DIGITAL CONTROL SYSTEM FOR EXTREME LOW ENERGY APARTME

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INTRODUCTION

In the frame work of IEA Task XIII, a pilot project URBAN VILLA has been realized in Amstelveen, The Netherlands, Ref. /1/. This project concerns the development of an apartment building of 42 luxurious apartments, of which 16 will have extreme low energy consumption. Success and failure of every new domestic design are ruled by the sensation of comfort, experienced by the residents. Therefore, in order to make this a successful project comfort requirements should be fulfilled.

THE ENERGY CONSUMPTION

The total primary energy consumption of these apartments are estimated at 3675 kWh/a of natural gas : for space heating 920 kWh/a, domestic hot water system 1630 kWh/a and pumps and the ventilators 1125 kWh/a, Ref. /2/.

THE INSTALLATION (Figure 1)

In order to achieve this goal, these apartments are very good isolated, use triple low energy glass and great care is taken to prevent air infiltration. Furtheron an atrium, equipped with a sun protection screen, controllable flaps on the roof, upper and lower side of the facade, is used to preheat the air that comes into the apartments and a solar collector system to preheat the domestic hot water demand. Furtheron in the winter balanced ventilation with heat recovery is used and in the summer natural ventilation with open windows. A High Efficiency boiler is used for the domestic hot water and central heating system; spiro tube convectors are used to bring the rooms very fast at temperature, Ref. /3/.

THE CONTROL SYSTEM

Because of the complexity of the installation and optimal integration is required to realize the low energy consumption, a digital control system is needed. Moreover, in modern houses, individual control per room is mandatory.

The control system of Urban Villa, Ref. /4/, Ref. /5/ consists of:

* 1 sun- and wind automatic for the sun shading devices
* 1 atrium control system
* 4 solar control systems, each one providing 4 apartments with solar energy for domestic hot water
* 16 individual home controllers, each apartment one
* A local CTR (Combi Talk Ready) bus system (based on RS 485) supports the communication between the whole control system

As can be seen from Figure 1, there is no such thing as a main station and sub stations. The atrium controller, the solar control system and the individual home controllers operates independent, although they can communicate with each other via the local bus system.The personal computer (10) can be plugged in on this local bus (or via a modem) to configure the systems for the first time and eventually collect data from them. Each system has a control board that consists of a LCD display and four keys to reprogram the control system (see Figure 2). It depends on a pin code security how many adjustments can be performed, and

which data are obtainable: for instance, a resident can only adjust the temperature set-points and the week programmes of each room, while the engineer can adjust the maximum water temperature. The structure of the controller is menu organized for easy access .

The sun and wind automatic (1)

The sun and wind automatic measures the outdoor temperature, the wind speed, the solar radiation and the rain fall. It contains a micro processor. Based on the weather conditions it determines whether the sun shading devices on the south facade of the apartments may be lowered or has to be pulled up (storm security, when the windspeed is above 15 m/s, and rain security). It has a delay period between two changes to prevent the sun shades from moving too often due to rapidly changing weather conditions. The data are send via the CTR local bus system (2) to the atrium controller (3) and the individual home controllers (5).

The atrium controller (3)

The main task of the atrium controller is to control the indoor temperature of the atrium. For this purpose the atrium controller has control over the sun protection screen and the roof, upper and lower flaps on the facade. Each of these components can be steered independently from each other. With the exception of the screen, which can only be pulled up or down, the flaps can be steered in steps.

The algorithm of the atrium control is based on the measured outside temperature $T_{outside}$, the atrium temperature T_{atrium} and the atrium temperature set point T_{a_set} and performed in a fixed sequence of actions.

The exact flap position X is proportional to the difference between T_{atrium} and T_{a_set} . The proportional factor P is adapted according to the temperature difference between $T_{outside}$ and T_{atrium} The lower the outside temperature the lower the factor. A good approximation is 4 for a summer situation and 1 for a winter situation.

i. when in the morning $T_{atrium} <= T_{a\_set}$, all flaps are closed and the screen is pulled up.

ii. when $T_{atrium} > T_{a\_set}$ the sequence is: first open the roof flaps, until they are fully open, then open the upper flaps until fully open. When the atrium temperature is still increasing, then the lower flaps are opened and finally the sun protection screen is lowered.

The momentary position X_{roof} of the roof flaps can be determined with

$$X_{roof} = P \cdot \frac{(T_{atrium} - T_{a\_set})}{(T_{atrium} - T_{outside})} \cdot 100 \quad [\%] \qquad 1$$

Every 10 minutes this position is recalculated with the new measured atrium and outside temperature T_{atrium} and $T_{outside}$, until at $T_{atrium} = T^*$, the roof flaps are fully opened:

$$T^* = \frac{(P \cdot T_{a\_set} - T_{outside})}{(P - 1)} \qquad 2$$

When the roof flaps are fully opened and T_{atrium} is still increasing then $T_{a\_set} = T^*$ and the calculation is repeated for the upper flaps and so on.

ii when $T_{atrium} < T_{a\_set}$ the sequence is reversed.

When $T_{outside} < 10\ ^{0}C$ and $T_{atrium} < 16\ ^{0}C$ during the night (23.00 - 06.00 hour) then the sun protection screen acts as an isolation screen and lowered to decrease heat losses.

Although the home controllers are autonomous, under certain circumstances the atrium controller overrules the home controllers. This is the case when the storm and/or rain securities are active, or when the glass washer security is switched on. Then the atrium controller will pull up the sun shades in the apartments, regardless whether it is in the automatic or manual control mode. After the protective mode is over, the control is returned. In the atrium itself, all the roof flaps are closed when the storm and rain security is active.
Besides the above mentioned securities, the atrium controller has also a fire and smoke warning system. When the atrium controller detects a fire or smoke, all roof flaps are fully opened. At the same time the inlet ventilators of all the IEA-apartments are switched off, to prevent the smoke to be sucked by the ventilators and blown inside the apartments.

The solar control system (4)

A solar collector system, consisting of approximately 19 m^2 flat plate collectors, a circulation pump, a drain vessel, 4 heat exchangers and 4 controlled valves, supplies a block of 4 apartments with solar energy to preheat the domestic hot water system. Each apartment has a hot water supply vessel of 200 l with two heat exchangers in it; one is connected by a controllable valve to the solar system to preheat the domestic hot water system and the other is connected to the boiler to heat the domestic hot water system to the required water temperature of 65 ^{0}C (to prevent the growth of legionella bacteria).

When the temperature difference between the collector temperature T (4) and the cold water temperature in one of the vessels (6, the lower temperature sensor T) is more than 10 K, then the valve of that particular vessel is opened. After a delay of several seconds the circulation pump is switched on and begins to rotate at maximum speed. In sequence the other valves are opened and after a preset period of time the pump slows down and rotates at its optimum speed. When the temperature difference decreases to 2 K in a certain vessel and there is one more valve still open, that particular valve closes. When that valve is the last valve that is still open, then the pump is switched off and that valve remains open for a preset period, until the water from the collectors are collected in the drain vessel just above the pump. Then this valve is closed too. On this way the solar collectors are protected against freezing water in the circuit in the winter.

The boiler automatic (7)

The boiler has its own control system, the boiler automatic (7). It controls the burner and the separated hot water and central heating water pumps. The home controller has no control over the boiler automatic. The boiler automatic is ruled by the following rules:

1. Hot water demand always overrules central heating demand. When domestic hot water is required and the central heating pump is on, it is immediately switched off and the hot water pump is switched on, immediately followed by the burner ventilator and the burner which is switched on at full capacity. After the hot water demand is satisfied, the hot water pump stops and control is returned to the central heating circuit.
2. When there is a demand from the central heating circuit and there is no domestic hot water demand, the boiler ventilator is switched on at minimum speed, followed by the central heating pump. Then the burner starts at low capacity. Every two minutes the capacity is increased by increasing the speed of the ventilator. After the central heating demand is satisfied, the burner is switched off and the central heating pump is still running for an additional 7 minutes before it is switched off. When the heat demand stops before the burner is switched on, still the pump will run for 7 additional minutes before it is switched off.

In addition to these rules, the boiler automatic has the following securities :

i. When the burner stops, it is not possible to restart it until the water temperature has dropped below 2/3 of the last measured water temperature, with a minimum of 60 °C.

ii When the water temperature increases with more than 12 K in 2 min, then the burner is switched off and blocked; only when the water temperature drops below 2/3 of the last measured value, then the burner will be deblocked and is it possible to switch it on again.

iii. The boiler automatic keeps the water temperature in the water supply vessel (6, top temperature sensor) continuous at 65 °C.

It is not possible for the home controller to interfere with the boiler automatic and the only communication between the home controller and the boiler automatic consists of a signal whether heat is required or not This is an on/off signal. Whether this demand will be fulfilled depends entirely on the boiler automatic.

The home controller (5)

Each apartment has its own individual home controller. The home controller controls the indoor climate of the living room and the 2 bedrooms, the storage vessel (7), the balanced (with heat recovery) or mechanical ventilation (9) in the living room, and the sun shades (8) of the living room and the south facing bedroom.

Because the apartments are very good isolated, the heat demand for central heating will be very minimal. To prevent that the boiler will be switched on and off too often, a storage vessel of 50 litres has been included in the central heating circuit. The water temperature in the vessel depends on the temperature difference between the temperature set point and the measured air temperature in the living room. When this difference is less or equal 0.5 K, the water temperature is 50 °C + 5 K and when this difference is more than 2 K, the water temperature is 75 °C + 5 K. In between these two limits the water temperature is proportional to this difference.

With the home controller, the living room and the 2 bedrooms can be programmed independently from each other with an individual week program, while each weekday (Sunday to Saturday) can be programmed for two daily periods.

In both bedrooms is a zone controller with a timer and an adjusting knob. By pressing the timer push button down, the day/night program is reversed into the night/day program for a period of maximum 2 hours. With the adjusting knob the temperature set point can be increased / decreased with 2 K. When the day program is on, a red control led is on, and with the night program (night set back) this led is off. When a window is opened and the heating is on, the heating will be stopped immediately and the led blinks very fast.

In the living room is a twin controller, the upper timer push button is for the heating and the lower push button is for the ventilation (Figure 3). The adjusting knob is only to increase / decrease the temperature set point in the living room . The capacity of the day ventilation is 175 m^3 /h and the night ventilation is 100 m^3/h. This can also be changed by the lower push button. In the kitchen and in the bathroom the ventilation rate can be increased to 250 m^3/h with a timer switch. When the lower led by 'raam open' is on, it indicates that the outdoor temperature is high enough to use natural ventilation and when a window is opened, the inlet ventilator is switched off.

The living room and the bedrooms are heated with spiro tube convectors with controllable thermal driven valves. It was very difficult to synchronize the very fast spiro tube convectors with the sluggish and slow thermal driven valves. Special time modulated algorithm has been

developed. It shows, that a normal PI-controller could be used to get a stable control between the fast spiro tube convectors and very slow thermal driven valves.

When the home controller receives the signal that the sun shades may be pulled down, it first checks, whether the indoor temperature is above 22 °C. Only then it will pull down the sun shades, when the sun shade is in the automatic mode. In the manual mode the resident can pull down the sun shades, every moment he wants, as long as the three securities are not active. The sun shades will stay in this position until they are reset manually. Only by switching the control to automatic mode will the control system regain control over the sun shades.

The ventilation control (9)

In winter the apartments use balanced ventilation with heat recovery. The heat recovery unit consists of separate inlet and exhaust ventilators build into one unit. The inlet air is taken from the atrium, preheated in the heat recovery system (cross flow heat exchangers) by the exhaust air and blown into the living room, the bedrooms and the kitchen. The exhaust air is taken from the kitchen, the bathroom, the toilets and the store room. The balanced ventilation has two programs, day program and night program. In the day program the ventilation rate is 175 m^3/h, while in the night program, the ventilation rate is 100 m^3/h. In the kitchen and in the bathroom the ventilation can be increased to 250 m^3/h with a timer switch. When the atrium temperature is above 18 °C and the outdoor temperature above 16 °C, the twin zone controller indicates by lighting the led 'open raam', to use natural ventilation. As soon as a window is opened, the inlet ventilator is switched off. The exhaust ventilator is always on.

REALIZATION OF THE CONTROL SYSTEM FOR URBAN VILLA

The realization of the control system is shown schematically in figure 4. The control system consist of one sun and wind automatic, one atrium controller, 4 solar control systems and sixteen individual home controllers, all connected by a CTR local bus system based on RS 485 for the communication. The system can be configurated by an extern personal computer.

To test the home control system, a test rig with a prototype of the home controller and a heating system that consists of the HE boiler, the storage vessel of 50 litres, and the thermal control valves that will be used in the apartments has been build at the laboratory of Refrigeration and Indoor Climate Control. The spiro tube convector has been build in a room with the dimensions of 2.6 * 2.5 * 2..5 m.

RESULTS Ref./6/

At first very high overshoots of the indoor temperature occurs due to the very slow closing thermal valves. Good results has been achieved by using a new time modulated algorithm for the thermal valves based on the fasted closing and opening time of the thermal valves and by lowering the water temperature.

The communication between the home control system and the boiler automatic has to be developed experimentally. At one morning after night set back the room has to be heated, but the boiler did not start. Only after 3 or 4 hours later the boiler is switched on. It seems that at night the boiler has been cooled to room temperature and when the pumps is switched on in the morning, the water temperature through the boiler jumps from 19 °C to 45 °C (water temperature in the storage vessel), so the boiler security is activated and the burner blocked. This has been solved by running the pump for several minutes before a continuous heat demand is send to the boiler.

Because the pump is controlled by the boiler automatic, it is not possible for the home controller to start the pump (when the water temperature in the storage vessel is sufficient to satisfy the heat demand). The home controller can start the pump by demanding heat from

the boiler, for a period long enough to start the pump, but too short to switch the burner on. When the pomp is running, it will run for 7 minutes (as long as there is no heat demand from the domestic hot water circuit) and by demanding heat again before 7 minutes has passed, the pump can run 7 more minutes. So with this indirect method the home controller gains control over the pump.

The storage vessel shows a higher heat loss than anticipated. It seems that the inlet tube comes into contact with the outer casing. This has been solved by the manufacturer by breaking off the cold bridge and adding an additional isolation layer on the casing.

Figure 5 shows the results of the home controller for a normal day program (08:00 - 23:00 day program; 23:00 - 08:00 night program). In the morning the heating system starts up with a high water temperature, because in the morning the temperature difference is more than 2 K. After the temperature is near the set point, the required vessel temperature 50 °C (min). When it drops below 50 °C, the boiler is switched on and heats it up till 50 °C + 5 K.

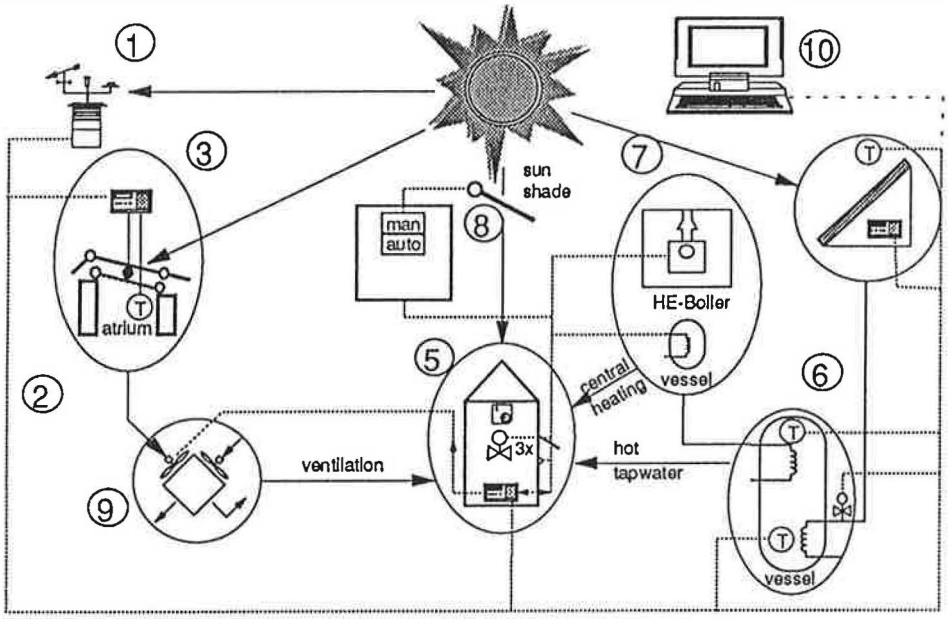

Figure 1 The components of the control system in Urban Villa

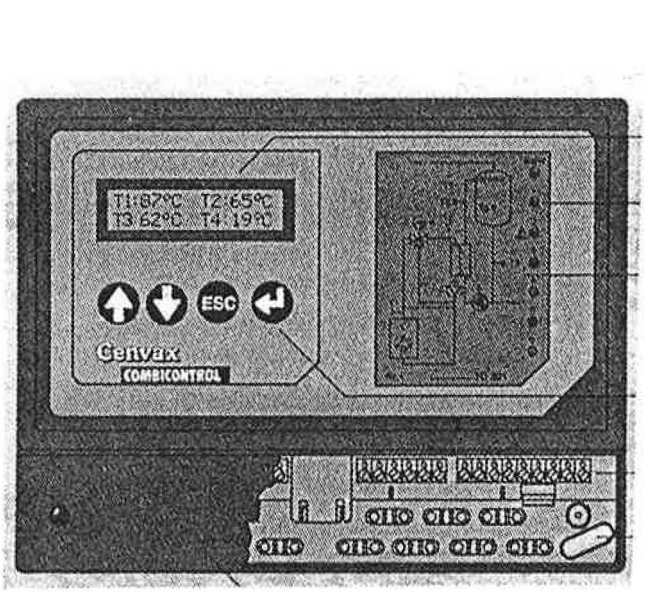

Figure 2 The control board

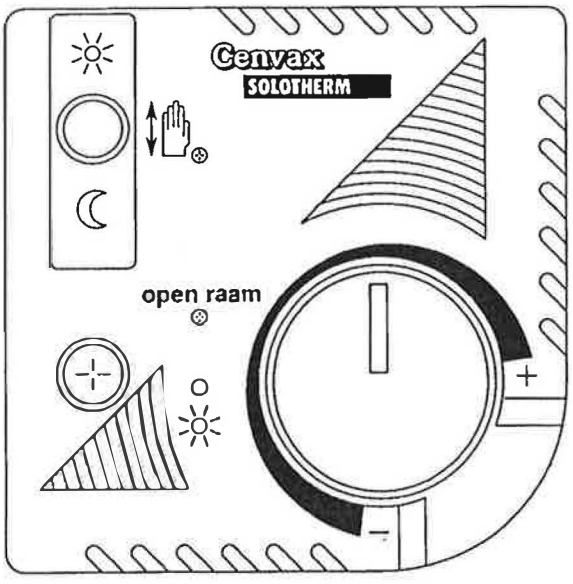

Figure 3 The Twin zone controller

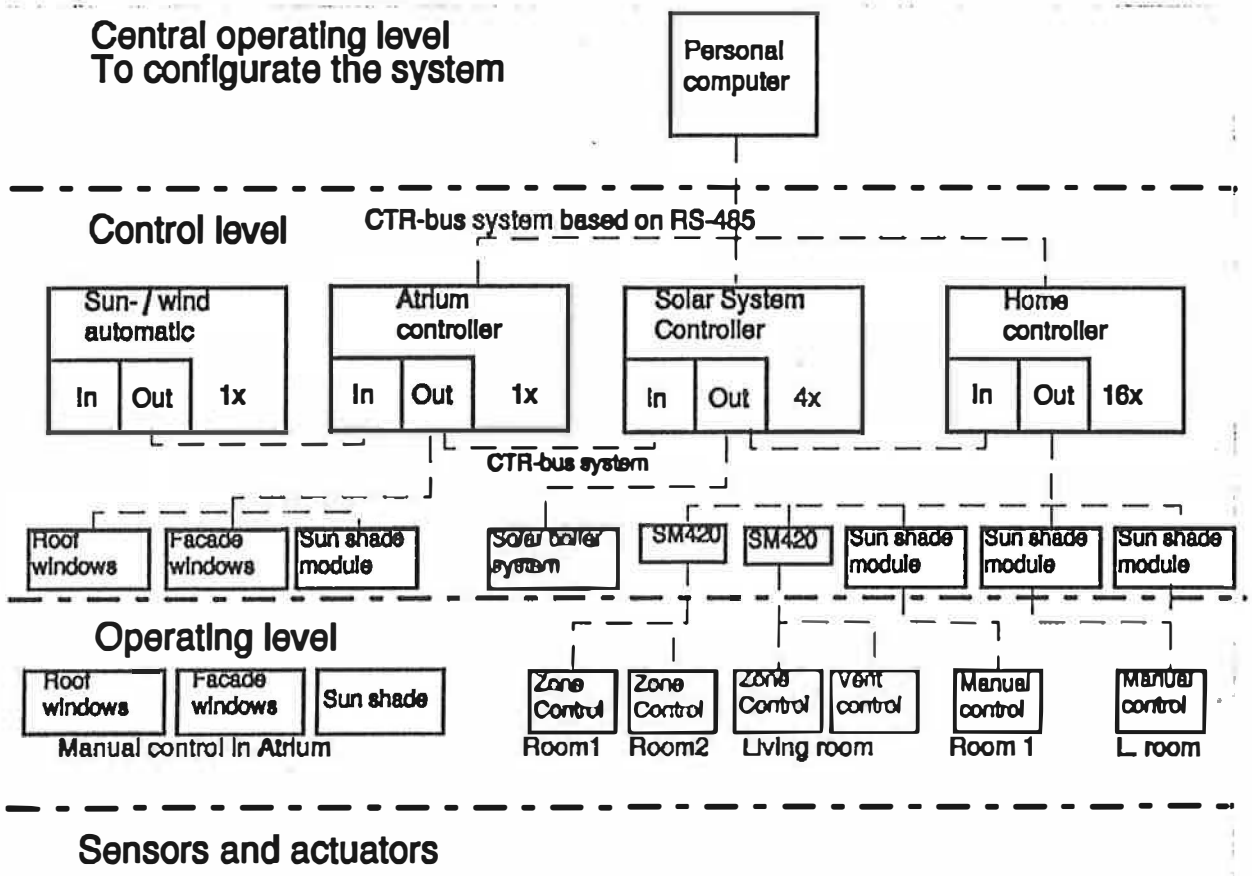

Figure 4 The realization of the control system for Urban Villa

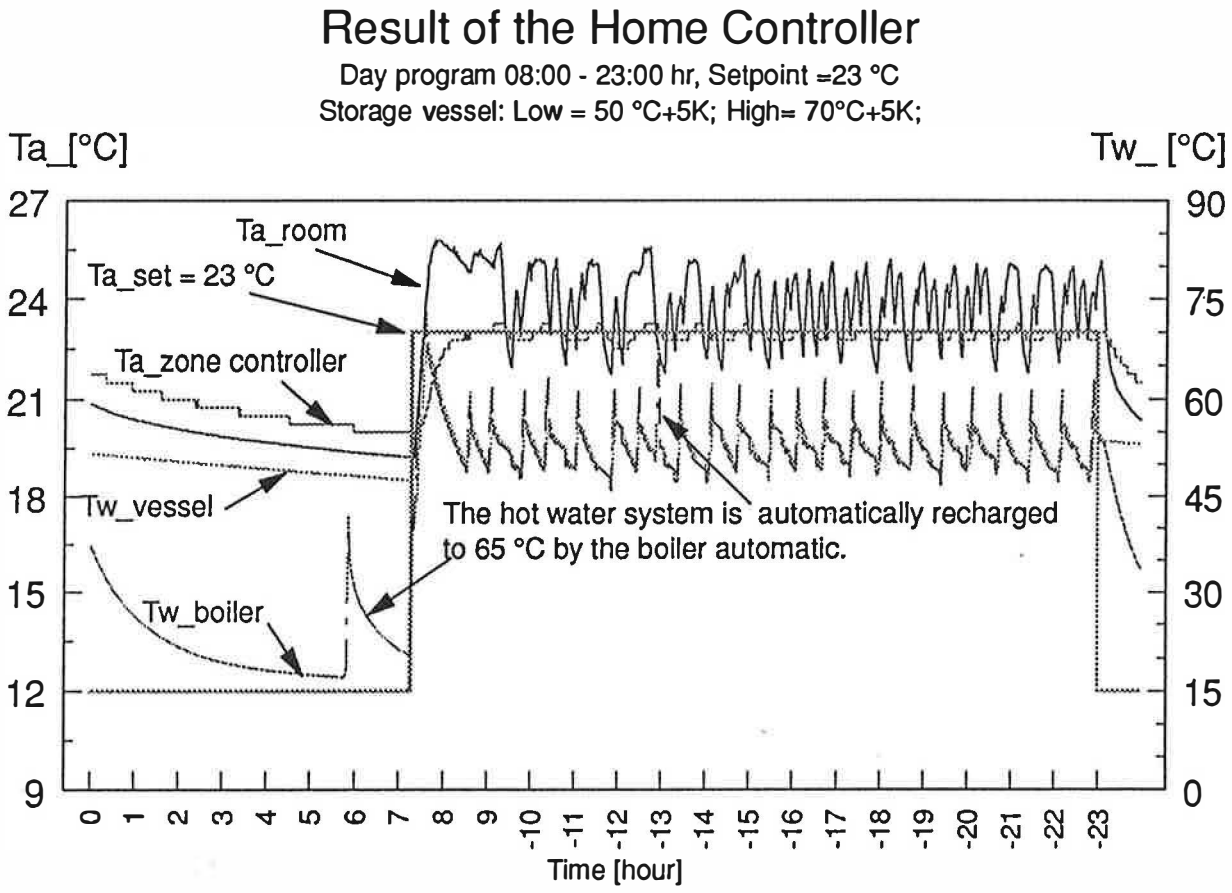

Figure 5 Result of the home controller for a normal day program