INSTALLATIONS IN LOW ENERGY HOUSES

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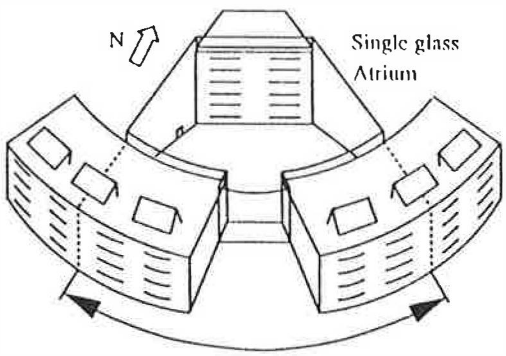
Summary

This article describes a study aiming at the design of air-conditioning equipment for an apartment complex optimized to reduce energy consumption to a minimum. The study related to a specific object, called "Urban Villa Amstelveen", which consists of 42 apartments and an atrium. The ultimate design uses passive solar energy for heating, a solar boiler system for hot tap water, balanced ventilation with heat recovery and natural ventilation with adjustable ventilation openings for effective cooling. A digital control system is used to realize the low energy consumption and to prevent room temperatures from becoming too high. The effect of the various parts of the installation on energy consumption and/or comfort was studied by means of computer simulations.

Introduction

The "Urban Villa" project was started as an experiment under IEA task XIII. It involves the building of 42 apartments, 16 of which will be designed to consume a minimum of energy. See figure 1 [1]. The objective of the project is to design houses with an extremely low energy consumption using advanced components and techniques which are not yet -but may be expected to become- economically feasible. The present article deals with the heating, ventilation and control items, with special reference to energy consumption and comfort. The following elements can be distinguished in the project:

- heating
- solar boilers as preheaters for tap water
- ventilation with heat recovery and the use of the atrium to preheat the ventilating air
- natural ventilation for cooling
- the control equipment.



Low Energy Apartments

Figure 1
Schematic front view of "Urban Villa"
Single-glass atrium ultra-low-energy apartments.

Figure 2 shows the components, integrated with the control system. This article discusses their selection and sizing. For this purpose use was made of the simulation program TRNSYS.

Basic Principles

The apartments are intended for modern double-income couples or well-to-do single persons. To ensure optimum utilization of solar radiation, the apartments have a large glass area (40%) facing south, with triple ISOS glass. Owing to effective insulation the overall U value of the facade will be lower than 1.3 W/m^2K. On the north side of the apartments an atrium has been planned. For the purpose of computer simulation it has been assumed that the apartment is occupied by a double-income couple (both partners being absent by day on weekdays). The way in which these occupants use lighting and appliances, together with the heat they generate themselves, represents an internal heat load of 2518 kWh/year. This heat generated inside the apartment, obviously, influences the heat demand. The windows on the south side of the apartment have been fitted with sunshades which can keep out 70% of the incident solar radiation. Besides, special adjustable openings have been provided in the facade to prevent overheating. Since these apartments will be owner-occupied property, private installations have been chosen wherever possible.

Heating

Simulations of one of the apartments proved its heat demand to be 141 kWh/year, concentrated chiefly in the winter months (84%). Nearly two thirds of this demand came from the living room. The low consumption is the combined result of insulation, ventilation using heat recovery, the use of the atrium to preheat the ventilating air and the large window area facing south. Further simulations were carried out with a model involving careless behaviour of the occupants. It was assumed that these occupants would open their window depending on the outside temperature (closed at 1°C; an air-change rate of 6 m^3/m^3h at 21°C). With a bedroom thus ventilated the heat demand went up by 50%. When the living room was also ventilated in this way, the heat demand even increased by a factor of 12. These values, obviously, relate to a theoretical occupants model; in real life things will be different. The figures do demonstrate, however, that energy consumption can suffer greatly through careless behaviour of the occupants.

Calculations performed according to Dutch Standard NEN 5066, which assumes that an additional 2 K/h is needed for warming up, result in a boiler capacity of 5 kW. This figure is considerably higher than it would be under continuous operation. An HR boiler was selected, to be installed in each apartment. The boiler must be able to deliver 8 litres of hot water per minute, which calls for a power of 28 kW. So this power is the criterion in choosing the boiler. It has been assumed that by reducing burner pressure the boiler power can be lowered to about 5 kW while preserving efficiency. This figure is still too high in relation to the required power. To prevent oscillatory behaviour of the installation, a 25-litre buffer vessel has been added, see figure 2.

After each heat demand the buffer contents will be raised to the required temperature by the boiler. For the transfer of heat to the rooms use is made of spiro tubes. A spiro tube is a copper or steel tube of 16 mm outer diameter enveloped in a spatial structure of copper wire attached by soldering. The control equipment has been designed so that the temperature level in each room can be regulated individually. The valve position is determined by the digital controller in each apartment. The occupants can set timers for each of the rooms and can override them manually, if required.

Solar Boilers

To ensure optimum utilization of solar energy, solar collectors with a surface area of 4.5 m^2 per apartment will be installed on the roof of the building. Their function is to preheat the tap water in the boilers of the apartments. Before the final choice was made, three variants were considered:

1 A central collector with storage facilities and individual afterheating, (80 l tapwater per day from 15 to 65 °C)

2 A central collector with individual storage facilities and afterheating.

3 Same as 2, but with simultaneous use of the storage vessel as buffer for space heating.

The drawback of system 1 is that the circulation pump is in continuous operation, which has an adverse effect on energy consumption. The drawback of system 3 is that the larger vessel gives rise to additional heat losses. System 3 should have the advantage that the solar energy also provides part of the space heating. A special study has shown, however, that a surplus of solar heat seldom coincides with a heat demand from the apartment [2].

This is due mainly to the fact that, owing the large glass area, the apartment already makes (passive) use of solar energy. Eventually, system 2 was chosen; it affords an overall saving of 1040 kWh/year (64% being supplied by solar energy). The collector is controlled centrally, the whole installation being split up into four systems for four apartments each. The pump of the collector circuit is started automatically as soon as a heat demand arises from one of the four storage vessels for tap water. The tap water temperature is controlled in the apartments themselves. To combat possible Legionella bacteria, the tap water temperature must be at least 65 °C. If the temperature at the top of the vessel drops below this value, the boiler will warm up the vessel via a heat exchanger. If the temperature is higher than 65 °C, cold water will be added.

Ventilation

Heat losses are due to a large extent to ventilation. Forced ventilation of a well-insulated apartment is essential for an adequate supply of fresh air as well as for the removal of moisture. In order to restrict energy consumption, it was decided to use heat exchangers in which the exhaust air gives up heat to the intake air. Besides, use is made of the atrium to preheat the ventilating air. Simulations have shown that the average atrium temperature is 4 K higher than the outside temperature. The influence of the heat exchanger efficiency, combined or not combined with the atrium, is shown in figure 3. In this figure data have been plotted for the following situations:

- No heat exchanger (0%)
- A single crosscurrent heat exchanger (70%)
- Two crosscurrent heat exchangers connected in series (82%)
- A regenerative heat exchanger (90%)
- No ventilation (100%)

The supply of fresh air is according to the regulations 300 m^3/h per apartment

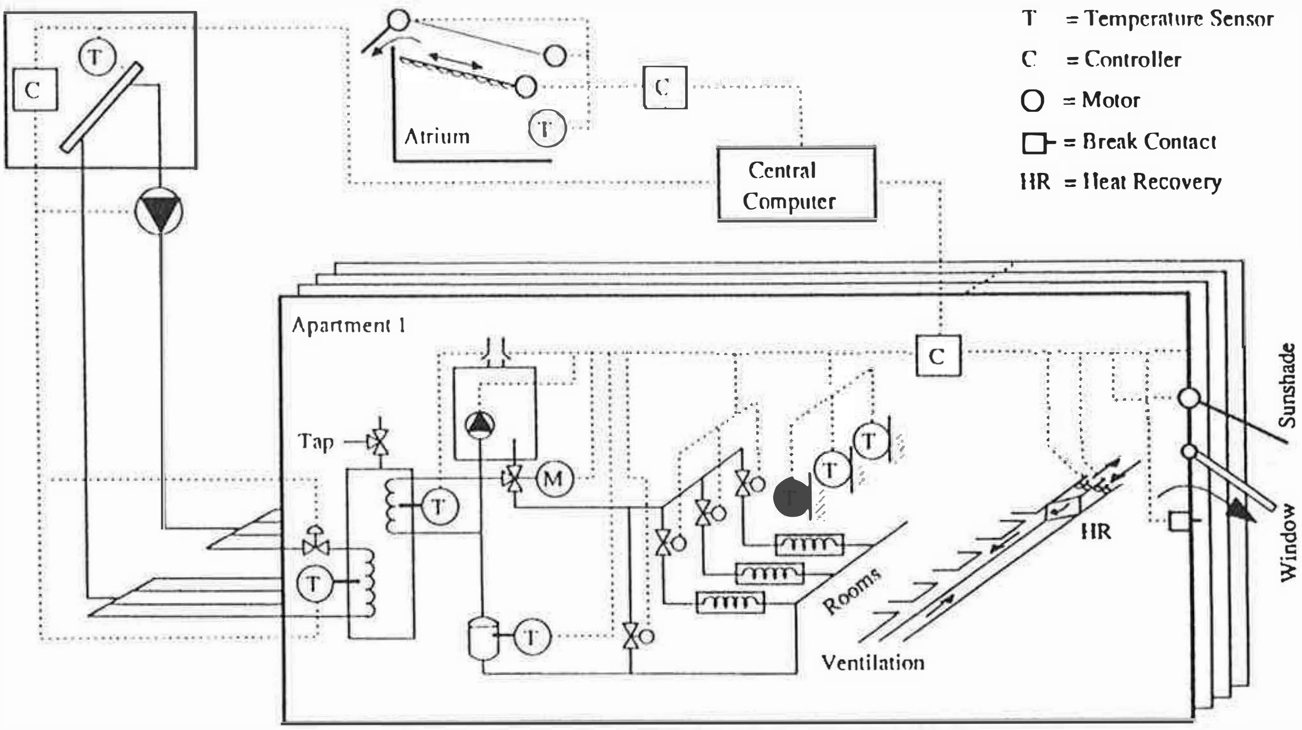


Figure 2
Schematic diagram of equipment in low-energy apartments

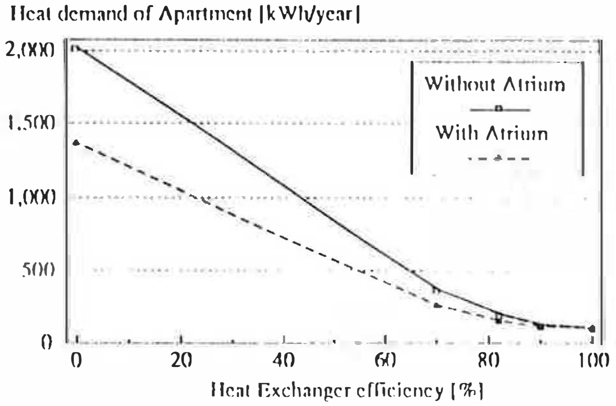


Figure 3
Influence of atrium and type of heat exchanger on the heat demand of the apartments.

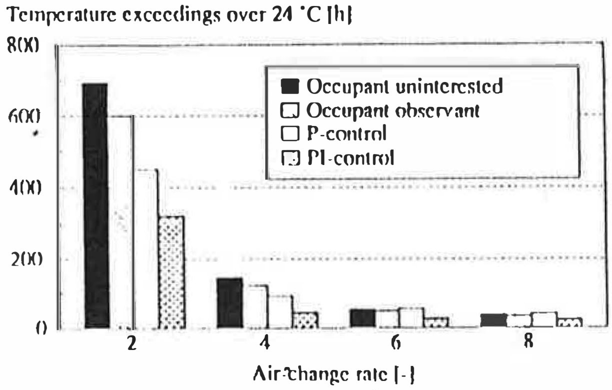


Figure 4
Temperature exceeding hours in the living room (with the occupants present) as a function of air-change rate.

From the energy point of view a regenerative heat exchanger is the best choice, but this type is not capable of sufficiently dehumidifying the air, because part of the moisture is recovered as well. So, in the end two crosscurrent heat exchangers connected in series were chosen. To prevent the temperature of the ventilating air supplied in winter from dropping below 15 °C, the atrium is used to preheat that air. In addition, the presence of the atrium will slightly reduce the heat demand (42 kWh/year per apartment).

The efficiency of the double heat exchanger has been checked in the laboratory [3]. It was concluded from the measurements that the efficiency will be between 67 and 80%, depending on the difference between inside and outside temperature and the number of air changes per hour. Thanks to the fact that the heat generated by the ventilators can also be utilized, the overall efficiency is likely to be 82%.

Simulations have revealed that, in view of the high temperature of the ventilating air supplied, heat recovery will be unnecessary or even undesirable for about half of the year. Since the energy consumption of the ventilators is high, it is desirable to switch off the supply ventilator when no heat recovery is needed. To guarantee the supply of fresh air, the occupant is warned to open a certain vent window. If he does, this will be registered by the control equipment via a break contact and the intake ventilator is switched off. This arrangement will effect a saving in electricity of up to 60 kWh/year.

Natural Ventilation for Cooling

Houses which make use of passive solar energy run the risk of being overheated, especially in summer. To eliminate this risk using a minimum of energy, cooling by natural ventilation is required. Simulations have demonstrated that air-change rate of $n = 6\ m^3/m^3h$ is needed to ensure a satisfactory level of comfort. Figure 4 shows the temperature exceedings as a function of the air-change rate. In order to realize the air-change rate of 6 with a burglarproof construction, upper windows and a ventilation opening in the parapet are necessary. Figure 5 shows how this has been realized.

Experimental studies performed at the Delft University of Technology in connection with the Passive Climate System have shown that the size of the openings can be simply determined as follows [4]. When both windows are open the average air velocity in the opening is 0.5 m/s.

In this situation the air enters the room through the lower opening and leaves through the upper window. The upper and the lower opening must then have the same free-passage area. Thus, the quantity of ventilating air through the free passage of opening A_v is equal to:

$$\Phi_v = 0.5\, A_v \qquad [m^3/s] \qquad (1)$$

For the upper window we have:

$$A_v = A_w \sin \alpha_w \quad [m^2] \qquad (2)$$

with A_w window area $[m^2]$
α_w angle of window [°]

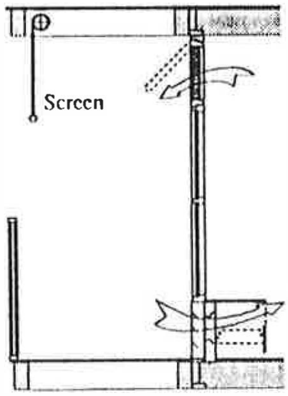


Figure 5
Cross section through front of low-energy apartments.

For the lower window we have:

$$A_v = C_f A_d \qquad [m^2] \qquad (3)$$

Here C_f is a compensating factor dependent on the type of grid and A_d the free-passage area of the grid. To realize an air-change rate of n in a space of volume V, the ventilating area must, according to formula (1), be equal to:

$$A_v = 2\, V\, \frac{n}{3600} \quad [m^2] \qquad (4)$$

Thus for an air-change rate of $n = 6\ m^3/m^3h$ in the living room of $68\ m^3$, the two openings must have each a minimum area of $0.23\ m^2$.