding the energy that will be recovered from the exhaust air. The graph only concerns the heat demand of the first and second floor of the building.

The results of the simulation show that the annual energy quantity that is needed for preheating the ventilation air is app. twice the energy quantity that is needed for the central heating system (respectively 102.4 and 53.5 GJ a year). The energy quantity for preheating the ventilation air is strongly dependent of the efficiency of the heat recovery system. Because the heat recovery system is simulated in a simpler way, the energy quantity can deviate somewhat from the actual value. In spite of the uncertainty in the energy quantity for heating the ventilation air, this energy quantity is an important part of the total energy quantity for heating an office building. This energy quantity also shows the necessity of a high efficient heat recovery system in the HVAC unit.

3.8 Room temperatures

In Figure 3-3 the cooling energy in the HVAC unit and the cooling input for the air in the ventilation grids are shown.

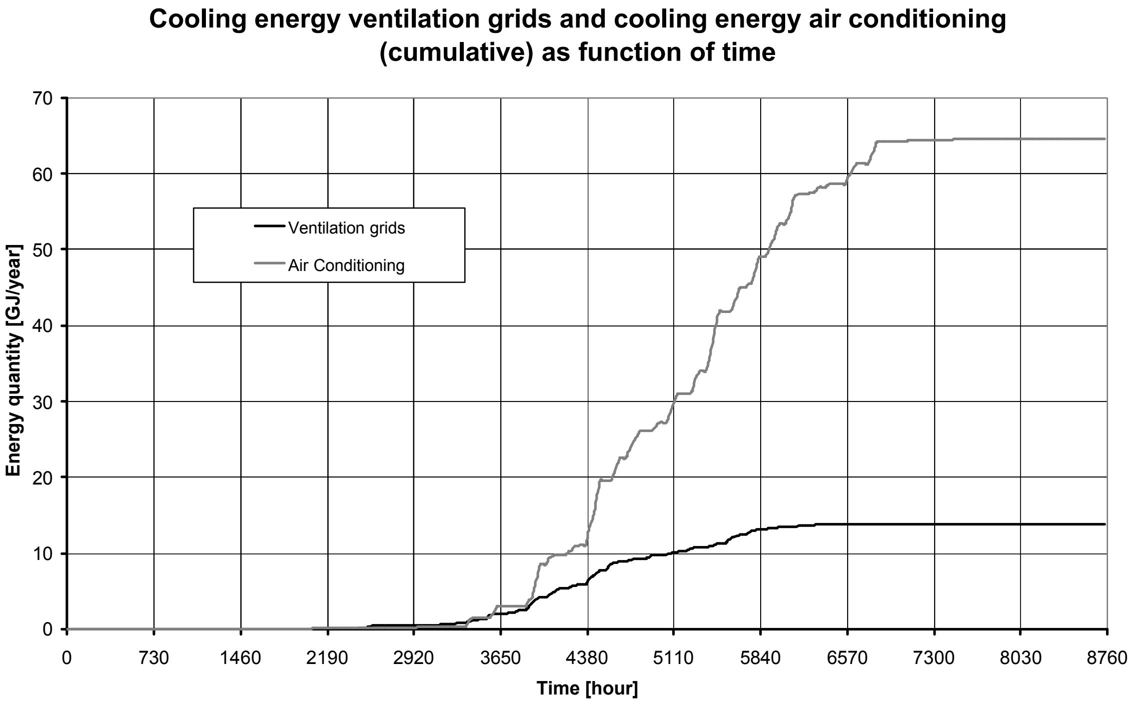


Figure 3-3 Cooling energy quantities as a function of time

The graph shows that the required cooling energy in the HVAC unit is much larger than the energy quantity that is needed for cooling the air in the ventilation grids (respectively 64.5 and 13.9 GJ per year). This big difference in cooling energy can be explained by the fact that by cooling the air in the HVAC unit, the air will also be dehumidified (absolute humidity decreases). Although the ventilation air is not controlled on a minimum relative humidity, there will always be dehumidification. Because the evaporation heat capacity of water is relatively high, a large amount of cooling energy is needed for dehumidification.

There is no condensation[4], thus no dehumidification necessary, in the ventilation grids of the air because the cold water supply temperature is at least 16 °C. In periods with an absolute humidity of 11.5 gr./kg dry air (20 °C, 80 % RH or 25 °C, 55 % RH), there can be no dehumidification. The ventilation grids only decrease the temperature of the ventilation air (and do not dehumidify) and this is the reason that the annual energy quantity for the ventilation grids is much lower than the energy that is needed for cooling in the HVAC unit.

3.9 Room temperatures

TRNSYS also calculates the air temperatures in all thermal zones and after each timestep of the simulation. In the graph in Figure 3-4 the air temperature during a period of one year is shown for 2 office rooms on the first floor. The temperatures that are shown are the temperatures at 2:00 PM for every day of the year.

[4] Due to cooling in summer air is dehumidified

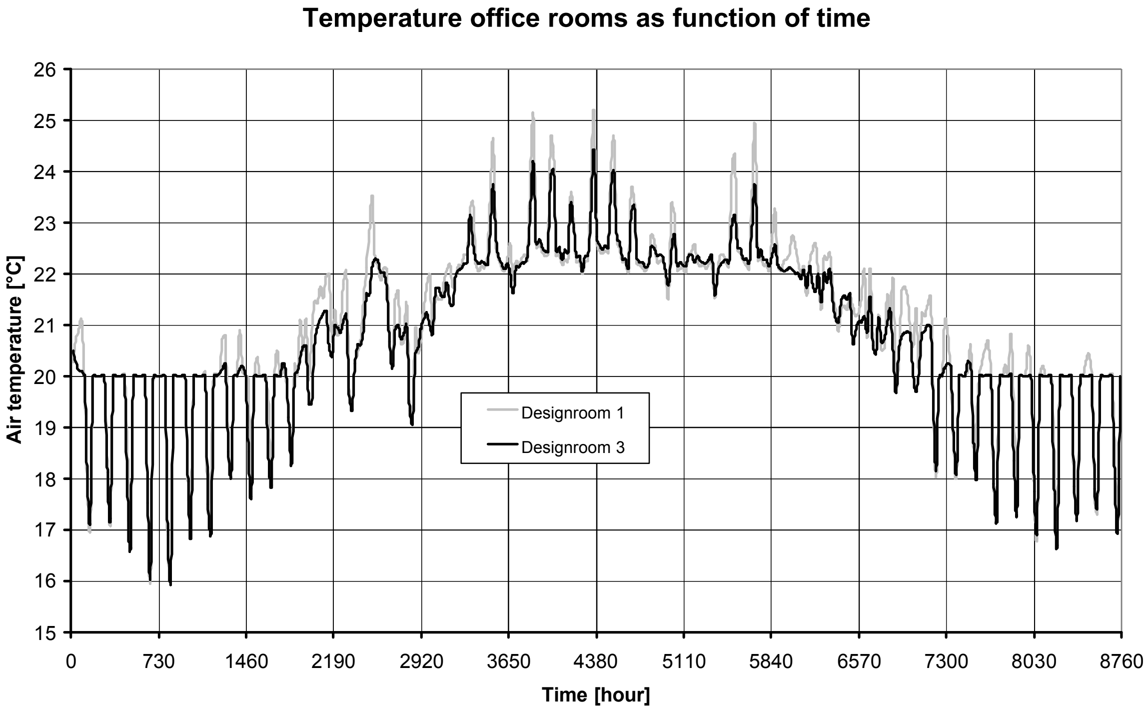


Figure 3-4 Air temperatures in 2 office rooms as a function of time

In the beginning of the year, the maximum temperature (for design room 1; D1.05) is app. 21 °C. This is caused by a relatively warm January day. After this day, the maximum temperature is 20 °C for a long time, corresponding to the set-point for room heating that is used in the simulations. The minimum temperature is 16 °C, this is the temperature set-point during the nights and weekends. The minimum temperatures shown in the graph in the beginning and at the end of the year are the temperatures in the weekends.

The maximum temperature in design room 1 is higher than the one in design room 3 (D1.04). This is caused by the difference in orientation between the 2 office rooms. Design room 1 has app. 12 m2 windows on a Southwest orientation and app. 9 m2 on a Northwest orientation, while design room 3 has app. 15 m2 on a Northeast orientation. The total window area of design room 1 is much larger that the window area of design room 3 and moreover there is more solar radiation on a Southwest orientation (design room 1; D1.01) than on a Northwest orientation (design room 2). This causes higher temperatures in summertime.

4. The building model in SEBOS

In order to use the inputs and results of the simulations of TRNSYS [Czlepak, 2002] and to process the user responses in SEBOS, a number of tables have to be filled with data as an input for the optimiser. This section describes in a stepwise fashion how this transformation is done.

4.1 Tailoring the SEBOS-shell; adaptations to version 1.0

In doing model calculations of the building in SMART, first a number of dry runs were performed to obtain numerical stability. To start with, parameters get their DryRun value. The DryRun value consists of a short week pattern description with first the default value, then after WD[5](timeStart-timeEnd) the working days value and after SS the Saturday Sunday value.

Then, a number of shadow runs using real-time data from the building were performed to balance the model. Thereafter actual real-time control of the installation takes place. During these runs apart from real-time data, data as expected in the near future are necessary. These data may be built up during a logging phase, but they also may be updated continuously in a circular buffer structure. In a directory PersistenceDirectory recently measured signals are stored. Availability of persistence data is a new feature in SEBOS.

Ventilation treatment. The variable `AirSpeed` (i.e. flow rate) can be made dependent on the ventilation strategy keywords. In the Kropman Nijmegen case possible values are ”`Uit`”, “`Standby`”, “`Comfort`”, “`Ventilation`” and “`RuimteTemp. Bewaking`”. Ventilation is discriminated in Interzonal Airflows, Infiltration Airflows and forced ventilation Airflows from the ventilation units.

4.2 Buildings materials description

The materials separating the building segments are shown in Table 4-1.

Table 4-1 Building material types in the Kropman building

```
SeparatorMaterials
DUNBUGEVEL               TransmissionCoefficient 0.253 HeatCapacityContribution 84000
PANEEL                  TransmissionCoefficient 0.242 HeatCapacityContribution 84000
DIKBUGEVEL               TransmissionCoefficient 0.245 HeatCapacityContribution 84000
BINNEN                   TransmissionCoefficient 0.518 HeatCapacityContribution 12359
BINNENDEUR         TransmissionCoefficient 0.855 HeatCapacityContribution 17280
VLOER                    TransmissionCoefficient 3.188 HeatCapacityContribution 84000
VERLPLAF                 TransmissionCoefficient 1.524 HeatCapacityContribution 0
TUSSENM           TransmissionCoefficient 1.326 HeatCapacityContribution 84000
MIDDENMUUR               TransmissionCoefficient 3.316 HeatCapacityContribution 105000
BIN107                   TransmissionCoefficient 0.381 HeatCapacityContribution 13277
BUITENDEUR   TransmissionCoefficient 0.855 HeatCapacityContribution 17280
EndSeparatorMaterials
```

The added keyword for the `HeatCapacityContribution` (in W/Km^2) denotes the contribution of the material to the heat capacity of the segment per m^2. This allows a considerably easier and more accurate heat-capacity calculation per segment. Furthermore it is possible to better describe the process of heat transfer by radiation take-up in the building materials in this way.

[5] Working day pattern descriptor

4.3 Segment description

For the segments used in the experiment, volumes and ventilation folds are defined as shown in Table 4-2. A zero `HeatCapacity` indicates, that, apart from the wall contributions, there is no additional contribution (from furniture etc.) in the model.

Table 4-2 Building segments used

```
BuildingSegments
       D1.01 HeatCapacity 0. Volume 329.37 OutsideInfiltrationFold 0.25
       D1.02 HeatCapacity 0. Volume 41.58 OutsideInfiltrationFold 0.25
       D1.03 HeatCapacity 0. Volume 37.72 OutsideInfiltrationFold 0.25
       D1.04 HeatCapacity 0. Volume 265.17 OutsideInfiltrationFold 0.25
       D1.05 HeatCapacity 0. Volume 522.47 OutsideInfiltrationFold 0.25
       D1.06 HeatCapacity 0. Volume 65.68 OutsideInfiltrationFold 0.25
       GANGEER HeatCapacity 0. Volume 208.55 OutsideInfiltrationFold 0.
       TUSSENBEG HeatCapacity 0. Volume 177.01      OutsideInfiltrationFold 0.
       TUSSENEER HeatCapacity 0. Volume 177.01      OutsideInfiltrationFold 0.

       MIDDEN HeatCapacity 0. Volume 316.23  OutsideInfiltrationFold 0.

       GANGTWEE HeatCapacity 0. Volume 213.24       OutsideInfiltrationFold 0.
       D2.01 HeatCapacity 0. Volume 127.62 OutsideInfiltrationFold 0.25
       D2.02 HeatCapacity 0. Volume 64.97 OutsideInfiltrationFold 0.25
       D2.03 HeatCapacity 0. Volume 103.73 OutsideInfiltrationFold 0.25
       D2.04 HeatCapacity 0. Volume 162.54 OutsideInfiltrationFold 0.25
       D2.05 HeatCapacity 0. Volume 100.17 OutsideInfiltrationFold 0.25
       D2.06 HeatCapacity 0. Volume 265.94 OutsideInfiltrationFold 0.25
       D2.08 HeatCapacity 0. Volume 64.88 OutsideInfiltrationFold 0.25
       D2.07 HeatCapacity 0. Volume 64.88 OutsideInfiltrationFold 0.25
       D2.09 HeatCapacity 0. Volume 129.25 OutsideInfiltrationFold 0.25
       D2.10 HeatCapacity 0. Volume 150.17 OutsideInfiltrationFold 0.25
       TUSSENTWEE HeatCapacity 0. Volume 177.01 OutsideInfiltrationFold 0.
EndBuildingSegments
```

As can be seen, the `HeatCapacity` is set to zero in the input. Instead it is accounted for and computed from the area of the separator materials. An additional keyword `OutsideInfiltrationFold` is added to account for the infiltration (outside air entering through cracks and crevices).

A large variety of segment orientations and segment sizes is present. Segments `TUSSENEER` and `TUSSENTWEE` are introduced to account for the air exhaust system via the ceiling. The `MIDDEN` segment is the segment connecting the floors to other parts of the Kropman building. As an example, a segment definition in terms of confining separators is shown in Table 4-3. With the segment and separator definitions the complete static physical properties and the ventilation regime is described.

Table 4-3 Sample segment definition

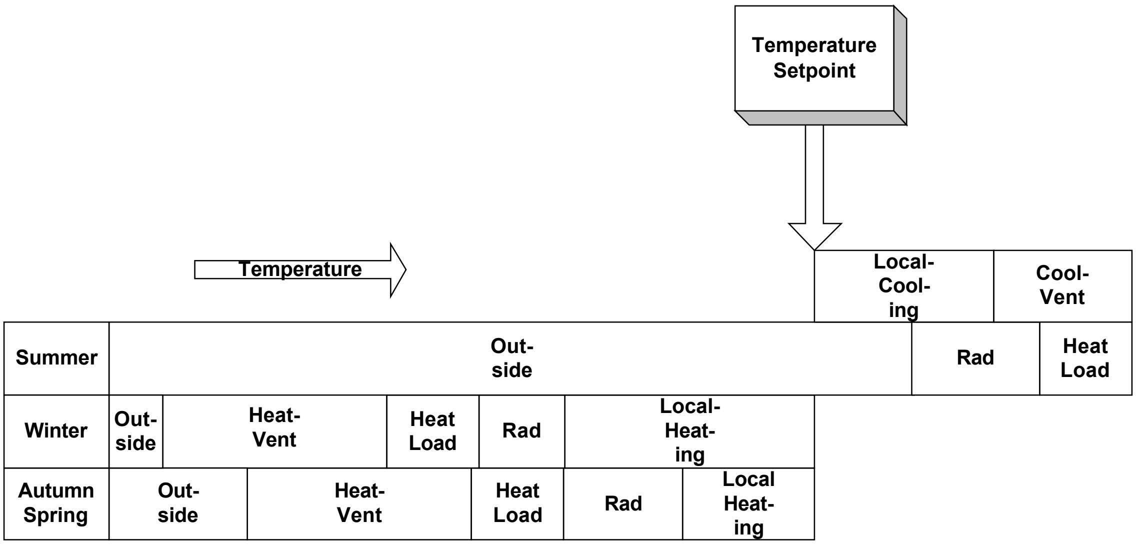
```
Separators
       //     D1.01
       // two sides exposed to outside
       DUNBUGEVEL     Separates      D1.01   OUTSIDEMODEL   Area   22.49
       PANEEL   Separates            D1.01   OUTSIDEMODEL   Area   2.96
       DIKBUGEVEL     Separates      D1.01   OUTSIDEMODEL   Area   16.81
       PANEEL   Separates            D1.01   OUTSIDEMODEL   Area   2.41
// adjacent walls
       BINNEN   Separates            D1.01   D1.03    Area         8.64

      BINNEN   Separates             D1.01   D1.02    Area         9.45
       BINNEN   Separates            D1.01   GANGEER        Area   26.82
       BINNENDEUR     Separates      D1.01   GANGEER        Area   1.8
       BINNEN   Separates            D1.01   D1.06    Area         18.9
       // upside and downside
       VLOER    Separ     ates       D1.01   TUSSENBEG      Area   121.99
       VERLPLAF       Separates      D1.01   TUSSENEER      Area   121.99

...........
```

4.4 Climate control in the segments

Table 4-4 Thermal contributions in building the ambient temperature



The factors contributing to building up the temperature in a room are depicted in Table 4-4. Outside refers the temperature outside dependent upon the season. Heatvent/Coolvent gives the contribution from the central ventilation system to the room temperature; Rad gives the radiative component and local heating/cooling the impact of the local post-treatment units. In the table, a distinction is made between the summer, winter and the autumn/spring situation. The central ventilation system performs one part of the climate control in the building (HeatVent/CoolVent); the local cooling and ventilation another part. The strategy and installation components involved depend upon the season.

Winter:
Heated air at about room temperature (ca. 18-20 °C) runs through the central ventilation system according to an outside temperature dependent heating curve. During working hours the air enters into the rooms at a fixed flow rate. At night and in the weekends the ventilation system is turned off.

Summer:
Cooled air (approx. 18 °C) runs through the central ventilation system. During working hours the cool air enters the rooms at a fixed flow rate. At night and in the weekends the ventilation system is turned off. At the segment level the in-blown air can be cooled further by a cooling water system at a temperature of approx. 16-18 °C, varying over time (using a 'cooling curve'). The local air flow consists of ¼ of in-blown (cool) air and ¾ recirculated air from the segment.

The HeatVent and CoolVent contributions are centrally controlled and defined by an air volume and the measured temperature of the air in the piping and the current temperature in the segment. This means that in winter a gas-fired heater preheats the inlet airflow and in summer, an electric cooling machine cools the inlet airflow. The heat load is composed of people (each contributing approximately 75 W) and electrical equipment. The solar radiation contribution is orientation and time-of-day dependent and are used by SEBOS to prevent cold losses during winter nights or for preheating segments in sunny early spring and autumn early mornings in an intelligent way.

4.5 Solar contribution to the thermal comfort in segments

4.5.1 Solar transmitter model

Solar transmission control is specified differently as compared to version 1 of SEBOS. A sample definition is shown in Table 4-1. Solar transmission models the attributes of windows and the window solar screens.

Table 4-4 Solar transmission height control definition

```
SolarTransmitters
//
//      ZONE D1.01

HRDPlus Separates D1.01 OUTSIDEMODEL Area 12.49 WattsDirect DIRSW WattsDiffuse DIFSW
        Orientation HoekSW CoverageModel "BewolkingsFactor" LightIntensity DIRSW
        SolarTransmissionController Luxaflex
        SunblindHeightControl D1.01SunblindHeightControlWest
        ControlledArea 12.49
        ControlValue
        WorkingTimeSetting    100.
        NonWorkingTimeSetting 0.
        Forbidden SunblindControlSwitch D1.01SunblindControlSwitchWest ByHand
```

Apart from stating the signal names in the `ivcomserver`-namespace, a `Forbidden` keyword is added. The sample illustrates, that Sunblind height control of `D1.01SunblindHeightControlWest` is allowed unless the `SunBlind-ControlSwitchWest` is set to `ByHand`. The latter will be the case when the presence-button is activated. The sunblind setting has to be known within the SEBOS to be able to calculate the local, radiation induced warming from the sun by direct or indirect radiation incidence or cooling from the sky. In calculations, predicting the building behaviour, it is assumed, that during non-working hours, SEBOS is allowed to utilise the sunblinds for additional heating in autumn and spring, to avoid cooling in wintertime from clear skies and to prevent excessive heating in summer.

Incoming radiation data from the TRNSYS-package pertain to the incoming angle for all relevant orientations during a year for the current geographic location. These data are used to calculate the attenuation of direct sunlight. Furthermore, the incoming indirect and direct contribution in W per m^2 for different degrees of cloud coverage is available for the various orientations. The cloud coverage is estimated from the readings of four radiation sensors at four locations on top of the building as described further on.

If the sunblinds shade off too much of the daylight and people are working in the segment, the lights near the windows are switched on automatically.

4.5.2 The solar transmission control model

The user and the building management system may operate the sunblinds. They may be smoothly operated from 0-100 % dependent on the amount of heat to import or export. Sunblinds are assumed to block the direct radiation completely and to be transparent to the indirect radiation. During runs making assumptions extending to working hours, operation of the sunblinds is assumed to follow operation of the working days before with a similar coverage factor. The sunblinds in the building can be controlled; for the segments at the corners of the building, that have windows to two different orientations, the one receiving direct solar radiation is controlled. The effect of the extra lighting on comfort, cost and energy is small in comparison with other measures. Therefore, this effect is neglected in the optimisation. This leads to a similar

SolarTransmissionControl model as we used in SEBOS [SEBOS-FA, 2003]. The presence of measurement devices in the four orientations of the building enables estimation of the real-time solar incidence in rooms and calculation of the effect in each room as a function of the orientation. From the individual measurements in the four orientations a CloudCoverageFactor for daylight time is determined according to [Czlepak, 2002]:

$$CloudCoverageFactor = (1.4286 * (diffuseHorizontal / totalHorizontal) - 0.3)^{1/2}$$

In using the four individual measurements, the approximation is made, that the lowest measured value represents the indirect, diffuse contribution of the sunlight. This contribution is subtracted from the other three measurements, which then are summed to give the total horizontal contribution.

4.6 Thermal comfort installations serving the building as a whole for ventilation

The building has central installations controlling the air temperature for ventilation purposes and the water temperature for the radiators. Ventilated air can be pre-cooled in summer and preheated in winter. The set-points of these installation parts are controlled by the building management systems according to an outside temperature dependent heating and cooling curve (see Figure 3-1 for the latter).

4.6.1 Interzonal airflows

Interzonal airflows are produced by the water-cooled, air heated/cooled ventilation system. This system distributes centrally generated preheated or cooled air, generated with a certain temperature set-point, to all the segments. Typical set-point values are between 16 and 18 °C. The ventilation system performs the main part of climate control in the building. The strategy and installation components involved depend upon the season. Individual room temperature customisation for heating is done by water radiators and for cooling by convection units in the ceiling. Inblown air is withdrawn from the segments by interzonal airflows, as described in Table 4-5. The air leaving one segment is blown into other segments. From model calculations it follows, that a possible contribution to the overall cooling capacity from the convection units is limited.

Table 4-5 Definition of the ventilation system

```
WatercooledVentilationInstallation Hoogbouw
ElectricityInMax 2000.
GasInMax 4000.
CoolingCapacity 2300
HeatingCapacity 2500
OffWorkinghoursVentilationMultiplier 0.1
ForcedCoolingVentilationMultiplier 5.
InterzonalAirFlows
       From   D1.01  To     TUSSENEER     Volume  700
       From   D1.06  To     TUSSENEER     Volume  140
       From   D1.05  To     TUSSENEER     Volume  1120
       From   D1.04  To     TUSSENEER     Volume  560
       From   D1.03  To     TUSSENEER     Volume  140
       From   D2.01  To     TUSSENTWEE    Volume  280
       From   D2.02  To     TUSSENTWEE    Volume  140
       From   D2.10  To     TUSSENTWEE    Volume  420
       From   D2.09  To     TUSSENTWEE    Volume  280
       From   D2.07  To     TUSSENTWEE    Volume  140
       From   D2.08  To     TUSSENTWEE    Volume  140
       From   D2.06  To     TUSSENTWEE    Volume  560
       From   D2.05  To     TUSSENTWEE    Volume  140
       From   D2.04  To     TUSSENTWEE    Volume  280
       From   D2.03  To     TUSSENTWEE    Volume  280
EndInterzonalAirFlows
```

The new keywords `OffWorkingHoursVentilationMultiplier` and `Forced-CoolingVentilationMultiplier` reflect the reduced and enhanced ventilation strategies as opposed to the regular ventilation volumes. So it is assumed, that the airflow enters the room at the Ventilation system's inlets and leaves through the air suction units in the ceiling with the volumes as defined above.

4.7 Internal heat loads

The internal heat load for each building segment is calculated by SEBOS as a function of time during one working week. The assumptions about the usage of the equipment and population of the workplaces are stated in 3.3.

4.8 Local thermal comfort aspect controls in building segments

Of key importance in the SMART-system are the local controllers of installation parts, which control the inner comfort. From SMART model calculations, optimal settings for these controllers are calculated using agent algorithms. In this SMART implementation two local controllers are included.

4.8.1 WaterRadiators

Table 4-6 Water radiator definition (see also section 6.4.2 for a complete description).

```
WaterRadiator D1.01HeaterControl
        In D1.01
        ConnectedTo RadiatorGroep1
        Capacity 39837.6// W
        ControlValue WorkingTimeSetting 19. NonWorkingTimeSetting 15.
```

Water radiators increase the temperature level in a room to the room defined temperature set-point. The Capacity of these radiators is the capacity at the maximum water temperature. Water radiators have variable control setting to import heat in a room from a central water heating installation. The set-point of the temperature of the water in this installation also is a variable. A possible energy efficiency opportunity can be found in adapting the central set-point of the central heating water temperature in the radiators. The Control Values are the set-points used as a first initial guess for doing dry-runs with the optimiser.

4.8.2 AirInlets

The description of air inlets can be found in Table 4-7. Air inlets are connected to the central ventilation unit, which delivers air at a certain temperature and cooling water at another temperature.

Table 4-7 Definition of an air inlet

```
AirInlet D1.01CoolerControl
        In D1.01
        ConnectedTo Hoogbouw
        AirVolume 700 // # of cubic meters per hours
        Capacity 1341.
        ControlValue WorkingTimeSetting 22. NonWorkingTimeSetting 25.
```

The temperature of the in-blow air depends on the central set point, the temperature of the water flowing through the inlet and the flow rate. This makes it very difficult to control the amount of cold delivered to a building segment.

4.8.3 Operating local thermal comfort installation parts in building segments

A building segment has one or more water-radiators attached to the walls, as well as air cooling/warming units on the ceiling, attached to the central ventilation system. The water flow in the radiators is controllable using the set point for heating. In winter, ventilation air is preheated to approximately 18 °C; in summer air is cooled to around 16 °C. The ceiling units also contain induction units to additionally cool the air before entering the segment. The water flow of the ceiling units is controlled by comparing the room temperature with the set-point for cooling. The strategy is as depicted in Figure 4-1.

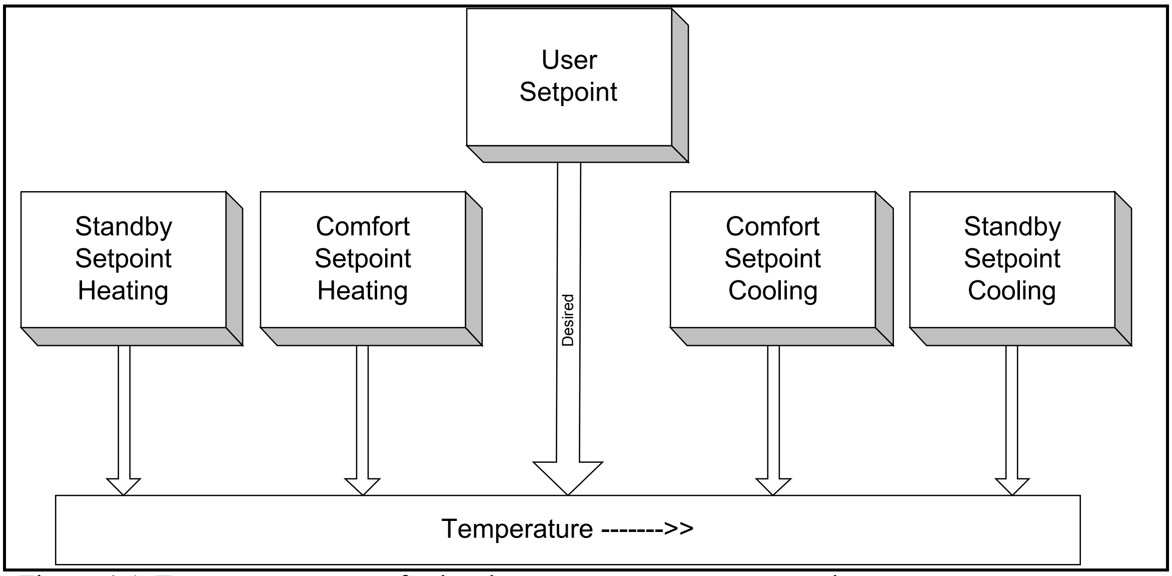


Figure 4-1 Temperature ranges for local segment temperature control

The temperature set-points in the *comfort* strategy typically differ 1 degree from the desired set-point. The *standby* operation mode set-points differ some 5 degrees from the desired value. In *ventilation* mode extra ventilation capacity is used to cool the building on very hot days.
The local controller issues settings for the controllable inlets for the heating water through the radiator and for the flow of cold water through the ceiling unit. This mechanism is linear, but differs for cooling and heating actuators. The characteristics are depicted in Figure 4-2. Finally, there is a mapping function from the emitted control value.

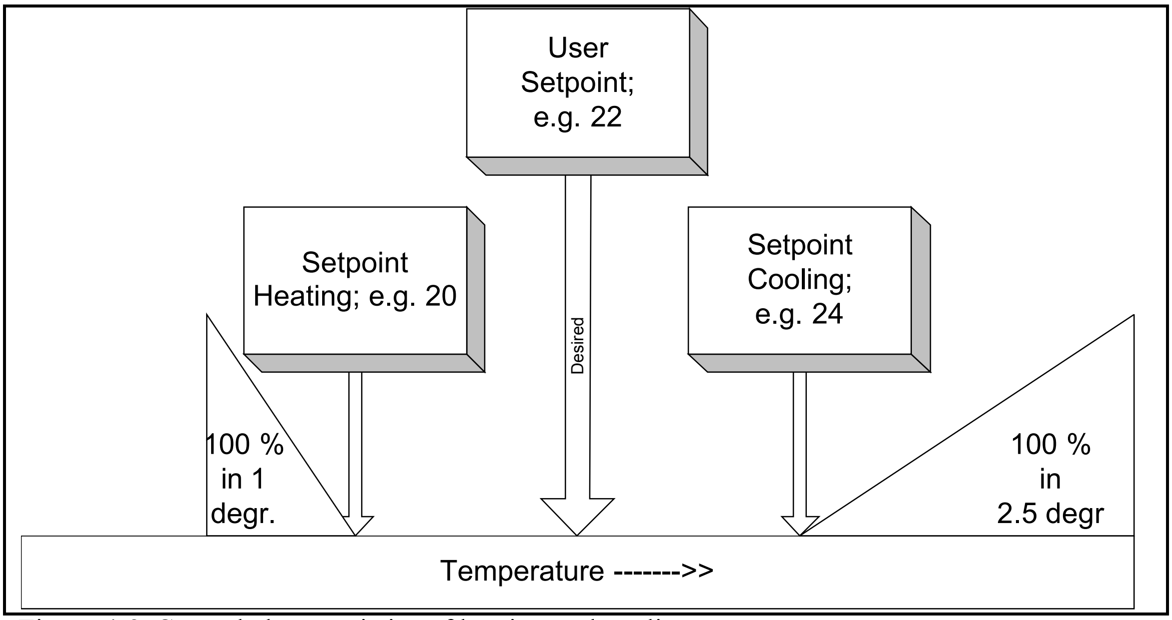


Figure 4-2 Control characteristics of heating and cooling

The actuator has a "dead band" of about 40 %. This means, that at sending out 40 % of a control value, there is a first opening of the valve. This is shown in Figure 4-3.

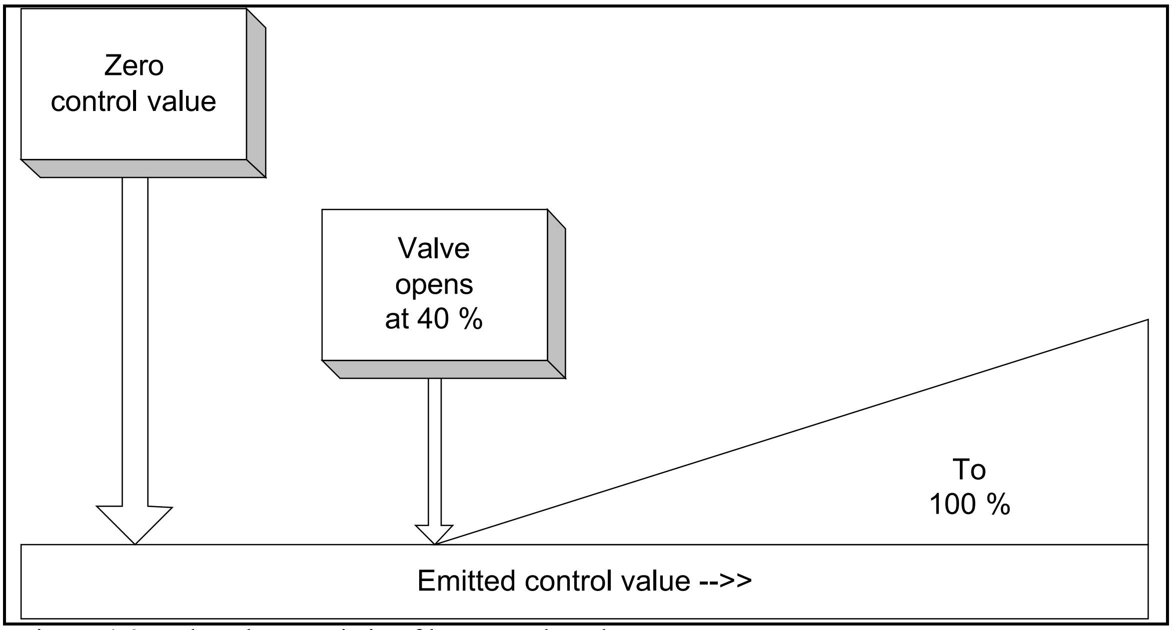


Figure 4-3 Valve characteristic of heater and cooler

Above operation scheme is important in translating the switch settings of comfort aspect controllers as they are used within SEBOS to heat transfers.

4.9 Modelling the meteorological conditions

From a weather station on top of the building the temperature, the wind velocity and direction, the relative humidity and the solar radiation is continuously measured on a vertical plane. The solar radiation is measured in four directions (North, East, South and West).

4.10 Comfort management per room

The layout of the rooms is depicted in Figure 2-2. A number of sensors and actuators are present to influence comfort in a room locally.

4.10.1 Sensors

The equipment and signals used for calculating the current Fanger comfort-index in the building are described Table 4-8.

Table 4-8 Sample signal definition for a room

```
BMSTable
PersistenceDirectory "..\\KropmanNijmegen\\GebouwBeheer\\Persistence"
BuildingSegment D1.01 Sensor AirTemperature
               SubStation "Onderstation-11" SignalName "D1.01TemperatureDisplay"
               Factor  1.0 Offset 0.0
               DayPersistent
               DryRun "16.;WD(7-17)=19.;WD(20-23)=21.;SS(7-17)=20.;WD(20-23)=21."
BuildingSegment D1.01 Sensor RadiationTemperature Assume 20.
BuildingSegment D1.01 Sensor RelativeHumidity
               SubStation "Onderstation-11" SignalName "RelatiefBuitenvocht"
               Factor  1.0 Offset 0.0        DayPersistent
               DryRun "16.;WD(7-17)=19.;WD(20-23)=21.;SS(7-17)=20.;WD(20-23)=21."

BuildingSegment D1.01 Sensor AirSpeed "StandBy=0.1;Comfort=0.1;Cooling=0.4;Off=0.001"
BuildingSegment D1.01 Sensor AirPressure Assume 1.
BuildingSegment D1.01 Sensor WallTemperature
               SubStation "Onderstation-11" SignalName "D1.01TemperatureDisplay"
               Factor  1.0 Offset 0.0
               DayPersistent
               DryRun "16.;WD(7-17)=19.;WD(20-23)=21.;SS(7-17)=20.;WD(20-23)=21."
```

As can be seen, assumptions are made for the wall and radiation temperature, which are not measured. The outside relative humidity is assumed to be present in the whole building, corrected for the occupation of the room and the time-of-year. Dryrun-values are the start-values used in the optimisation.

The SignalNames as defined in the `IVComserver`-interface are described in chapter 7.

4.10.2 Actuators

The signal types used for controlling the comfort aspects in a room are shown in Table 4-9.

The *maximum radiator capacity* depends upon the maximum water temperature. In the current implementation, the optimal water temperature from the central water heating and cooling installation is determined from the local actuator settings. If all radiators or all inlet cooling controllers do not use their full capacity, the central water temperature set-point is adjusted. This mechanism may be used in this case, because the heat-price is considered to be independent of time.

Table 4-9 Actuators on the room level and related sensors

```
ComfortAspectControl D1.01HeaterControl
        Actuator WaterRadiator SubStation "Onderstation-11"
        SignalName "D1.01CurrentTemperatureSet-pointHeating"
        Factor 1.0 Offset 0.0 DryRun 0.1

ComfortAspectControl D1.01CoolerControl
        Actuator AirInlet SubStation "Onderstation-11"
        SignalName "D1.01CurrentTemperatureSet-pointCooling"
        Factor 1.0 Offset 0.0 DryRun 0.1

ComfortAspectControl
        D1.01SunblindHeightControlWest
        Actuator SunblindHeightControl
        SubStation "Onderstation-11"
        SignalName "D1.01SunblindHeigthControlWest"
        Factor 1.0 Offset 0.0 DryRun 0.1

ComfortAspectControl
        D1.01SunblindControlSwitchWest
        Sensor SunblindControlSwitch
        SubStation "Onderstation-11"
        SignalName "D1.01SunblindControlSwitchWest"
        Factor 1.0 Offset 0.0 DayPersistent DryRun 0
```

The actual heat flow from the radiators/coolers into the segment depends on the switch settings (between 0 and 1). As a common figure 70% of this heat flow is convection heat, heating the air in the segment, and 30% of the heat flow is radiation heat, which is absorbed by the construction.
The gross energy needed for the actual heat flow can be calculated using the conversion characteristics (i.e. the efficiency of natural gas combustion) of the central heating installation and the heating value of the consumed resource `NaturalGas`. The energy cost is calculated from the export heat prices of the central heating installation linearly.

As an input to the optimiser kernel, the radiator is defined as follows:

Table 4-10 Radiator definition in optimiser terms (in section 6.4.2 a more extensive specification is given.

```
Radiator <radiatorName>
        ConnectedTo <centralHeatingName>
        Resource Heat
        Capacity <value>
        SwitchingEnergy <value>
        InitialSettingCACSetting CProfile
                { Cprofile }
        EndInitialSettingCACSetting
EndRadiator <radiatorName>
```

The `CACSetting` profile contains the 'switch' settings (between 0 and 1), which determine the percentage of the maximum radiator capacity, used to heat the segment at each period. The `SwitchingEnergy` is set to 0.

The local ventilation controller is defined similarly. Apart from a base-cooling level, which is established by the ventilation air, there is a local cooling control. This local controller is connected to a central water-cooling system.

4.11 Installation signals

The measurement and control signals present in the installation are used to get access to control of the central heating and the cooling system.

Table 4-11 Water heating installation related measurement signals

```
Installation RadiatorGroep1
                Sensor WaterTemperature
                SubStation "Onderstation-11" SignalName "AanvoerWaterTemperatuurCV"
                Factor  1.0 Offset 0.0        DayPersistent
                DryRun "16.;WD(7-17)=19.;WD(20-23)=21.;SS(7-17)=20.;WD(20-23)=21."
                Actuator WaterTemperatureSet-point
                SubStation "Onderstation-11"
                SignalName "CVTemperatuurSet-point"
                Factor 1.0
                Offset 0.0
                DryRun 0.1
```

The central heating installation converts the (import) resource *NaturalGas* into *Heat*, which is transported to the segment radiators as hot water. In this SEBOS-implementation, the central heating water temperature is adapted radiator demand driven as described in chapter 8. The gas-heat conversion is done at a given *efficiency*, which is fixed for the installation.

The price conversion from gas price to heat price can be made by the building supervisor as a first step to affect the energy consumption of the building. The comfort optimiser calculates with these 'artificial' heat prices. The ventilation and central heating installations in the building are monitored using two signals as specified in Table 4-12.

Table 4-12 Installation parameters of the ventilation system

```
Installation Hoogbouw
               Sensor WaterTemperature
               SubStation "Onderstation-11" SignalName "WaterKoelingAanvoerTemperatuur"
               Factor  1.0 Offset 0.0        DayPersistent
               DryRun "16.;WD(7-17)=19.;WD(20-23)=21.;SS(7-17)=20.;WD(20-23)=21."
               Actuator WaterTemperatureSet-point
               SubStation "Onderstation-11"
               SignalName "KoelWaterTemperatuurSet-point"
               Factor 1.0
               Offset 0.0
               DryRun 0.1

Installation Hoogbouw
               Sensor AirTemperature
               SubStation "Onderstation-11" SignalName "LuchtAanvoerTemperatuur"
               Factor  1.0 Offset 0.0        DayPersistent
               DryRun "16.;WD(7-17)=19.;WD(20-23)=21.;SS(7-17)=20.;WD(20-23)=21."
               Actuator AirTemperatureSet-point
               SubStation "Onderstation-11"
               SignalName "InblaasLuchtTemperatuurSet-point"
               Factor 1.0
               Offset 0.0
               DryRun 0.1
```

The main operation mode of the central ventilation installation is fixed, since it is operated at a constant level, induced by e.g. indoor air quality requirements. Apart from that, the comfort management system SEBOS, optimises locally within segments.
Control for import of cold by ventilation can be done during the summer, when there is a demand for extra local cooling of the ventilation air. The energy required for cooling can be calculated using the amount of extracted cold from the cooling water, the conversion within the central ventilation installation and efficiency of `Electricity` in lowering the temperature of air. The imposed cost follows from the export negative heat (cool water) resource price of the central ventilation installation.

4.12 External signals

The external signals for the SEBOS comfort control are the ambient air temperature, which is used in calculating the heat losses of the building and the signal `CloudCoverageFactor`, that is obtained from the four light sensors and is used to control the sunblinds and to estimate the radiation contribution.

4.13 Installation level and local controller optimisation

The central ventilation system is designed to deliver the largest proportion of the heat demand or cold demand in the individual rooms. The heat recovery unit is preheating the inlet air by exchanging heat with the exhaust air from the air-suction system. So adjusting the temperature set-point to as low a value as possible in winter and to as high a value as possible in summer, keeping the local control possibilities as high as possible provides an opportunity for energy efficiency. On the whole building installation level, an energy saving potential is present by adapting the central heating water temperature and the cooling water and air temperature from the ventilation system more precisely, using the predicted meteorological circumstances (cloud level, solar incidence) , than currently is done using the heating and cooling curves.

The factors contributing to building up the temperature in a room are depicted in Table 4-4. Heat and cold may be imported in a building segment in several ways. Apart from that, the mechanism for controlling devices is not based on continuous actuator settings. Instead, a mapping mechanism is acting, with a certain bandwidth and delay in altering the amount of heat/cold admitted to a room. Characterising this mechanism in terms of several, separate controllers, thus, for the SEBOS-optimiser is not a trivial task.

In order to achieve this, apart from a solar transmission controller, a virtual cooler and heater are introduced in SEBOS, of which the control actions are translated into adapting set-points for the local and central devices in the building by the the SEBOS-shell. Thus, installation and control complexity is not visible within the optimisation kernel. There only is a heater linked to natural gas as a resource, a cooler operating on electricity and a solar transmitter.

The desired heating or cooling loads have to be mapped to a setting of the comfort control devices in the building. In case of a net heat load for all segments, the minimum of the required loads on a per m3 basis yields the ideal central installation heat load to be delivered. This gives an optimal ventilation temperature set-point. In the following, this option is worked out further.

Assuming, that, for energy efficiency, it is not important where the air is heated, the ventilation heating or cooling load is calculated as:

$$Q_{vent} = (T_{air,sp} - T_{air,in}) * V_{air} * C_{p,Air}$$

The amount of heat linearly depends on the volume per time-unit, the temperature difference between in-blown air and the room and the heat capacity of air at constant pressure.
The desired extra heat loads per building segment are obtained per building segment by subtracting the central load (on a per m3 basis) as obtained above. The temperature bandwidth, then, of the local controllers is determined in such a way, that the room having the largest controller switch setting of all rooms just has a maximum opportunity for control. This gives us the minimum central heating water temperature.

In case all rooms have a cooling demand, the procedure is the other way around. In a mixed heating/cooling demand configuration for several segments, the central heating part is minimised and the central water temperature is tuned to serve the segment with the heating demand and the cooling water temperature is tuned to the segment to the highest cooling demand.

5. Characterization of the building

5.1 Introduction

During 8 months the behaviour of the building was monitored by measuring a large number of signals pertaining to the installation, the comfort related controls in the room and the user actions. The data logging facilities of the InsiteView package were utilised. Not all signals could be logged using this package. Using the interface built for SEBOS, a small data collection module was built to get access to additional signal values in the building. In this chapter an analysis of these signals is given in terms of the thermo-physical behaviour of the individual rooms, the user control actions and the operation of the installation. In this analysis 4 rooms on the first and 10 rooms on the second floor were involved. The rooms form a representative set of size and orientation. The period monitored includes winter, spring and summer conditions. In
table the range of temperatures during the measurement period is presented. Typically each 8 minutes a new set of values was collected. This yielded a wealth of information about the operation of the building management system.

5.2 Segment temperatures and ventilation

A typical plot of the temperature in a room over the time of day is given in Figure 5-1. The temperature can be seen to hardly drop below 20 degrees, even when no heating takes place or in the weekend.

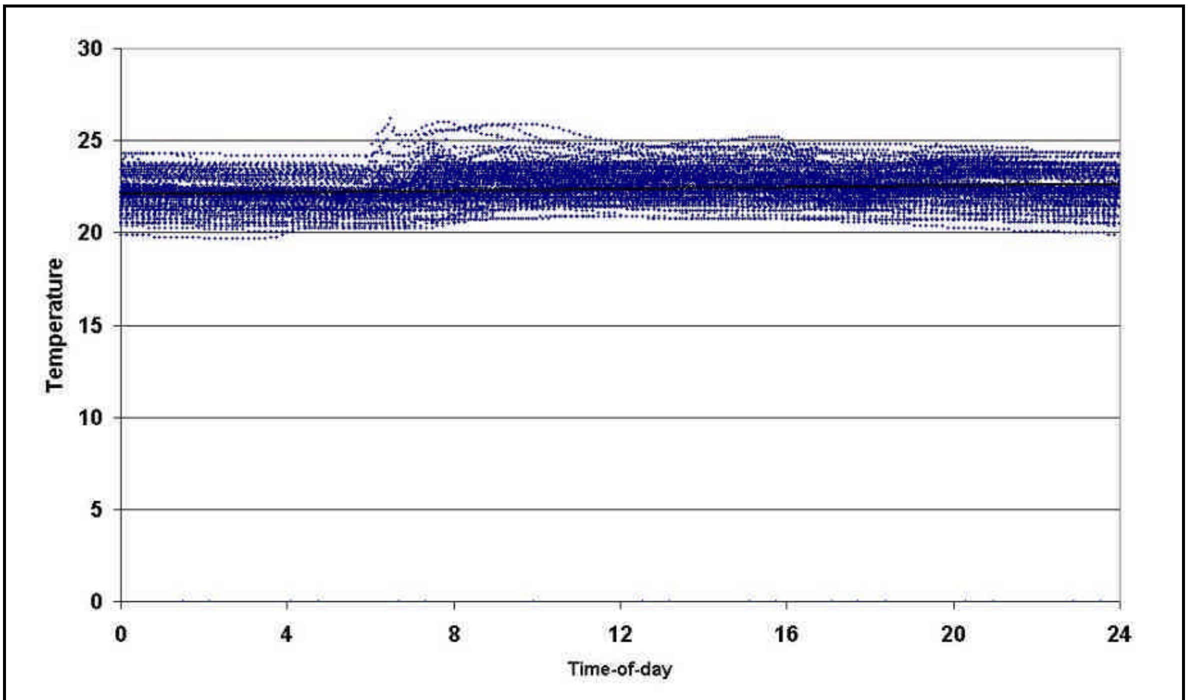


Figure 5-1 A plot of the temperature in a room as function of the time of day

As a check, a summary of the collected data is given in Table 5-1. The rooms are designated according to their location, their identification number and their orientation. In Figure 5-2 a three-dimensional plot of a number of meteorological parameters is shown. One axis represents the time over a day (0-24 hours). Another represents the day number (from day 29, January 29, to day 222, August 10) and the height and the color represent the measured values. This way of representation allows a quick inspection of a large amount of data. The temperatures in a number of rooms located at the four corners of the building are shown in Figure 5-3. It can be seen, that southwest oriented rooms have the largest comfort problems during hot summer days.

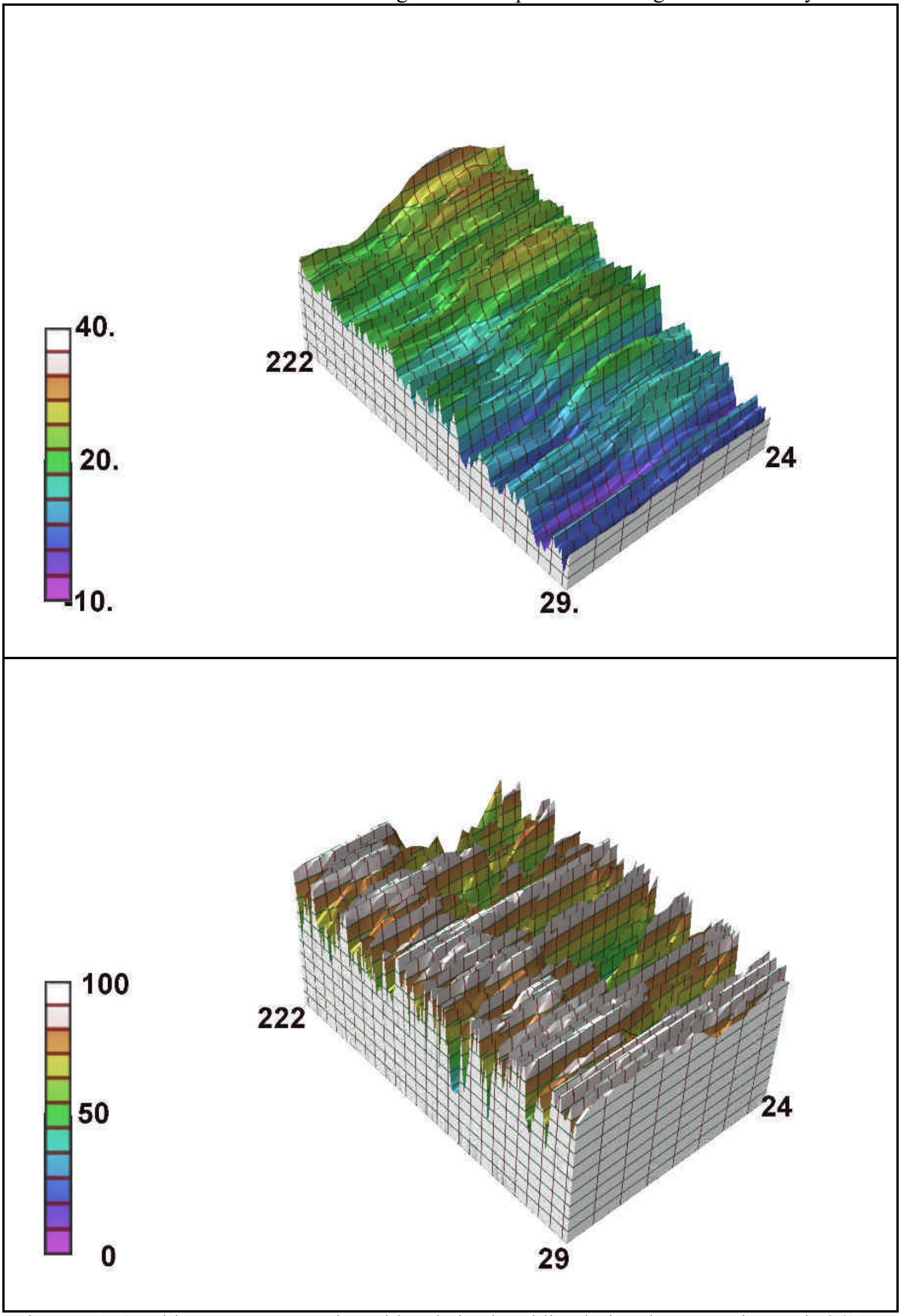


Figure 5-2 Outside temperature and outside relative humidity during the measuring period (29 jan.- 10 aug.)

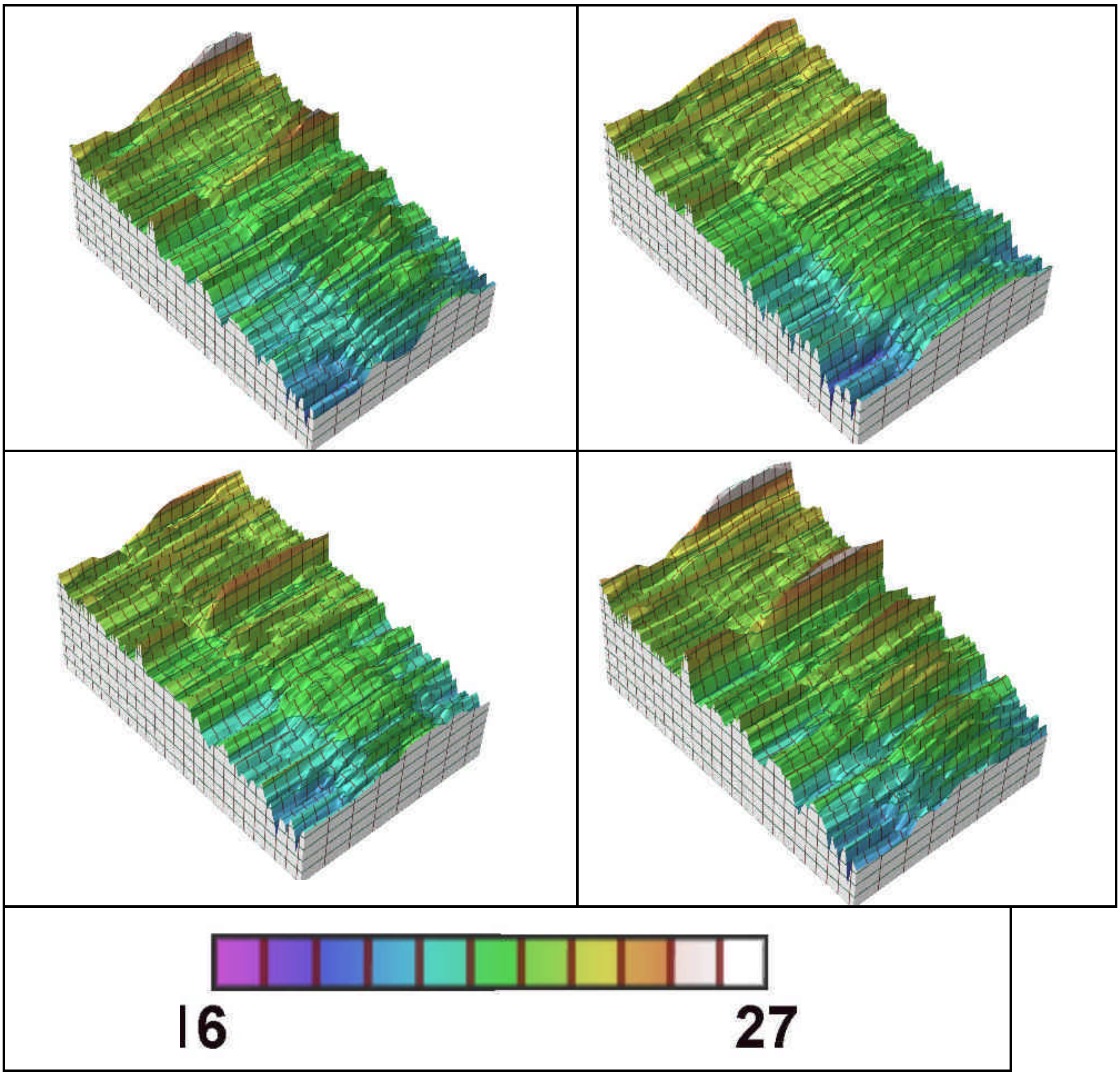


Figure 5-3 Measured temperatures voor rooms NE,NW (upper) and SE,SW (lower) during the measuring period (29 jan.- 10 aug.)

Table 5-1 Average temperature of a number of rooms

Room	T-Minimum	T-Maximum	T-Average
D1.01NWTemperature	17.1	26.2	22.0
D1.06WTemperature	18.2	26.4	22.3
D2.01NWTemperature	17.4	26.9	22.0
D2.02NTemperature	19.0	26.4	22.5
D2.03NTemperature	18.0	25.6	22.1
D2.04NETemperature	16.6	26.4	22.0
D2.05ETemperature	16.6	24.9	21.9
D2.06SETemperature	17.7	25.2	22.3
D2.07STemperature	19.3	25.8	22.5
D2.08STemperature	19.4	25.8	22.7
D2.09SWTemperature	17.4	26.6	22.4
D2.10WTemperature	18.5	26.7	22.6
OutsideTemperature	-6.0	36.2	12.4

The measuring period can be seen to cover freezing weather in winter and a very hot period in July and August. More specifically for the winter period, the period of January to March, the results of the analysis are shown in
Table 5-2. Apart from d1.05, where erroneous data were collected, high correlations[6] are found between rooms.

Table 5-2 Average temperatures and correlation coefficients between temperatures during the winter period

Room	d1.01	d1.04	d1.06	d2.01	d2.02	d2.03	d2.04	d2.05	d2.06	d2.07	d2.08	d2.09	d2.10
T(degr)	21.63	20.99	21.48	20.94	21.70	20.86	20.74	20.32	21.15	22.02	22.04	21.37	21.84
Stdev	0.94	1.14	1.20	1.05	0.76	0.95	1.23	1.08	0.92	0.89	0.87	1.28	0.99
d1.01	1.00												
d1.04	0.71	1.00											
d1.06	0.91	0.55	1.00										
d2.01	0.92	0.70	0.89	1.00									
d2.02	0.81	0.81	0.63	0.76	1.00								
d2.03	0.80	0.87	0.75	0.81	0.81	1.00							
d2.04	0.67	0.95	0.55	0.70	0.79	0.90	1.00						
d2.05	0.58	0.79	0.54	0.63	0.58	0.79	0.81	1.00					
d2.06	0.80	0.85	0.75	0.83	0.76	0.91	0.87	0.80	1.00				
d2.07	0.86	0.74	0.82	0.85	0.76	0.82	0.74	0.69	0.88	1.00			
d2.08	0.80	0.54	0.83	0.79	0.59	0.72	0.54	0.61	0.79	0.88	1.00		
d2.09	0.91	0.55	0.92	0.89	0.68	0.71	0.53	0.52	0.76	0.88	0.89	1.00	
d2.10	0.94	0.63	0.93	0.91	0.73	0.78	0.61	0.55	0.80	0.85	0.86	0.93	1.00

This leads to the conclusion, that the temperatures reached are mainly the result of the central air heating ventilation system. Individual systems are tuned similarly and the heatflow between segments is large compared to other heat-losses. This is further shown in Figure 5-4.

[6] Correlation refers to the standard correlation coefficient.

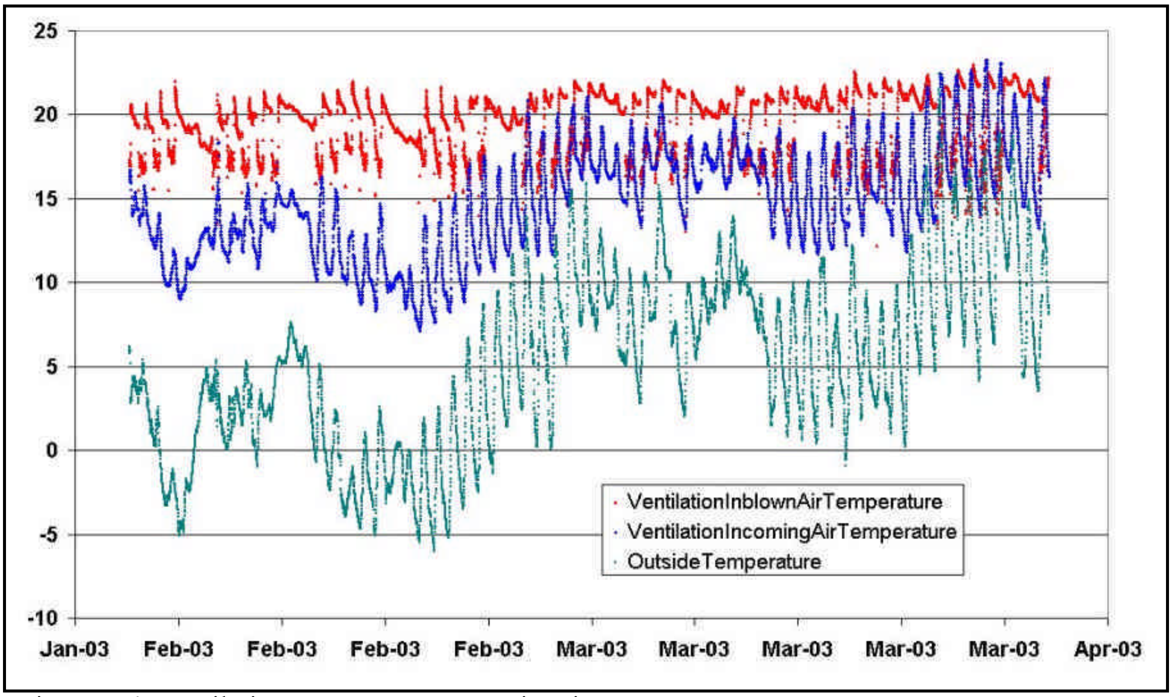


Figure 5-4 Ventilation system parameters in winter

The lower curve in Figure 5-4 represents the outside temperature, the middle curve the temperature of the air entering the ventilation heating system, and the upper curve the temperature of the air entering the rooms. It can be concluded, that the heat-recovery unit raises the temperature of the incoming air mostly, but also that the next main contributor and energy consumer in realising the temperature in the offices is the central ventilation system.

For the spring period (April-June) the data are shown in Table 5-3 and Figure 5-5 in the same manner as for the winter period. For cooling as well as for heating the main ventilation system is the largest contributor to realising the temperature level in the rooms.

Table 5-3 Temperature data and correlations for the spring period

Room	d1.01	d1.04	d1.06	d2.01	d2.02	d2.03	d2.04	d2.05	d2.06	d2.07	d2.08	d2.09	d2.10
T(degr)	22.47	22.17	22.63	22.30	22.70	22.39	22.40	22.38	22.55	22.72	22.97	22.66	22.85
Stdev	0.66	0.80	0.81	0.88	0.55	0.85	0.94	1.03	0.78	0.66	0.75	0.87	0.75
d1.01	1.00												
d1.04	0.66	1.00											
d1.06	0.90	0.58	1.00										
d2.01	0.91	0.70	0.90	1.00									
d2.02	0.77	0.76	0.70	0.80	1.00								
d2.03	0.76	0.76	0.71	0.81	0.87	1.00							
d2.04	0.70	0.88	0.62	0.77	0.82	0.84	1.00						
d2.05	0.65	0.79	0.62	0.74	0.76	0.81	0.87	1.00					
d2.06	0.77	0.82	0.75	0.83	0.79	0.84	0.85	0.90	1.00				
d2.07	0.61	0.52	0.67	0.62	0.64	0.73	0.48	0.59	0.76	1.00			
d2.08	0.55	0.43	0.59	0.53	0.60	0.67	0.38	0.49	0.65	0.91	1.00		
d2.09	0.89	0.59	0.90	0.88	0.68	0.70	0.61	0.64	0.82	0.75	0.67	1.00	
d2.10	0.90	0.64	0.91	0.91	0.78	0.79	0.69	0.72	0.83	0.74	0.66	0.91	1.00

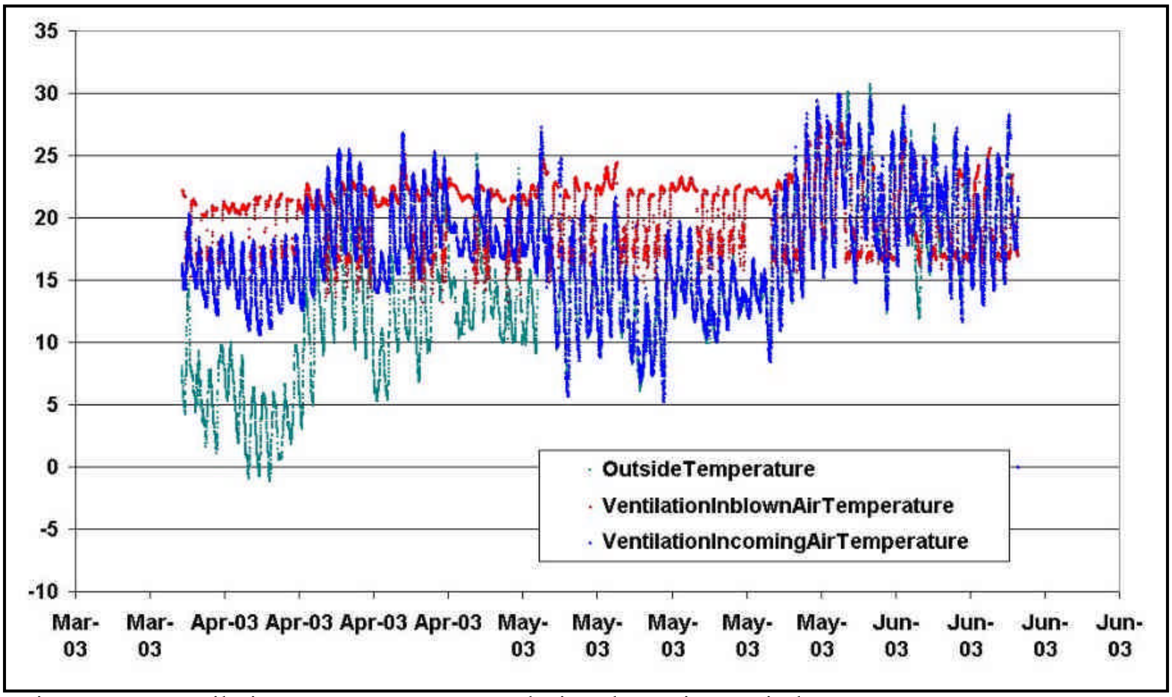


Figure 5-5 Ventilation system parameters during the spring period

From Figure 5-5 it can be seen, that during Spring, gradually, the heat recovery unit contributes less to the increase of the ventilation air temperature. The upper curve still shows that the incoming air is heated, while temperatures in the rooms are above their set-points. This gives an opportunity to save energy. Giving the users a larger proportion of control over the heat inflow via the water radiators should give a smaller deviation from their preferred comfort level as well.

For the summer period the same data is shown in
Table 5-4 and Figure 5-6. The correlations are higher in this period. This means the opportunities and ranges for individual inner climate control are narrowed.

Table 5-4 Average temperatures and correlations in summer period

Room	d1.01	d1.04	d1.06	d2.01	d2.02	d2.03	d2.04	d2.05	d2.06	d2.07	d2.08	d2.09	d2.10
T(degr)	23.05	23.20	23.04	23.09	22.99	23.21	23.38	23.25	23.26	22.74	23.00	23.30	23.30
Stdev	1.06	1.12	1.10	1.10	1.06	1.23	1.09	1.10	1.05	1.15	1.25	1.22	1.13
d1.01	1.00												
d1.04	0.89	1.00											
d1.06	0.92	0.86	1.00										
d2.01	0.96	0.87	0.93	1.00									
d2.02	0.94	0.91	0.92	0.92	1.00								
d2.03	0.89	0.86	0.82	0.87	0.86	1.00							
d2.04	0.91	0.88	0.86	0.90	0.90	0.91	1.00						
d2.05	0.84	0.88	0.80	0.83	0.86	0.87	0.93	1.00					
d2.06	0.91	0.90	0.85	0.89	0.90	0.88	0.96	0.95	1.00				
d2.07	0.88	0.88	0.87	0.86	0.90	0.88	0.93	0.91	0.94	1.00			
d2.08	0.84	0.85	0.83	0.82	0.86	0.88	0.90	0.87	0.89	0.96	1.00		
d2.09	0.88	0.81	0.86	0.90	0.84	0.84	0.90	0.85	0.90	0.90	0.89	1.00	
d2.10	0.88	0.82	0.86	0.89	0.86	0.85	0.91	0.87	0.91	0.91	0.91	0.95	1.00

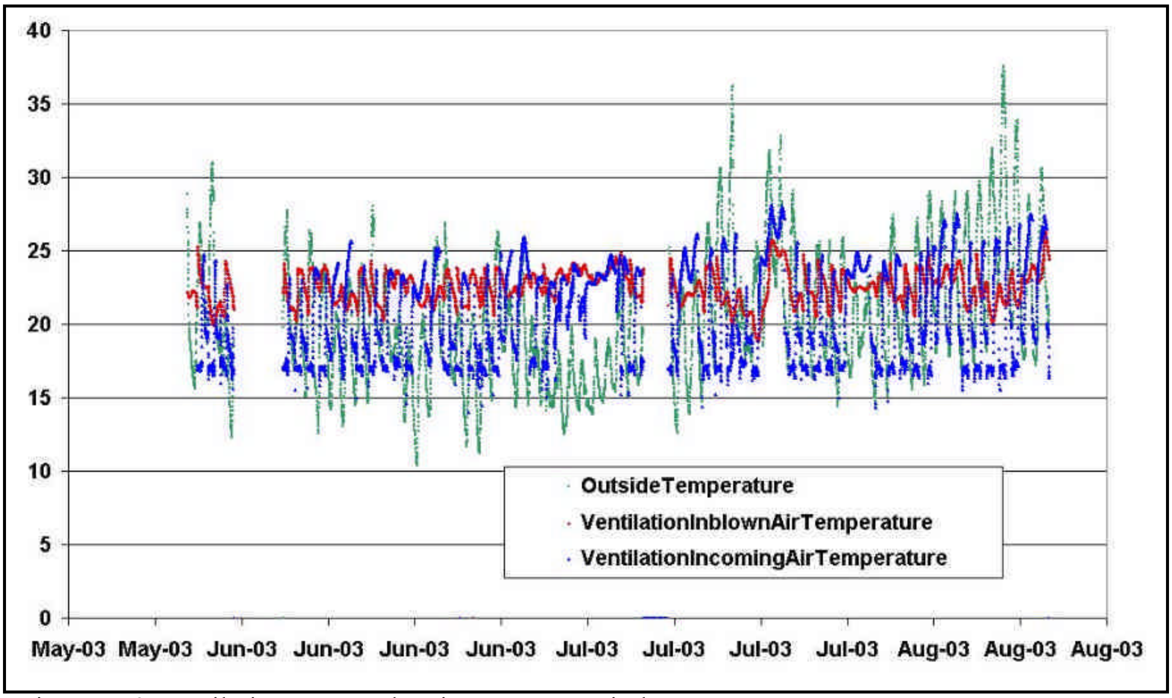


Figure 5-6 Ventilation system data in summer period

In the ventilation plot, it can be seen, that the inblown air still has a gain in temperature with respect to the air coming in into the ventilation system. Three-dimensional plots of these three temperature are shown in Figure 5-7.

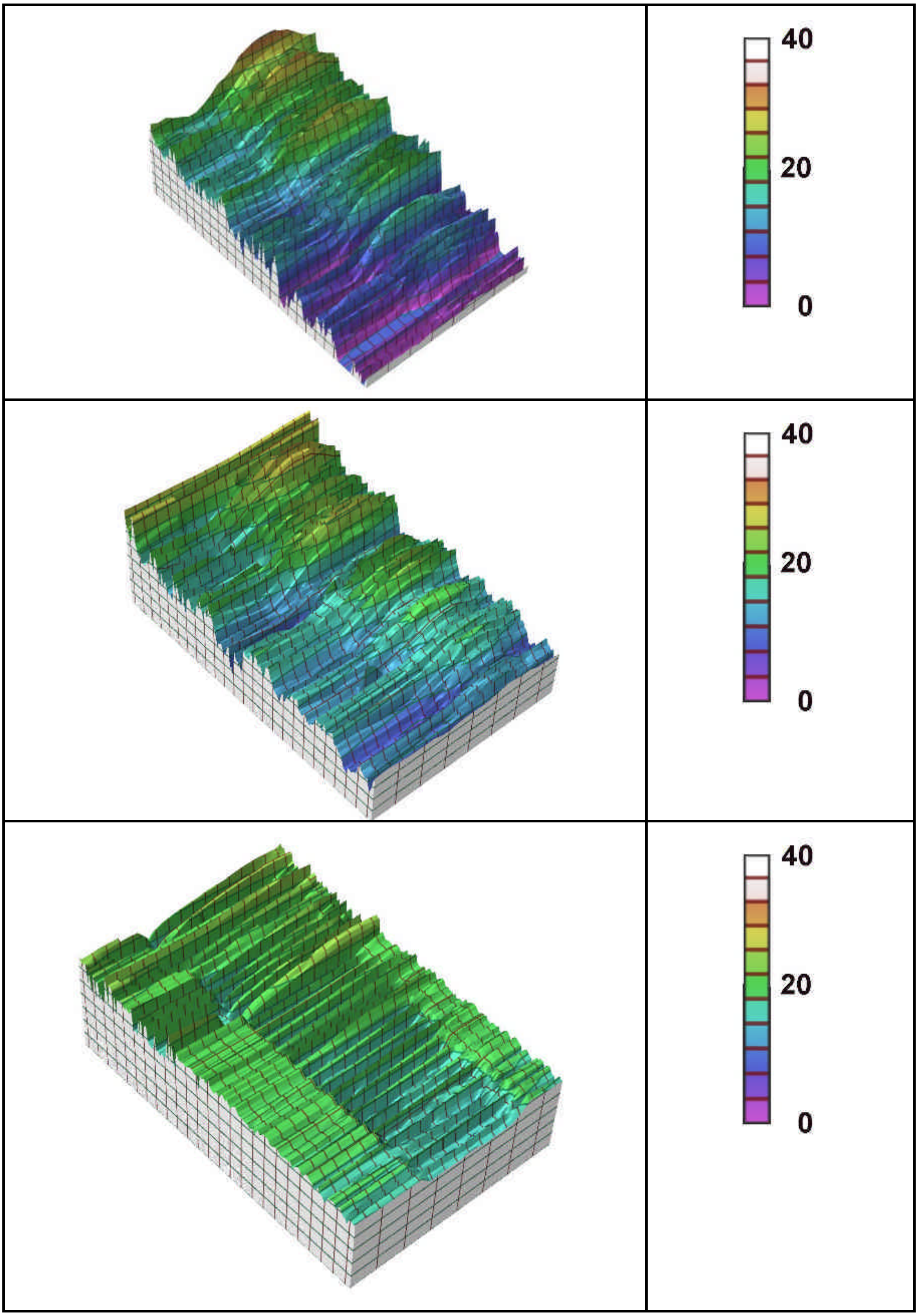


Figure 5-7 Outside air temperature, temperature of ventilation input, and temperature of air inlet in the room, per hour and day (period from 29th Jan to 10th Aug.).

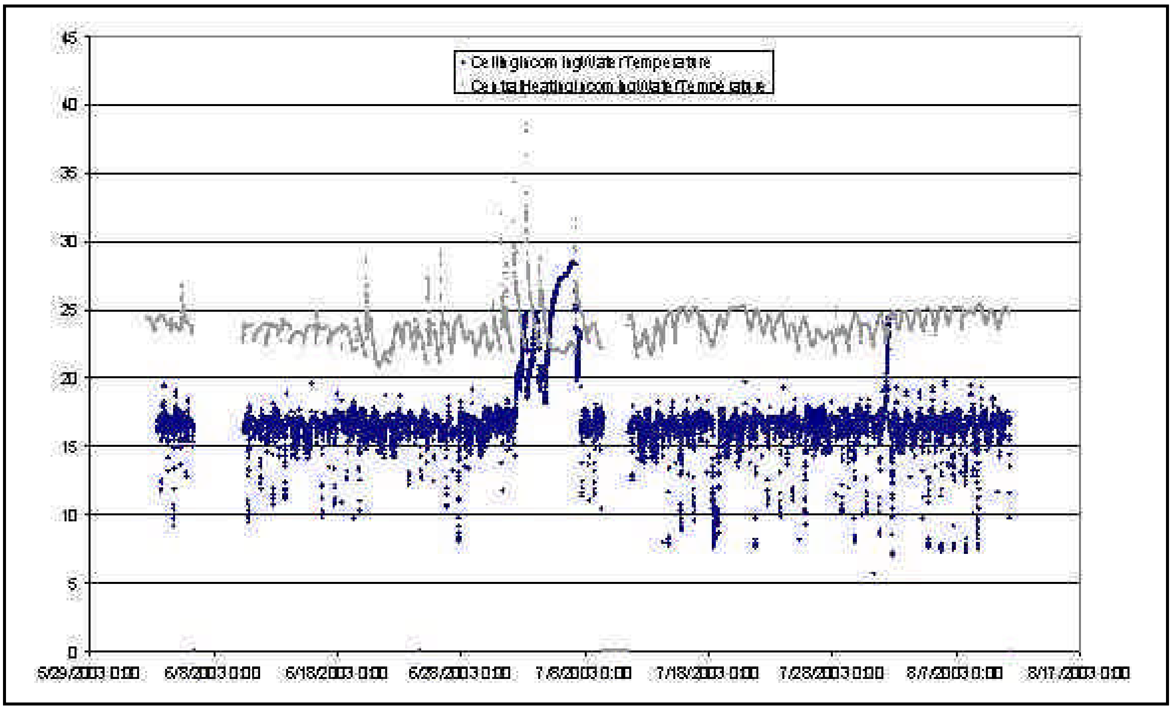


Figure 5-8 Central heating water temperature and ceiling cooling water temperature (period from 29 jan to 10 aug.)

5.3 Central water heating and cooling

In the central heating water and cooling water temperatures are shown. The temperature of the central heating water is also plotted in 3D in Figure 5-9.

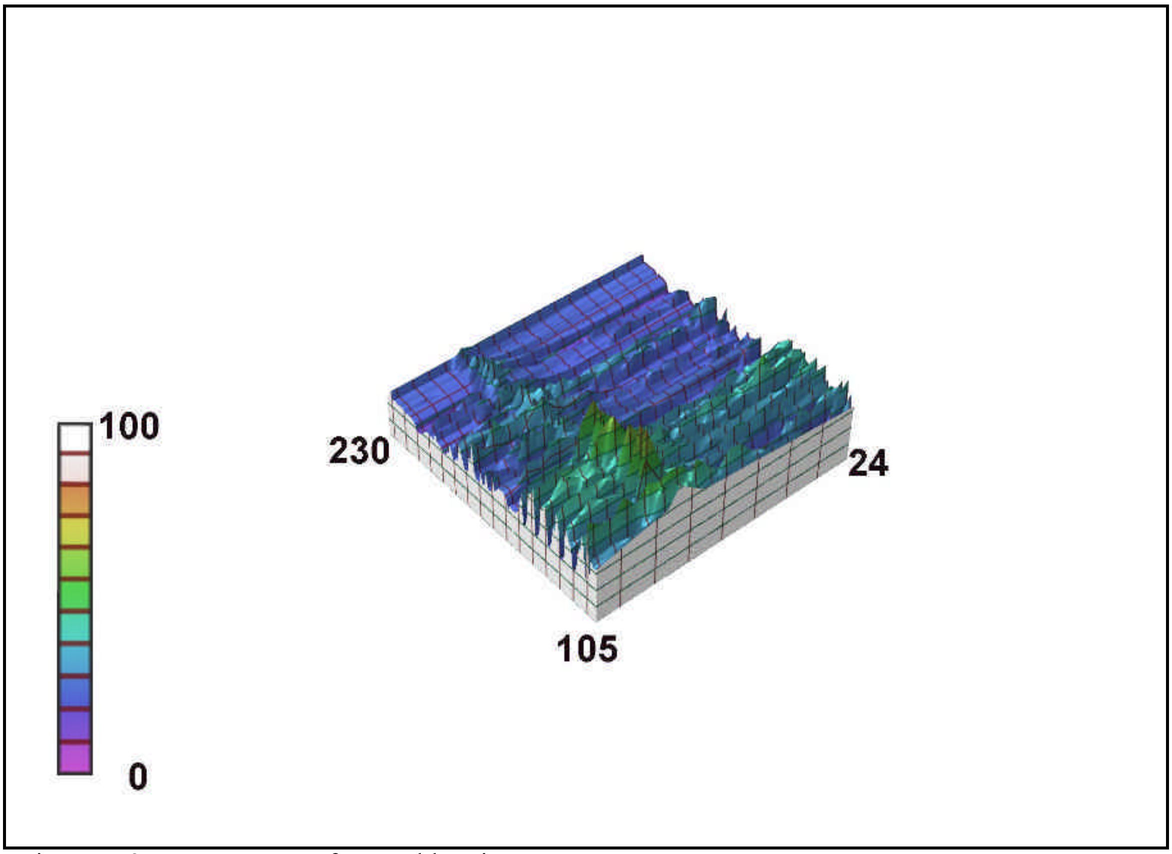


Figure 5-9 Temperature of central heating water

Peaks in the central heating water temperatures occur early in the morning following the heat curve; anomalies in the cooling water temperature occur between 18:00 and 19:00 hours when the ventilation is switched off. The cause of this heating, even in cases where there is no heat demand, may be the low early morning temperature triggering the central heater according to the heat curve.

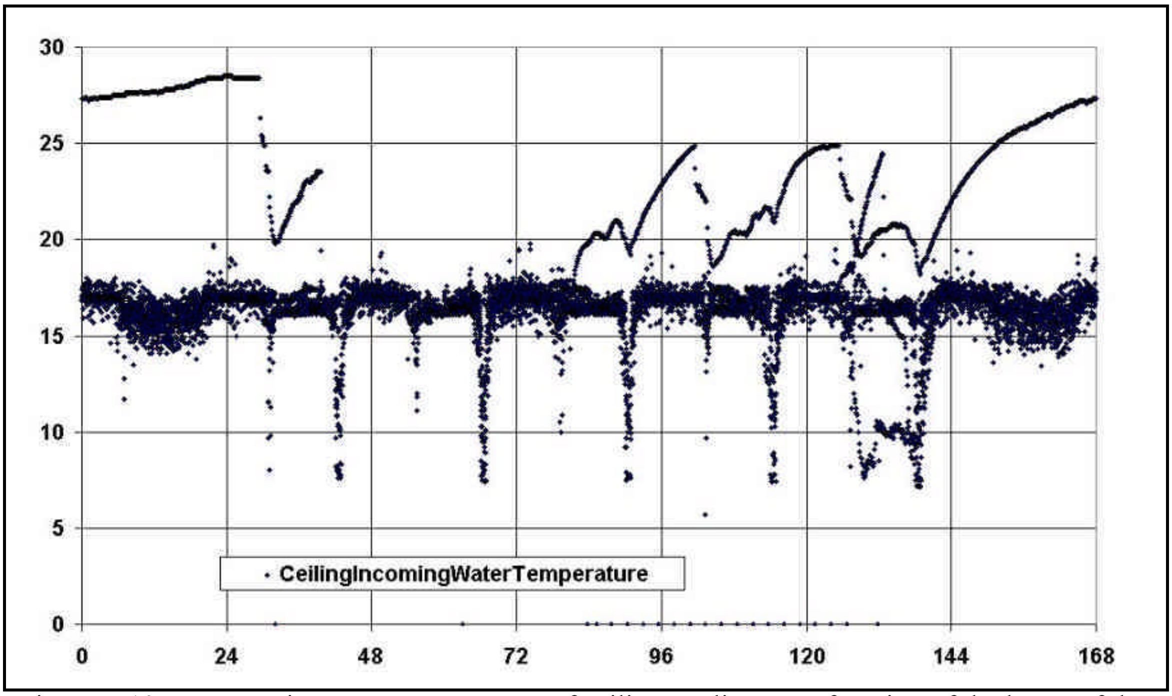


Figure 5-10 Incoming water temperature of ceiling cooling, as a function of the hours of the week (from 0 to 7*24 hrs) in early summer

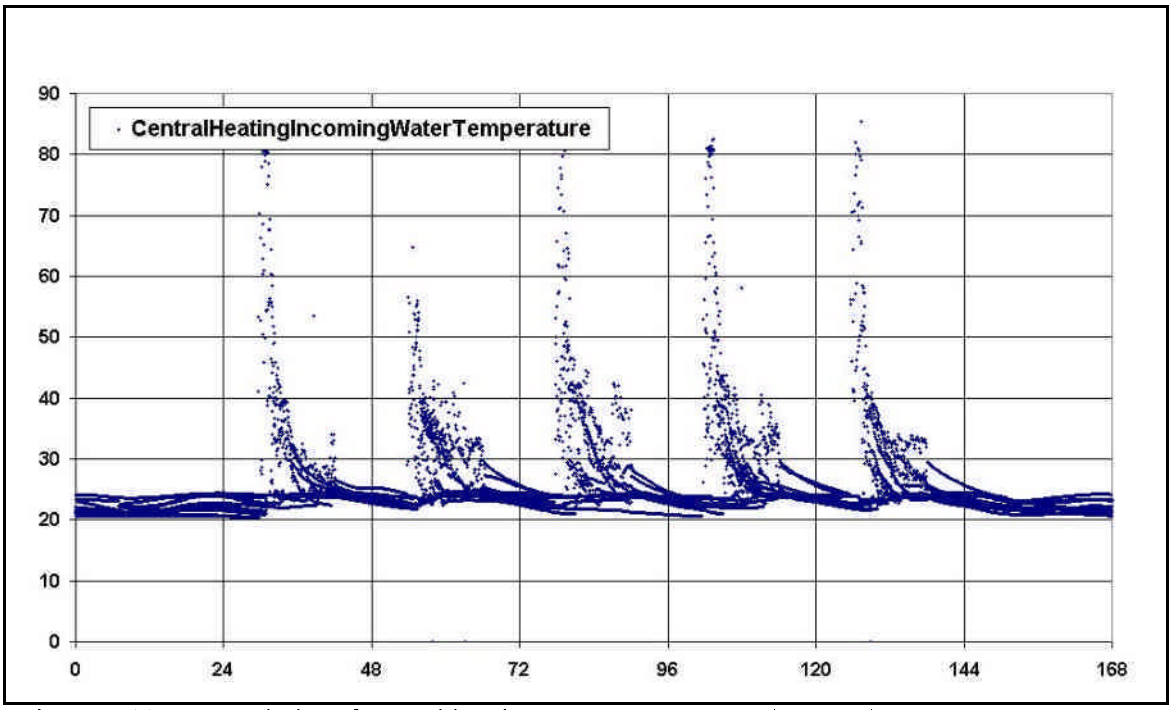


Figure 5-11 Weekplot of central heating water temperature (summer)

In Figure 5-10 and Figure 5-11 this effect is illustrated further. During early morning and at the beginning of the evening a drop in cooling water temperature can be seen. A slight reaction of the central heating system in heating the water as a response to the heating curve can also be seen. A similar effect has been noted in earlier studies of building management system operation [Strootman, 2003]. In order to compensate for the building mass heat inertia, option suggested there is to base the heating control curve onto the measured mass temperature of the building.

5.4 User actions and comfort perception

In Figure 5-12 a plot is presented of the inside vs. the outside temperature for one of the large rooms. It can be seen, that with higher outside temperatures, the comfort installation slightly follows the outside temperature trend. In Figure 5-13, for the same room, the user defined set-point correction versus the outside temperature are plotted. It can be seen, that with increasing outside temperature the user is indicating, that a larger temperature drop from the comfort installation is desired. The trend can be quantified using the average set-point correction.

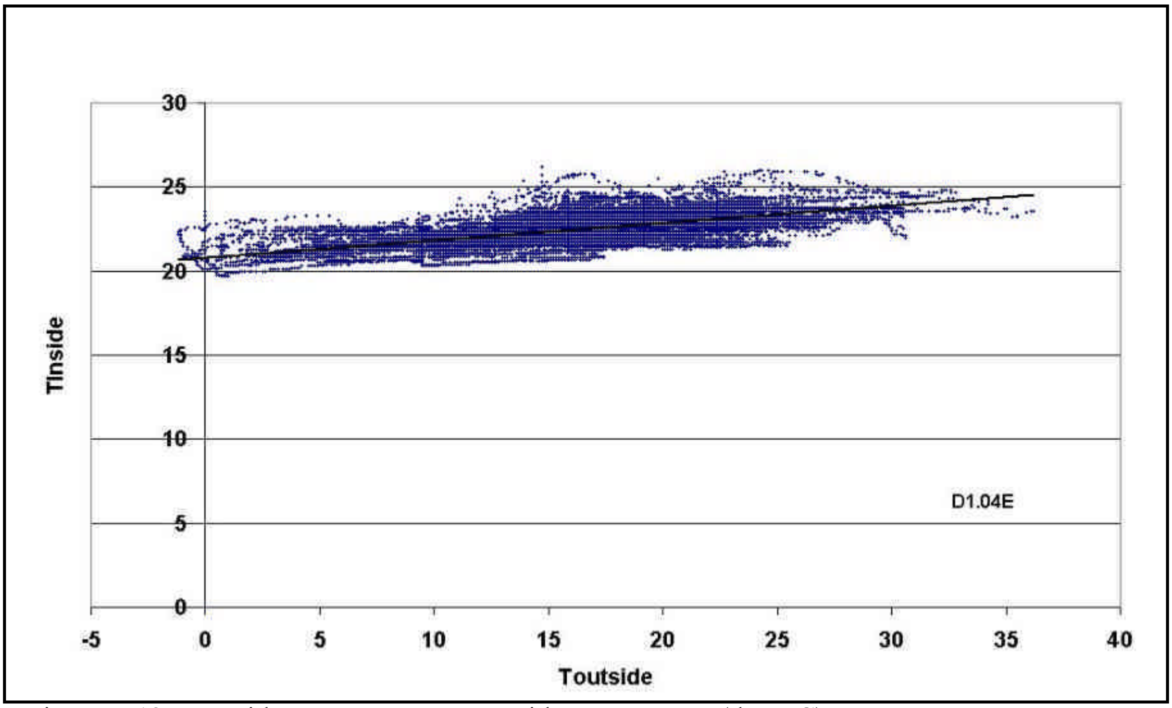


Figure 5-12	Inside temperature vs. outside temperature (degr. C)

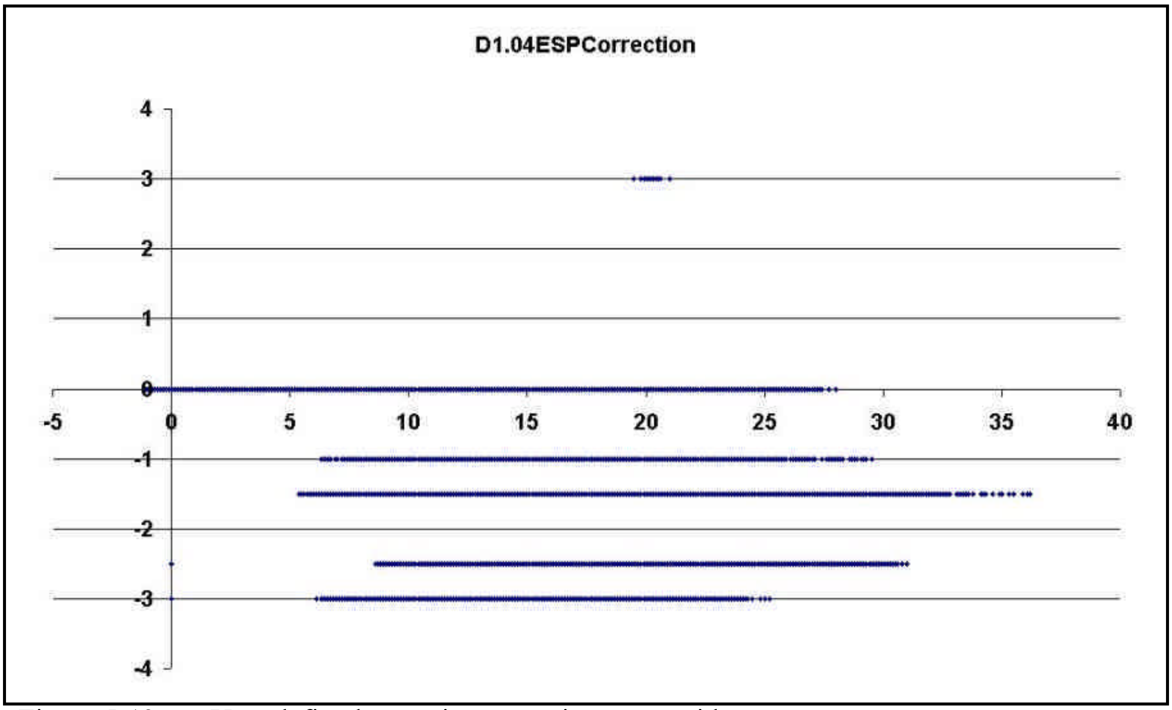


Figure 5-13	User defined set-point correction vs. outside temperature

In the experimental setting, during working hours, a bandwidth for the control of the inside temperature is given by a temperature range between 21 to 22 degrees.
In Figure 5-14 the average temperature in the rooms is given (z-coordinate) and the set-point

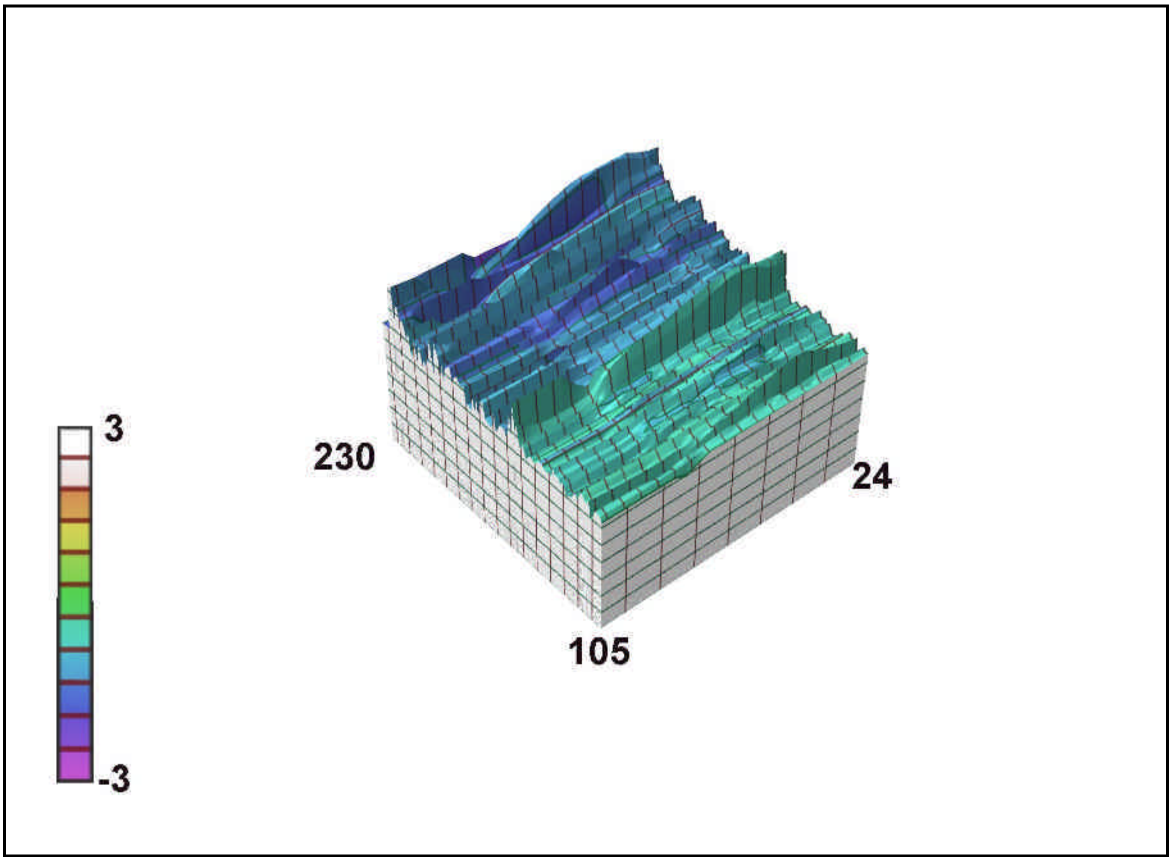


Figure 5-14 Average temperature of all rooms (Z) and set-point correction (color) as a function of day number

correction (color-coded). It can be seen, that with increasing inside average temperature, the user sets the set-point to lower values without attaining the goal of reaching a lower temperature.

Table 5-5 gives an overview of the collected set-point data and the temperatures realised in the rooms during working hours in the period from April to July (during certain periods D1.05 had an erroneous value of the set-point correction). It can be seen, that the response of control is less than the user might expect. Data from D2.01 and D2.03 illustrate this. These rooms are on the same floor and have grossly the same orientation. The users of D2.01 have not made any temperature set-point corrections during the measurement period. The users of D2.03 have a set-point correction of more than 2 degrees. The resulting temperatures, however, differ only by 0.3 °C. The conclusion may be, that in warmer outside temperature conditions the ceiling cooling has not enough capacity, as is already indicated from the TRNSYS-building model calculations.

Table 5-5 Realised set-points and temperatures and their standard-deviations

Name	Average	StdDev
D1.01NWSPCorrection	-0.48	0.73
D1.01NWTemperature	22.64	0.78
D1.04ESPCorrection	-1.62	1.08
D1.04ETemperature	22.64	0.94
D1.05WSETemperature	8.63	13.38
D1.05WSPCorrection	-0.89	1.34
D1.06WSPCorrection	-0.69	1.21
D1.06WTemperature	22.97	0.89
D2.01NWSPCorrection	0.00	0.00
D2.01NWTemperature	22.49	0.88
D2.02NSPCorrection	-0.12	1.14
D2.02NTemperature	22.87	0.74
D2.03NSPCorrection	-2.24	0.67
D2.03NTemperature	22.71	0.87
D2.04NESPCorrection	-1.27	1.48
D2.04NETemperature	22.89	0.91
D2.05ESPCorrection	-0.73	1.41
D2.05ETemperature	22.78	1.12
D2.06SESPCorrection	-0.15	0.45
D2.06SETemperature	22.89	0.90
D2.07SSPCorrection	-0.91	1.08
D2.07STemperature	22.83	0.94
D2.08SPCorrection	-1.39	1.48
D2.08STemperature	23.09	0.99
D2.09SWSPCorrection	-0.12	0.65
D2.09SWTemperature	22.91	1.08
D2.10WSPCorrection	0.39	0.75
D2.10WTemperature	23.06	1.01
D2.10aWSPCorrection	24.72	1.79
D2.10aWTemperature	22.48	1.16

5.5 Window blind operation

Apart from temperature control, the users have the opportunity to affect the lighting conditions by operating the window blinds. The data collected in the spring and summer period are summarised in

Table 5-6. The correlation to the output reading from four light sensors each at one face of the building is shown. The individual readings are shown in Figure 5-15.

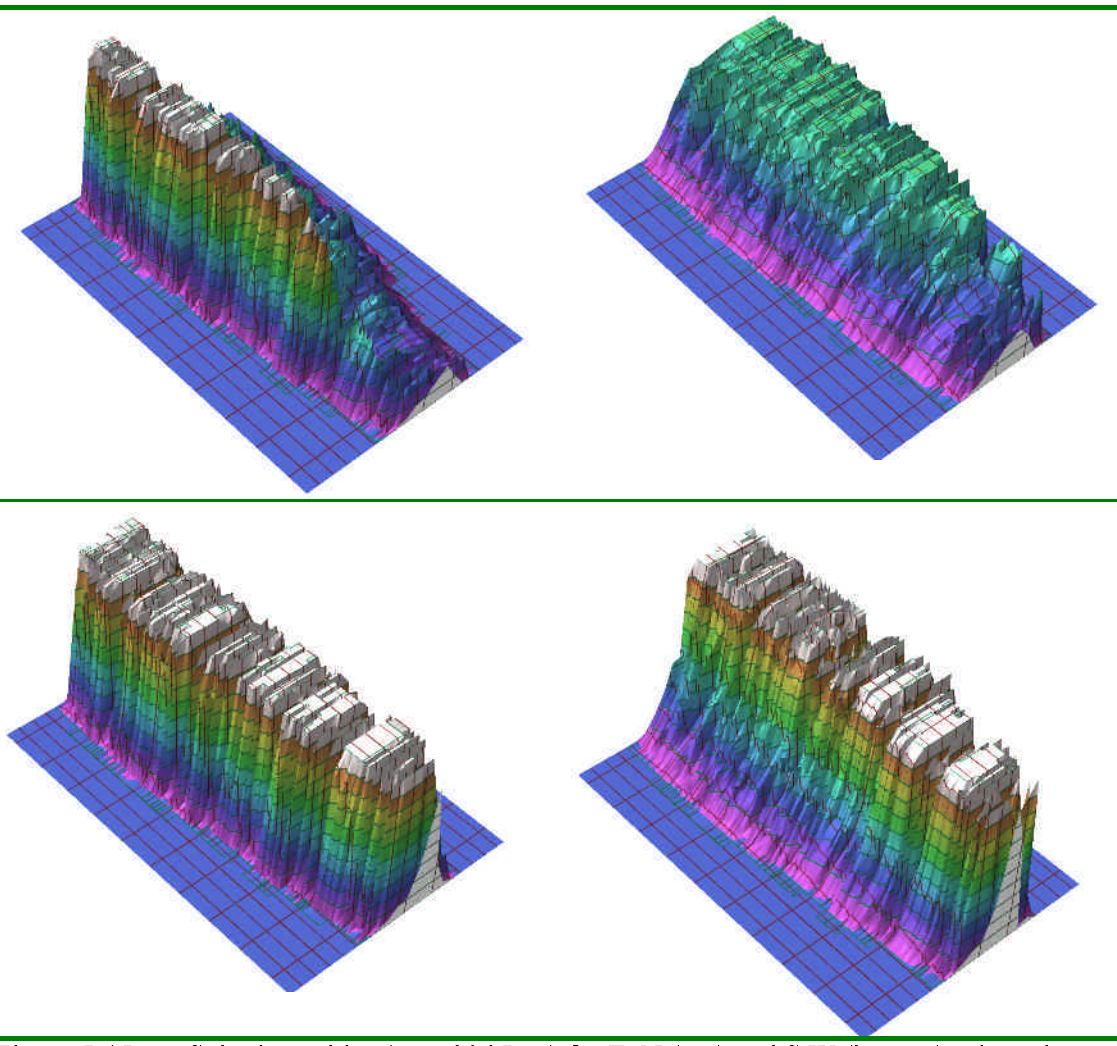


Figure 5-15 Solar intensities (max 30 kLux) for E, N (top) and S,W (bottom) orientation from april to august 2003

Highest correlation to the sun blind's position (100 % is down) and the reading is for the northern orientation. This means, that the indirect solar radiation contribution, which is most accurately measured at the north orientation, would be the best driver for control of the sun blind position. When looking at temperatures, it can be seen that the north intensity reading is most correlated with the realised temperature. Other correlations are smaller. This means direct radiation is effectively shielded by the manual operation scheme for the sunblinds. Where the standard deviation in the sunblind setting correlation is highest (i.e. more frequent manual adjustment during the day), it can be seen, that the correlation is best. This means, that in rooms, where the frequency of adjustments is higher, shielding from direct radiation is done most effectively. The correlation between the sunblind setting and the temperature indicates a small positive correlation. The sunblinds do not completely take away the increasing temperature effect of the solar radiation. Part of the temperature increase is also caused by the internal heat load.

Table 5-6 Correlation between parameters involved in sunblind control

Correlation	D1.01NWSunblindN	D1.01NWSunblindW	D1.01NWTemperature	D1.04ESunblindE	D1.04ETemperature
LightIntensityEast	0.02	0.19	0.01	0.01	0.24
LightIntensityNorth	0.00	0.42	**0.21**	**0.62**	0.26
LightIntensitySouth	0.00	0.12	0.02	0.17	0.12
LightIntensityWest	0.00	0.10	0.06	0.15	0.06
Average	0.03	52.04	22.59	62.53	22.40
Stddev	1.50	41.53	0.87	48.38	1.09
Corresp. T	0.00	0.20	1.00	0.26	1.00
Correlation	**D1.05WSESunblindE**	**D1.05WSESunblindS**	**D1.05WSESunblindW**	**D1.05WSETemperature**	**D1.06WSunblindW**
LightIntensityEast	0.43	0.35	0.41	0.09	0.25
LightIntensityNorth	0.46	0.37	0.63	0.04	0.71
LightIntensitySouth	0.21	0.16	0.24	0.02	0.21
LightIntensityWest	0.10	0.08	0.15	0.00	0.18
Average	61.58	61.43	68.49	9.00	56.97
Stddev	45.87	43.06	46.35	13.36	49.49
Corresp. T	0.22	0.23	0.19	1.00	0.26
Correlation	**D1.06WTemperature**	**D2.01NWSunblindN**	**D2.01NWSunblindW**	**D2.01NWTemperature**	**D2.02NSunblindN**
LightIntensityEast	0.09	0.02	0.24	0.07	0.03
LightIntensityNorth	0.35	0.59	0.71	0.23	0.60
LightIntensitySouth	0.08	0.07	0.20	0.05	0.07
LightIntensityWest	0.11	0.15	0.18	0.07	0.15
Average	22.71	46.34	56.66	22.44	46.36
Stddev	0.98	49.84	49.54	1.01	49.86
Corresp. T	1.00	0.18	0.19	1.00	0.18
Correlation	**D2.02NTemperature**	**D2.03NSunblindN**	**D2.03NTemperature**	**D2.04NESunblindE**	**D2.04NESunblindN**
LightIntensityEast	0.04	0.03	0.06	0.54	0.03
LightIntensityNorth	0.17	0.60	0.26	0.70	0.60
LightIntensitySouth	0.03	0.07	0.05	0.28	0.08
LightIntensityWest	0.04	0.16	0.08	0.16	0.16
Average	22.79	46.52	22.62	64.11	46.64
Stddev	0.82	49.87	1.05	47.95	49.86
Corresp. T	1.00	0.29	1.00	0.26	0.25
Correlation	**D2.04NETemperature**	**D2.05ESunblindE**	**D2.05ETemperature**	**D2.06SESunblindE**	**D2.06SESunblindS**
LightIntensityEast	0.19	0.54	0.22	0.47	0.44
LightIntensityNorth	0.28	0.69	0.26	0.60	0.56
LightIntensitySouth	0.10	0.28	0.11	0.24	0.22
LightIntensityWest	0.07	0.16	0.06	0.14	0.13
Average	22.59	63.86	22.58	70.34	73.16
Stddev	1.13	48.02	1.16	45.62	44.29
Corresp. T	1.00	0.24	1.00	0.17	0.16
Correlation	**D2.06SETemperature**	**D2.07SSunblindS**	**D2.07STemperature**	**D2.08SSunblindS**	**D2.08STemperature**
LightIntensityEast	0.17	0.44	0.07	0.53	0.04
LightIntensityNorth	0.24	0.56	0.19	0.70	0.16
LightIntensitySouth	0.10	0.22	0.08	0.28	0.05
LightIntensityWest	0.07	0.13	0.06	0.16	0.05
Average	22.79	73.13	22.77	63.58	23.05
Stddev	0.95	44.32	0.89	48.10	0.97
Corresp. T	1.00	0.07	1.00	0.11	1.00
Correlation	**D2.09SWSunblindS**	**D2.09SWSunblindW**	**D2.09SWTemperature**	**D2.10WSunblindW**	**D2.10WTemperature**
LightIntensityEast	0.54	0.25	0.11	0.25	0.07
LightIntensityNorth	0.70	0.71	0.26	0.71	0.23
LightIntensitySouth	0.29	0.21	0.08	0.21	0.05
LightIntensityWest	0.17	0.18	0.09	0.18	0.07
Average	63.80	56.65	22.80	56.65	22.93
Stddev	48.01	49.54	1.04	49.54	0.95
Corresp. T	0.15	0.18	1.00	0.12	0.85

The temperature is higher if the sunblinds are down. The indirect solar radiation is the prime agent adding heat; not the direct solar radiation, as it is screened off effectively. In case there is a larger indirect measured contribution, then the sunblinds are an effective means for shielding. This is further illustrated in Figure 5-16.

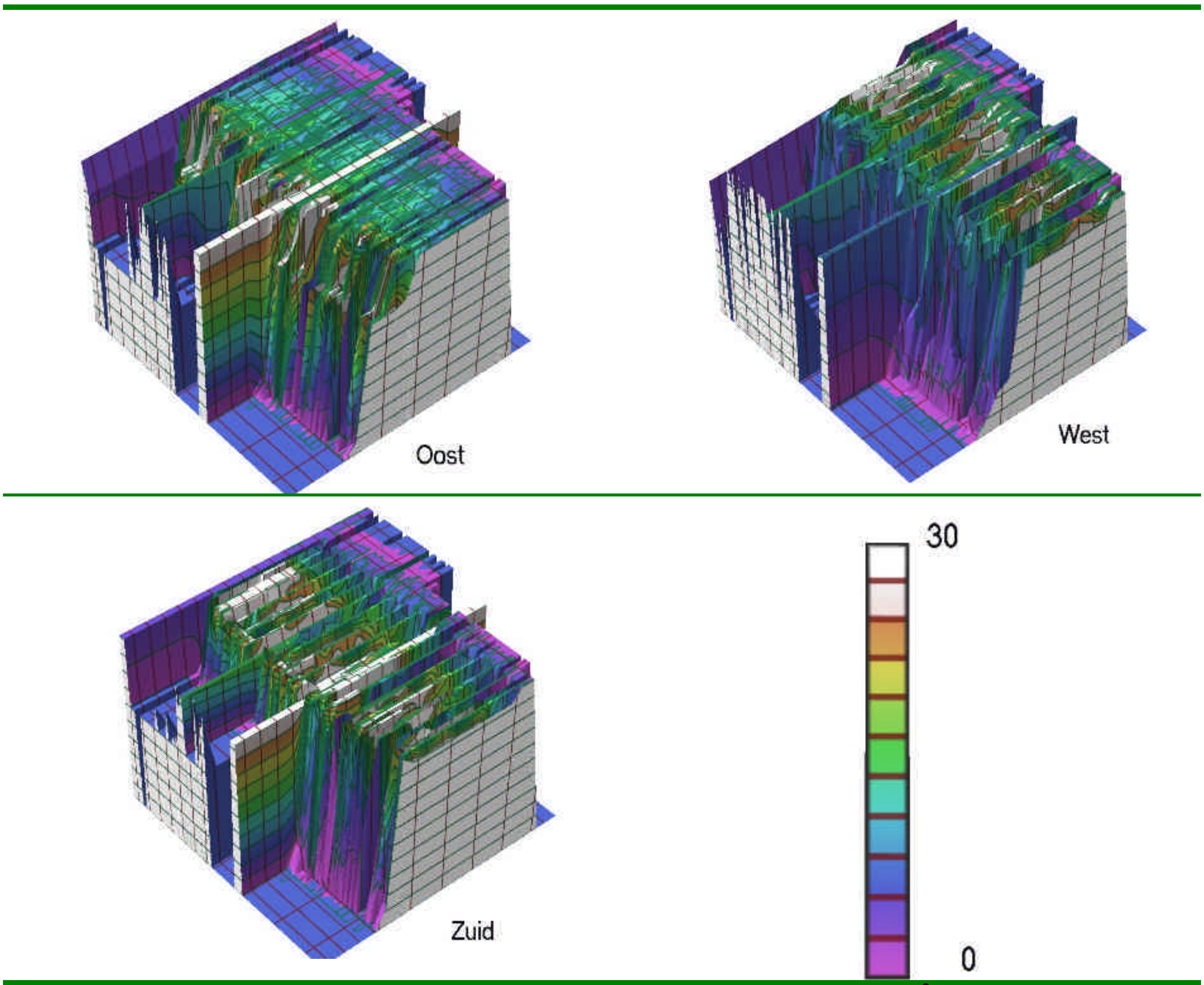


Figure 5-16 Sunblind position (Z) and incident radiation intensity kLux/m^2 (color)

Where in the figure a high value of the z-coordinate is presented and a white color is shown, effective shielding is achieved.

5.6 System performance to user actions

There is a discrepancy between the design objectives of comfort installations in utility buildings and the realised functionality and user perception [ICEEE, 2003]. Even in the current building with its refined user interaction , radical differences in user settings only lead to a few tenths of a degree in the temperature in a room. The local cooling system has to small a capacity and the impact of user actions, especially in summer, is small.

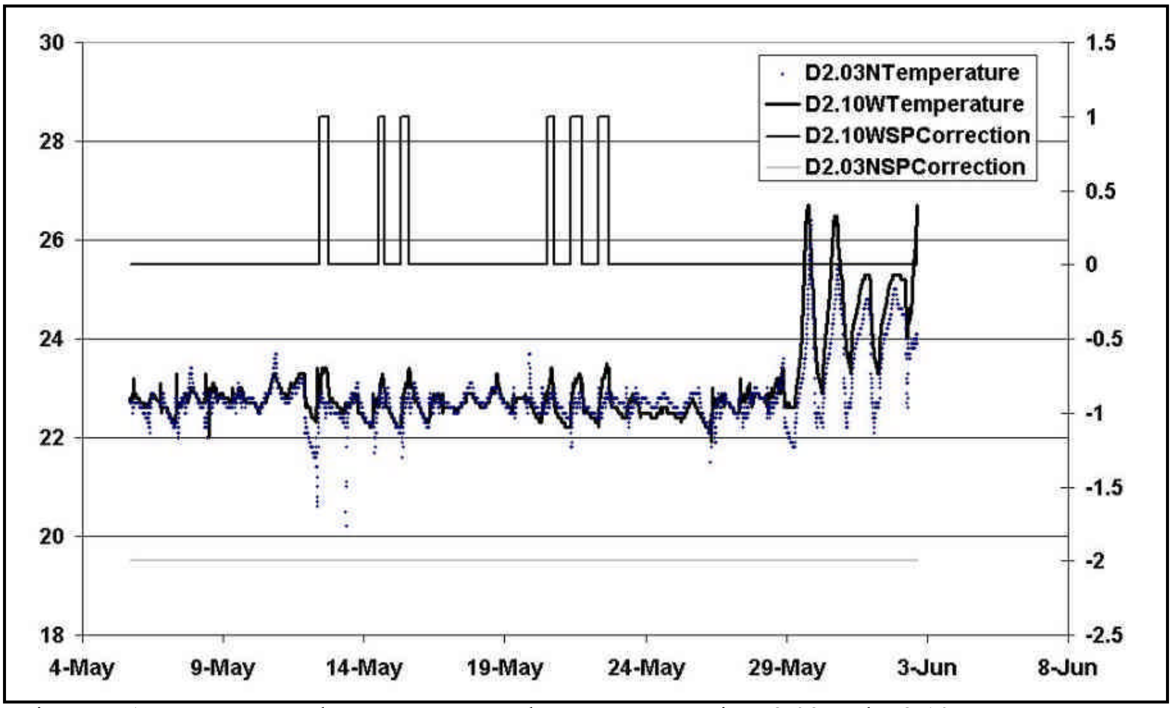


Figure 5-17 Measured temperatures and user responses in D2.03 and D2.10

It can be seen from Figure 5-17, that continuous setting of the cooling set-point by the user to a deviation of 2 degrees, does not lead to a significant deviation from a user specifying an increase in set-point of 1 degree. This is further illustrated in Table 5-7. The table shows all averaged measured temperatures and individual user set-point corrections per room for one particular day. It shows that in this case there is no correlation between the user influencing the inner climate and the temperature realised. Even rooms in which users don't affect their inner climate are slightly cooler.

Table 5-7 Effect of user control on a warm day

Room	T	user SP-delta	deltaMeasured
D1.01TemperatureDisplay	23.4	0.0	0.16
D1.04TemperatureDisplay	23.2	-2.5	-0.1
D1.06TemperatureDisplay	23.3	0	0.05
D2.01TemperatureDisplay	23.3	0	0.05
D2.02TemperatureDisplay	23.3	0	0.05
D2.03TemperatureDisplay	23.3	-2.3	0.05
D2.04TemperatureDisplay	23.2	-1.8	-0.05
D2.05TemperatureDisplay	23.2	0	-0.05
D2.06TemperatureDisplay	23.2	-0.5	-0.05
D2.07TemperatureDisplay	23.2	-1.5	-0.05
D2.08TemperatureDisplay	23.2	-3	-0.05
D2.09TemperatureDisplay	23.2	-0.4	-0.05
Average	23.25		
Variability without control	0.05		
Variability with control	-0.03		

6. Utility functions and the optimisations scheme

6.1 Goal and scope

The SEBOS model implements an innovative strategy for managing the thermal comfort in utility buildings. Based on user preferences on comfort, cost and energy use, and using information from various sources, such as weather predictions, market prices for energy and static and dynamic building behaviour, the SEBOS optimizer determines an optimal strategy for controlling the thermal comfort in a building. For this optimization it applies a pre-emptive, forward looking strategy using intelligent agents. A complete description is given in [SEBOS-FA, 2003]. The context of SEBOS is sketched in the figure below.

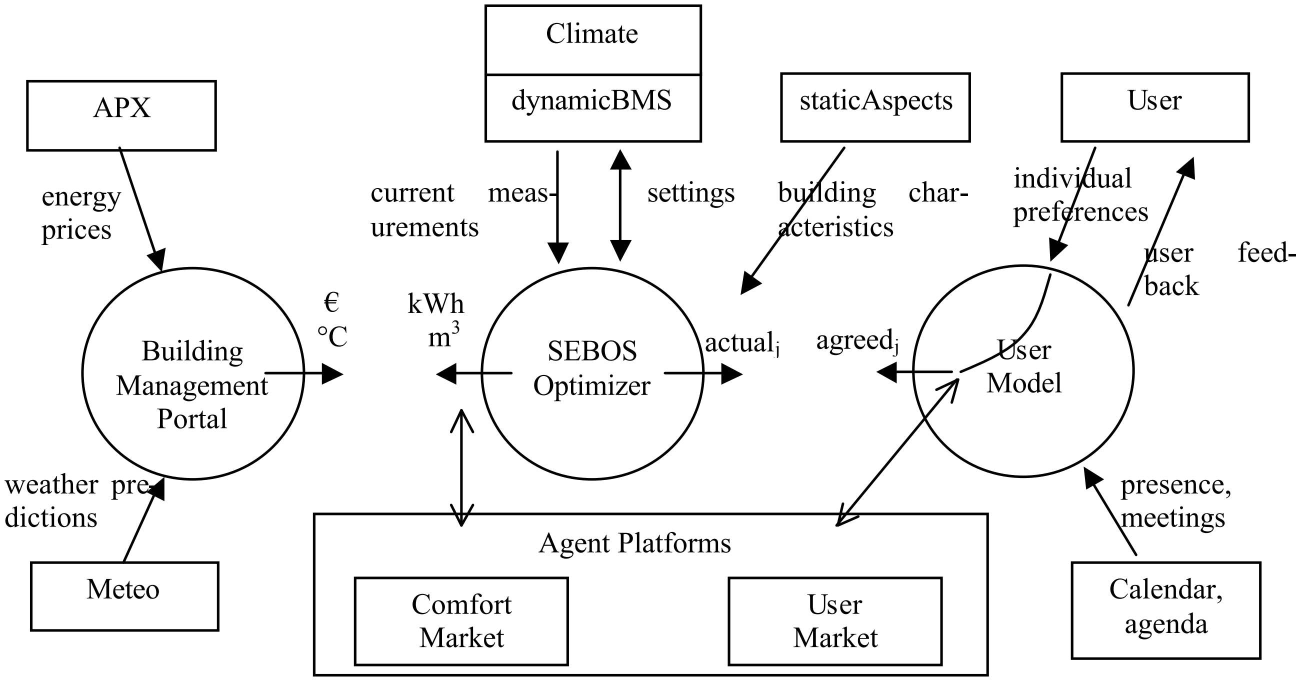


Figure 6-1 The SEBOS model context

The optimization scheme of a segment or room within the building deals with several controllers, that compete or cooperate with each other in realising thermal comfort. Controllers can be radiators, ventilation inlets (hot or cold air), air conditioners, sunblinds (control of solar radiation), etc. Each controller can contribute to the room climate at a certain price and at the cost of a certain amount of energy. The SEBOS optimizer aims at maintaining an optimal thermal comfort at minimal cost and energy consumption. This multi-goal optimization is carried out by weighing the deviation from desired comfort against cost and energy consumption, using a utility function as described in [SEBOS-FA, 2003].

6.2 The comfort perception

Traditionally, the thermal comfort in a room can only be affected by adjustment of the temperature. However, other aspects determine the comfort perception of a person in a room as well. The Fanger model acknowledges besides the air temperature the following comfort aspects: radiant temperature (influences from radiation of the sun and of large surfaces), humidity, air velocity (e.g. draught and ventilation), a person’s clothing level and his / her metabolism (activity level).

The Fanger model is quantified in the Fanger index, the 'Predicted Mean Vote' or PMV, which ranges from –3 (too cold) to +3 (too hot), with PMV = 0 as the optimal thermal comfort. This optimal comfort level is characterised by a 'Predicted Percentage Dissatisfied' (PPD) of 5%[7] of all people within a target group (note that there is no comfort level which satisfies all individuals at the same time). As we can see in Figure 6-2 this PPD rapidly increases when the PMV deviates from 0. We can also see in this figure the margins between the traditional comfort target of a Building Management System (BMS) and a cost-effective comfort target without increasing the percentage of dissatisfied people. Note that we assume here the heating season, where delivering heat costs money and energy. In the summer the picture is the other way around.

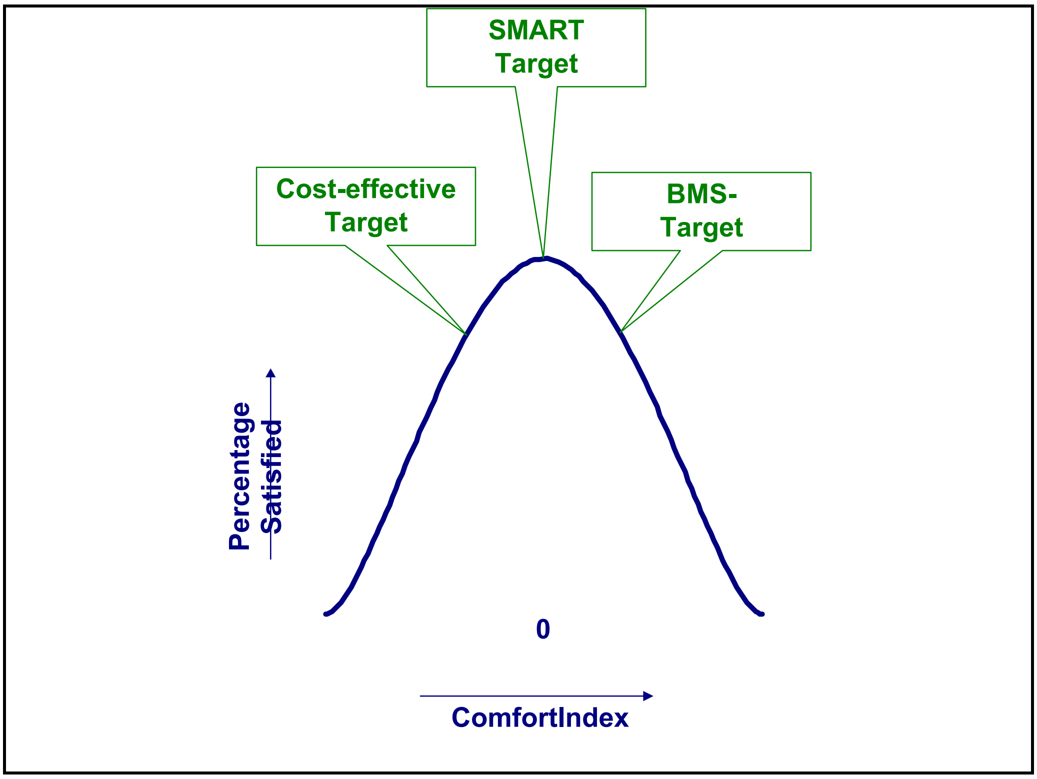


Figure 6-2 Predicted Percentage Dissatisfied in relation to the Fanger index

Using knowledge of the building and installation and the building environment (especially the outdoor climate) we can determine the climate in each segment or room of the building, depending on an initial situation and the settings of each controller and of the building installation. The SEBOS optimizer uses a simplified model for this calculation, since a complete TRNSYS simulation would take too much time and resources. Simulation runs have shown that in comparison with TRNSYS the simplified model serves well in predicting the indoor climate, especially since long-term effects are corrected using real measured values. One of the goals in the IIGO project is to show that the SEBOS model functions in a real-time environment.
If we know the comfort preferences of the persons in the building, we can also determine the deviation from the preferred comfort and the comfort perception for each person given the calculated indoor climate. We can use this information in finding an optimal control strategy such that the total comfort perception for all users is maximal and the total cost and energy consumption is minimal. For mathematical optimization we need to express the comfort perception, cost and energy in a utility function and find a satisfactory weighing of these elements.

[7] That means that even in conditions of (objective) perfect comfort. 5 % of all users is dissatisfied. It is impossible to set comfort in a population to please everyone.

6.3 The utility function

The choice of utility function has to be determined according to its purpose: it should give a penalty if the comfort perception is low (i.e. the deviation from the preferred comfort is high), if the cost is high and if the energy consumption is high. In previous projects [SEBOS-FA, 2003] we have defined a highly artificial net utility function of the form:

$$u_{net}(c) = \begin{cases} -\dfrac{d_{\max}^2 \cdot d^2}{d_{\max}^2 - d^2} \cdot e^{\frac{k}{1-k^2}} & \text{for } d^2 < d_{\max}^2 \\ -\infty & \text{for } d^2 \geq d_{\max}^2 \end{cases}$$

where $d < d_{max}$ is the comfort deviation and $-1 < k < +1$ is a combined cost- and energy factor, which is free to determine. For $k \rightarrow 1$ each deviation in comfort is punished heavily and this leads to a 'perfect' comfort. For $k \rightarrow -1$ the utility function approaches zero even when the comfort deviation is near the maximum allowed deviation d_{max}. The resulting 'optimal' comfort will be rather Spartan, since cost and energy savings are the determining factors.

The asymptotic behavior of the utility function can give problems when the calculations end up in the undefined area where $d > d_{max}$. Another property of the utility function is that it is symmetric around $d = 0$. It equally weighs positive and negative deviations. The utility function is difficult to interpret. Also we have some questions about the performance of the utility function.

Therefore we have defined and tested an alternative utility function which prevents a number of the previously mentioned disadvantages:

1. The comfort utility function is based on the *sum-of-squares* principle, which is easy to interpret, since it gives a measure of the deviation of the comfort w.r.t. the preferred comfort.
2. The comfort utility function is non-symmetric, since we use different weightings d_{up} and d_{low} for positive (too warm) and negative (too cold) comfort deviations.
3. Parameterization can be done by variation of the cost and energy factors and weights in the net utility function.

The comfort part of the utility is defined as:

$$u(c) = \begin{cases} -\dfrac{d^2}{d_{up}^2} & for\, 0 \leq d \leq d_{up} \\ -\dfrac{d^2}{d_{low}^2} & for\, d_{low} \leq d \leq 0 \end{cases} \qquad \text{where } d = (c - c_{pref})$$

The above function scales *u(c)* to 1 when the upper or lower allowed deviation is reached. Note that we use d_{up} and d_{low}. In the previous function we defined an absolute boundary d_{max} for the comfort deviation.

The net utility function also comprises elements for cost and energy and is defined as:

$$u_{net}(c) = \sum_i u_i(c) - P \cdot \sum_i wp_i \cdot \cos t_i(c) - E \cdot \sum_i we_i \cdot energy_i(c)$$

$u_i(c)$ is the comfort utility in period i as defined above, $cost_i(c)$ and $energy_i(c)$ are the sum of costs in period *i*, and the sum of energy in period *i*, in order to obtain comfort *c*.

P and *E* are the generic weight factors between the comfort, cost and energy for a session and will be based on a base usage of a building or segment given the number of 'degree days' or 'degree hours' in the session, and the overall energy – price balance.

wp_i and we_i are the personal weight preferences of a user in period i. With these parameters the user can give his or her preferences for cost and energy efficiency in order to reach almost preferred comfort. Higher efficiency then leads to slightly less overall comfort.

6.4 IIGO Installations and Controllers Kropman Nijmegen

In the SMART project [SEBOS-UM, 2003] we developed a physical building model (PBM), part of which is the building installation model. For the IIGO project we have enhanced this model with installation and controller elements within the Kropman Nijmegen building.

6.4.1 Central heating

The central heating installation converts the (import) resource *NaturalGas* into *Heat*, which is transported to the segment radiators as hot water. The gas-heat conversion is done at a given *efficiency*, which is fixed for the installation. The temperature setting of the hot water is determined using a *heating curve*, which depends on the outside temperature and which varies over time. The heating curve influences the maximum capacity of the radiators in each period.

The central heating installation is defined as follows:

```
CentralHeatingInstallation <centralHeatingName>
      HeatingCurveProfile MProfile
            { Mprofile }
      EndHeatingCurveProfile
      EfficiencyProfile <value>
            { Mprofile }
      EndEfficiencyProfile
      NumberOfImportedResources 1
      Resource NaturalGas
            Price Mprofile
                  { Mprofile }
            EndPrice
      EndResource NaturalGas
      NumberOfExportedResources 1
      Resource Heat
            Price Mprofile
                  { Mprofile }
            EndPrice
      EndResource Heat
EndCentralHeatingInstallation <centralHeatingName>
```

The `HeatingCurveProfile` profile is optional for the `CentralWaterHeating-Installation`. It will not be used, since the radiator controllers receive a dedicated capacity profile, for which the calculations are already done in the SEBOS shell. The `Heating-CurveProfile` contains values for the temperature of the hot water that the installation produces. The price conversion from gas price to heat price can be made by the building supervisor as a first step to affect the energy consumption of the building. The comfort optimizer calculation uses these ‘artificial’ heat prices.

6.4.2 Central ventilation

The central ventilation installation is defined as follows:

```
CentralVentilationInstallation < centralVentilationName >
      PreTreatment <bool>
      PreTreatmentEfficiency <value>
      TempSet-pointProfile MProfile
```

```
        { Mprofile }
    EndTempSet-pointProfile MProfile
    TempExhaustProfile MProfile
        { Mprofile }
    EndTempExhaustProfile MProfile
    NumberOfImportedResources 1
    Resource [NaturalGas | Electricity]
        Price MProfile
            { Mprofile }
        EndPrice
    EndResource [NaturalGas | Electricity]
    NumberOfExportedResources 1
    Resource [Heat]
        Price MProfile
            { Mprofile }
        EndPrice
    EndResource [Heat]
    OffAllowedSchedule CProfile
        { Cprofile }
    EndOffAllowedSchedule
EndCentralVentilationInstallation < centralVentilationName >
```

If air *pre-treatment* is allowed then outside air is preheated by the exhaust air from the building as far as necessary to reach the *ventilation air temperature set-point*, which can vary over time (16 - 20 °C, see Figure 3-1). The *exhaust air temperature* is determined by the SEBOS shell, based on a persistency model. If this profile is not defined, the current segment temperature is used as a 'best' estimate.
During working hours the ventilation air (always at *ventilation air temperature set-point*), mixed with recirculation air (at segment temperature) from the segment, is blown into the rooms at a fixed flow rate. At night and in the weekends the ventilation flow can be turned off centrally.
The local inblow air (the mix of ventilation air and recirculation air) can be locally cooled as explained in Chapter 4.4.
The flow rate of the air from the central ventilation installation is fixed, since it is induced by e.g. indoor air quality requirements.

6.4.3 Central cooling

In the Summer local cooling can be controlled. At a local level the ventilation air, mixed with recirculation air from the segment, can be cooled further by a cooling water system at a *central cooling temperature set-point* of ca. 16 °C.
Note that if the central ventilation is turned off, no local cooling is possible.

```
CentralWaterCoolingInstallation < centralCoolingName >
    TempSet-pointProfile MProfile
        { Mprofile }
    EndTempSet-pointProfile
    NumberOfImportedResources 1
    Resource [NaturalGas | Electricity]
        Price MProfile
            { Mprofile }
        EndPrice
    EndResource [NaturalGas | Electricity]
    NumberOfExportedResources 1
    Resource [Heat]
        Price MProfile
```

```
                    { Mprofile }
                EndPrice
            EndResource [Heat]
EndCentralWaterCoolingInstallation < centralCoolingName >
```

6.4.4 Controller: radiator

The *radiator capacity* depends on the value of the heat curve in each period. This capacity can be calculated from the characteristics of the radiator, i.e. the area, the *maximum capacity* at the *maximum set-point* for the water temperature, the *actual set-point* of the water temperature, and the *slope*, which follows from calculations for the Radson-type radiators that are present in the Kropman Nijmegen building.

*capacity = maxCapacity – slope * area * (maxSet-point – set-point)*

where

area	total (radiation) area of the radiator, in m^2
maxCapacity	capacity of the radiator at the maximum set-point, in kW
maxSet-point	maximum set-point for water temperature in central heating system, in °C
set-point	actual set-point for water temperature in central heating system, in °C
slope	the slope of the linear function which describes the radiator capacity, in $kW/(m^2 °C)$

The actual heat flow into the segment depends on the switch settings (between 0 and 1). As a common figure 70% of this heat flow is convection heat, heating the air in the segment, and 30% of the heat flow is radiation heat, which is absorbed by the construction.
The gross energy needed for the actual heat flow can be calculated using the conversion characteristics (i.c. the efficiency) of the central heating installation. The energy cost is calculated from the export heat prices of the central heating installation.

*heat flow = setting * capacity (70% convection heat, 30% tion heat)*
energy = heat flow / central-heating.efficiency
*cost = heat flow * central-heating.export-resource.price*

The local radiator is defined as follows:

```
Radiator <radiatorName>
      ConnectedTo <centralHeatingName>
      Resource Heat
      Area <value>
      CapacityProfile MProfile
            { Mprofile }
      EndCapacityProfile
      ModelIdentifier Linear
            MaxSet-point<value>
            Slope <value>
      EndModelIdentifier Linear
      SwitchingEnergy <value>
      InitialSettingCACSetting CProfile
            { Cprofile }
      EndInitialSettingCACSetting
EndRadiator <radiatorName>
```

The `CACSetting` profile contains the ‘switch’ settings (between 0 and 1), which determine the percentage of the maximum radiator capacity used to heat the segment at each period. The `SwitchingEnergy` normally is set to 0.

6.4.5 Controller: air inlet

The local ventilation air inlet is defined as follows:

```
WaterCooledAirInlet <airinletName>
      Connectedto <centralVentilationName>
      FractionVentilationAir <value>
      Cooling <bool>
      SwitchingEnergy <value>
      Resource Heat
      EfficiencyProfile MProfile
            { Mprofile }
      EndEfficiencyProfile
      VentilationVolume MProfile
            { Mprofile }
      EndVentilationVolume
      InitialSettingCACSetting CProfile
            { Cprofile }
      EndInitialSettingCACSetting
      Controllable CProfile
            { Cprofile }
      EndControllable
EndWaterCooledAirInlet < airinletName >
```

The *fraction ventilation air* (ca. ¼) is locally mixed with recirculation air (ca. ¾). The only control of ventilation can be done during the summer, by demanding extra local *cooling* of the mixed ventilation air. This cooling is carried out using a central water cooling system at a given set-point temperature (see 6.4.3) with a given local *efficiency-profile*.
The energy required for ventilation and cooling can be calculated using the amount of extracted cooling from the cooling water, the conversion within the central cooling installation and the heating value of `NaturalGas` or efficiency of `Electricity`. The imposed cost follows from the export negative heat (cool water) resource price of the central ventilation installation.

6.4.6 Solar transmission control

The local solar transmission control is defined as follows:

```
      SolarTransmissionControl <sunblindName>
      AttachedTo <solartransmitterName>
      CoveredFraction <value>
      ShieldingFraction <value>
      InitialSettingCACSetting CProfile
            { Cprofile }
      EndInitialSettingCACSetting
      Controllable CProfile
            { Cprofile }
      EndControllable
      EndSolarTransmissionControl < sunblindName >
```

The sunblinds in the building can be controlled, except for the segments at the corners of the building, since these segments have windows on two different orientations. If the sunblinds shade off too much of the daylight and people are working in the segment, the lights near the windows are switched on automatically. Since we assume that the effect of the extra lighting on comfort, cost and energy are small in comparison with other measures we will neglect these influences in the optimization.
As an enhancement to the SEBOS model in [SEBOS-FA, 2003] we will make use of an extra option in the control of the sunblinds: the choice between automatic control and manual control.

In the experiment we will use the latter for all rooms during working hours. In order to be able to switch easily between these two control options we add a `Controllable` profile to each controller in the model. The default will be set to `true` (1). For each period in which automatic control is not allowed we set the value to `false` (0). In this case the `InitialSetting-CACSetting` profile is filled with the expected user settings, based on a persistency model.

Note that the `Controllable` profile will be defined for all controllers and can be used in all circumstances where hand control is required.

6.4.7 Effects regarded as negligible

In the above models several small effects on comfort, cost and energy are neglected:

- Relative humidity in central ventilation cooling is assumed not to have much impact on comfort when kept in a reasonable range.
- Heat load and electricity used for extra lighting when the sunblinds close is assumed to be only a small fraction of the total heat load and energy.

7. Software interfacing to insite view; the building management supervisory system

7.1 Object structure

Table 7-1 Object structures

SuperClass	SubClass	SubSubClass
Device	AnalogousActuator	SunblindAngleControl
		SunblindHeightControl
		TemperatureSet-pointControl
	AnalogousSensor	SunblindPosition
		CloudCoverageSensor
		TemperatureDisplay
	DigitalActuator	LightControl
		PresenceButton
		StrategyDisplay
		SunblindControlSwitch
	DigitalSensor	

Table 4-1 indicates the structure of the InsiteView-objects created. Given this structure some 130 signals were considered in the project of the installation and of individual comfort management parameters in the rooms. In SEBOS [SEBOS-FA, 2003] a physical building model (PBM), part of which is the building installation model was developed. For the IIGO project this model was enhanced with installation and controller specific elements within the Kropman Nijmegen building. In Nijmegen, extensive process visualisation and analysis of historical data is possible using the InsiteView package [InsiteView, 2001]. In this chapter the signals used via this package are described. The detailed IVCOMServer<>SMART bridge is similar to the one described in [SEBOS-UM, 2003].

8. Experiment planning

8.1 Logging

Part of this report is devoted to the data collected since January 2003. Logging will continue for the experimental test. From all rooms on the first and second floor the measured comfort parameters and control settings as visualised in Figure 2-2 will be collected. Parameters from the installation are monitored as well. The logging frequency is in the order of once per 8 minutes. Data collected from several sources were processed and analysed using the Merger-program [Kamphuis, 2003]. Merger combines tabular data from various sources into a file format suitable for import in Excel.

8.2 Changes in the control strategy

Building management systems have an opportunity for better satisfying user wishes, at the same time as decreasing the energy usage and cost [ICEEE, 2003]. In this test-experiment the following opportunities are utilised:

- **PPD-control**. The PPD (percentage of people dissatisfied)-curve in the Fanger model is used for control of the thermal comfort. Building managers, driven by user complaints, are inclined to operate a building on the warmer side of the Gaussian shape of the PPD-curve (see Figure 6-2) and make less use of a number of comfort aspects and activity levels taken into account by the Fanger model. An equal number of dissatisfied persons can be achieved by targeting the colder side of the Gaussian curve. In the SEBOS-system this is achieved by setting the allowed comfort deviation setting. Given the cost optimisation drive, the model will automatically try to heat less in winter and to cool less in summer keeping the larger percentage of building users satisfied. The latter will be most difficult to achieve in view of the findings presented in chapter 8.2. Opportunities will be sought in using the central ventilation system for pre-cooling the building mass in non-office hours. An example of temperatures, when equivalent PPD's are used can be seen in Figure 8-1. One line represents the measured temperature; the other line is the (calculated) lower temperature with equal PPD. The temperature average would drop from 21.9 to 20.2 in this period.

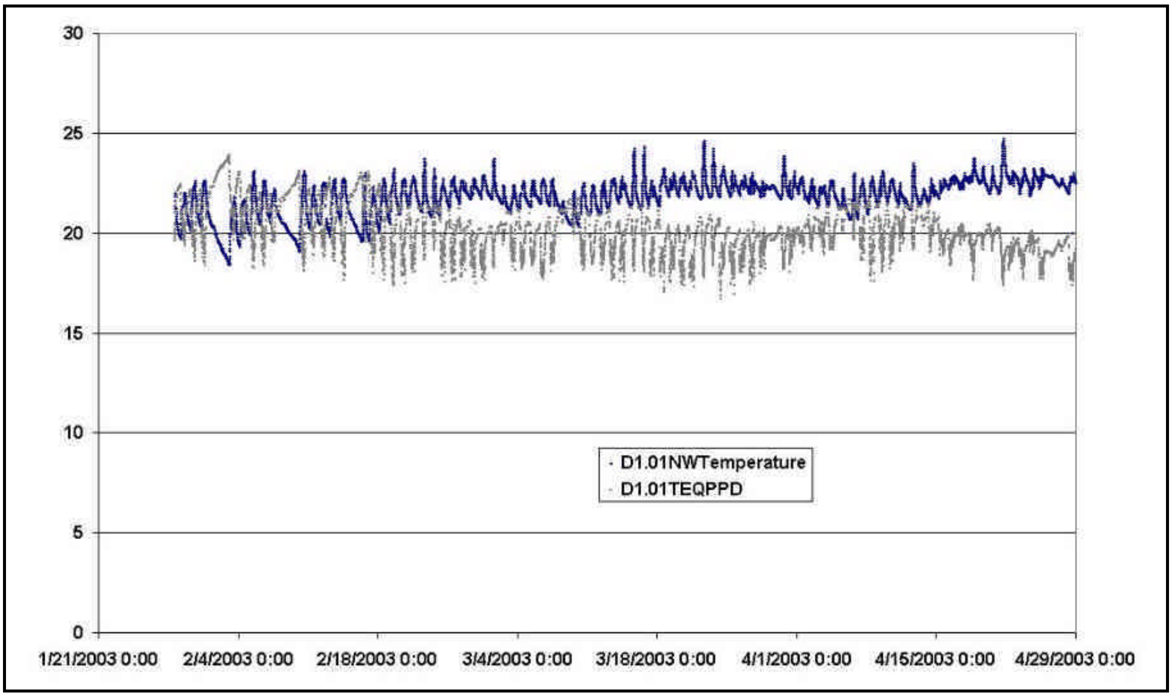


Figure 8-1 Measured and equivalent temperatures with the same PPD

- **Using persistent information**. An attempt is made to build a learning curve from the user voting behaviour. Preserving the existing wall-box and interface on the computer, the response of the user will be interpreted differently. The overall voting behaviour as a function of the time of the day will be included in determining the action of the local comfort aspect controllers. This gives SMART the opportunity to avoid situations, especially in slowly responding buildings, that a user action (say: a request for heating in the morning) gives a response of the installation, that only leads to another user action (say: request for cooling in the afternoon) later on the day. In SMART, the response of the building within a time horizon of up to 24 hours is included in the optimisation, thus leading to an overall minimisation of these effects. Instead of precisely controlling the actuators in the room, SMART will operate as a filter, that will translate the user response into a change in set-point, which takes into account the response in terms of building physics and other preferences expressed earlier. SMART in this way builds up a comfort profile, which gradually adapts best to the user wishes. In the first preliminary practical experiment of the SMART software it was shown, that a consistent and user desired comfort profile can be built up in the time span of six weeks. For fully using all the information now collected in the building, the SEBOS-shell will also operate with persistent values of all installation signals in all real-time scenario calculations. Depending on the kind of physical parameter, persistence will be on a day- or week-basis.

- **Solar transmission control outside working hours**. The existing user definable operation mode is preserved. In non-working hours, the effects of incoming solar radiation and radiation from the building to the sky are minimised energetically per segment. This means, that in the morning in spring and autumn preheating energy consumption can be diminished. Furthermore, the convection losses may be prevented.

- **Improved control of the central ventilation.** As can be seen, the central ventilation part in the temperature build-up of the inner comfort in rooms leads to temperature overshoot. The control strategy should allow for more anticipation in this respect.

- **Improved central heating water temperature control.** As shown in previous chapters the central heating water temperature can be improved. In SEBOS the required heating demand of each individual room is available for a number of periods ahead. Given the required heat demand and the capacity of all the radiators, it is possible to determine the maximum temperature of the central heating water.

To get insight into the user perception before and after the experiment there will be frequent user inquiries. During the test, a monthly Email will be sent out giving the results of the experiments.

9. References

COMFY, 2000	E. Boertjes, J.M. Akkermans, R. Gustavsson, and R. Kamphuis [2000]: *Agents to Achieve Customer Satisfaction - The COMFY Comfort Management System*, in Proceedings 5th Int. Conf. on the Practical Application of Intelligent Agents and Multi-Agent Technology PAAM-2000 (Manchester, 10-12 April 2000), pages 75-94, The Practical Application Company Ltd., Blackpool, UK, 2000. ISBN 1-902426-07-X.
ICEEE, 2003	Jaap Jelsma, René Kamphuis and Wim Zeiler, *Learning about smart systems for comfort management and energy use in office buildings* Refereed paper at the eceee 2003 Summer Study, June 2nd - 7th, 2003.
IIGO, 2001	IIGO project voorstel. Onderzoeksvoorstel als ingediend binnen de NOVEM-DEMOS regeling.
InsiteView, 2001	InsiteView, a building management supervisory package. Kropman R & D Rijswijk.
Kamphuis, 2003	Programma beschrijving MERGER, ECN 2003.
Lute, 1992	P.J. Lute. The use of predictions in temperature control in buildings. A passive climate system application. Proefschrift TU Delft,1992.
Czeplak, 2002	Kasten Czeplak, Solar Energy Vol.24, S 177-189. Pergamon Press Ltd.
SEBOS-FA, 2003	I.G. Kamphuis, C.J. Warmer, D.H. van Dok. SEBOS, A Smart Enhanced Scope Building Management System Optimiser Shell: Functional and Architectural description. ECN-CX—02-102, 2002.
SEBOS-UM, 2003	I.G. Kamphuis, C.J. Warmer, D.H. van Dok. SEBOS, A Smart Enhanced Scope Building Management System Optimiser Shell: Functional and Architectural description. ECN-CX—02-102, 2002.
Strootman, 2003	Monitoring en evaluatie gebouw 40. Ontwerp versus praktijk, ECN-C--03-005. 2003.
TRNSYS,2001	TRNSYS and TRNSHELL. Version 15.2. Transsolar Energietechnik. www.transsolar.com.