SIMULATION OF DEMAND CONTROLLED VENTILATION IN A LOW-ENERGY HOUSE

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ABSTRACT

In low energy dwellings the ventilation heat losses are significant. Reducing this heat losses can be done by introducing demand controlled ventilation i.e. ventilating at a normal rate only when rooms are occupied. Simulations, using TRNSYS 14.2, of a dwelling, equipped with a demand controlled ventilation system are carried to determine the extra conservation on natural gas for space heating. Demand controlled ventilation schedules are used in the simulation program by using typical Dutch occupation schedules of a four person family for the dwelling. Preliminary results indicate an extra energy conservation of 15- 20% with regard to the reference situation.

INTRODUCTION

In order to reduce the CO_2 exhaust from burning natural gas for spaceheating, the Dutch government has set limits to the energy consumption in new to build dwellings, offices and other utility buildings. Depending on that size new dwellings will not get a building permit if its energy consumption for space heating and hot water production exeeds 800 m^3 of natural gas. At the ECN test location near Petten in the Netherlands, four typical Dutch dwellings were built to demonstrate the possibility of building houses of which the energy required for space heating can be reduced to 50% of this prescribed amount with low additional building costs. Figure 1 gives a view of the project.

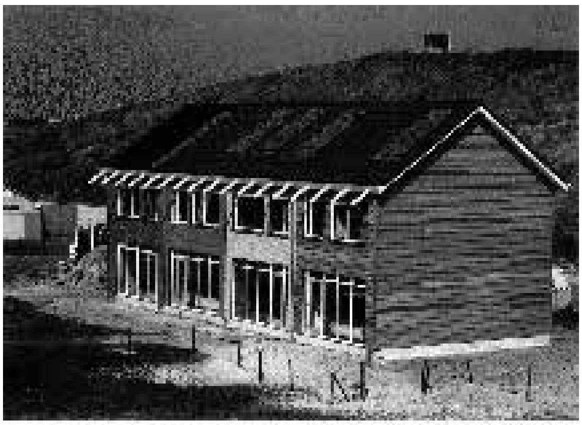

Figure 1: *Low energy dwellings testsite*

The four buildings are equal in size but differ in the used installations for space heating and in building mass. Two houses on the left do have heavy concrete walls and floors while the two buildings on the right are, with exception of the ground floor, timber build houses. The facade of this complex is oriented North-South for a maximum heat gain from the sun in wintertime. Much attention is paid to reduce the heat losses from roofs, floors and facades. This is done by using 20 cm of isolation resulting in a heat resistance of 5 $K/m^2 \cdot W$. Heat losses through the glazing are reduced by using windows with a U-value of (depending on the building) < 1,1 $W/m^2/K$
In most of the dwellings in winter time mechanical ventilation is used with a 90% heat recovery
Space heat is in two dwellings provided by heat pumps, two dwellings have high efficiency gas boilers (efficiency >90%) . No occupants are planned in the buildings in the near future.

MEASURING SYSTEM

All dwellings are equipped with an extensive measuring system. In all rooms room temperature and air humidity is measured and stored in databases for analysing. The heat flow in the heat supplying systems (radiators and floor heating system) is measured as is the total amount of heat supplied by the gas boiler. Weather data (wind speed, wind direction, ambient temperature, solar radiation and relative humidity are measured in the vincinity of the test facility and stored for analyses.

TEST PROGRAM

For the next two years an extensive testing program will be carried out at the testside. From all four dwellings the heat balance will be calculated from measured data. The different installations will be monitored. Test data will be used for several projects including a validation project in which several building simulation programs will be evaluated against measured data. The effects of occupancy is simulated by electric heaters and air humidifiers, controlled by the data acquisition system. The results will be used to verify wether to target of 50% primary energy reduction was reached and to specify further measures for energy conservation.
The monitoring servers as an assessment of the equipment efficiency and as an aid to better simulate the dynamic behaviour of systems plus building.

TEST BUILDING

The building on the near right is totally constructed from timber, with exception of the ground floor and the first floor on which a concrete layer has been laid because of the floor heating system. Beside the floor heating system heat to the rooms is supplied by radiator elements. A high efficiency gas boiler supplies the heat to these systems for space heating. Each room has its own room thermostat to control the room temperature and the flow of hot water for space heating is turned of by a thermostat valve
All windows have double glazing wherby the total U-value is 1,1 W/m2.K.

Element	Construction	U-value
Ground Floor	Cover layer, concrete, insulation	0.16
External walls	Woodplates, Gipsum plate, insulation, gipsum plate	0.17
Internal walls	Gipsum plate, insulation, gipsum plate	0.49
Roof	Woodplate Isulation, woodplate, rooftiles	0.13
Windows	Double glazing	1.1

Table 1: *Fabric elements of building used in simulation*

All outside construction parts (groundfloor, roof, and facade have a U-value of 0,2 W/m^2. K resulting from the 20 cm of isolation.

VENTILATION SYSTEMS

The ventilation systems consists in fact of three subsystems:

- Mechanical supply and exhaust in winter time with 90% heat recovery.
- Natural supply and exhaust in summer time through windows in the facades at the south- and north orientation.
- Natural supply and mechanical exhaust in times that the outside wind can not create sufficient air flow in the rooms.

All ventilation system are controlled by the home network which is installed in the dwelling.
For the balanced mechanical ventilation system in wintertime, ventilation rates are controlled by detection of movement in the rooms. If no movement is detected supply to and exhaust from rooms is kept at such a level that the air quality remains acceptable (temperature, air humidity). If movement in a room is detected ventilation valves are opened so that the prescribed levels are reached.

Movement is detected by a Passive InfraRed detector, located in one of the corners of each room. Data are send to the room controller in the vicinity of the PIR detector which is connected to the home network.
Figure 3 gives an impression of room controller and PIR movement detector.

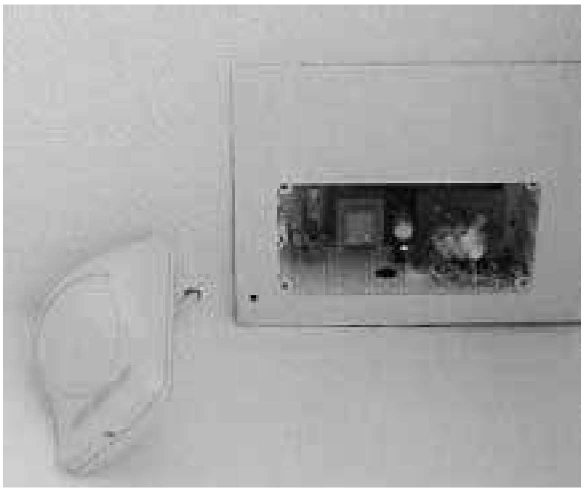

Figure 2 *Roomcontroller and PIR detector*

Ventilation rates are also switched to a higher level if air humidity in the room is in excess of 70%

The natural supply and exhaust system is based on the outside wind flow. The test location is situated in the North-West part of the Netherlands where wind directions is mainly south to south west as shown in the next figure.

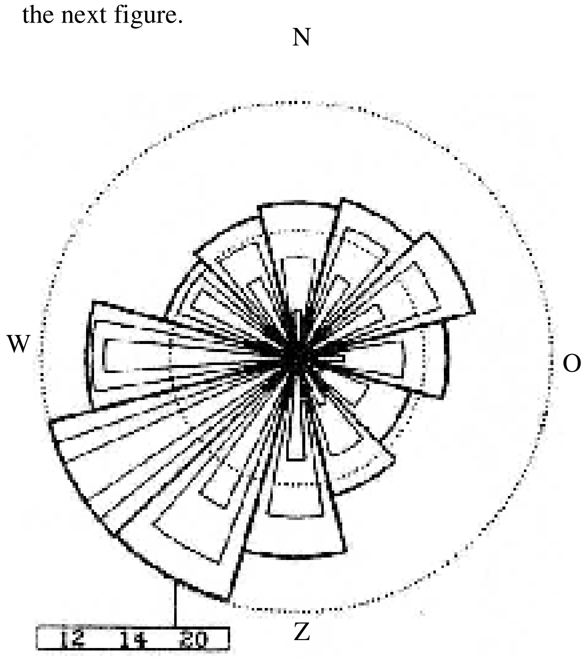

Figure 3.: *Distribution of measured wind direction in NW Holland in 1996*

*Data taken from the Dutch reference year, reveals that in summertime about 24% of the time the wind speed is less than 3 m/sec. In that case natural supply and mechanical exhaust will be used to establish sufficient ventilation in the rooms. Window opening for natural ventilation in the rooms is regulated on basis of the outside wind speed. Windows are opened between 3 m/sec and 10 m/sec whereby the opening is based on the outside windspeed. If the wind speed is less than 3 m/sec or greater than 10 m/sec then the exhaust fan is turned on and window opening is adjusted according to the wind speed.
The window openings will always be adjusted in such a way that air velocity in the living room never will exceed 0.2 m/sec.

Figure 4: *Automatically opened passage between living room and corridor for natural based ventilating system*

For a building of this size the following values for mechanical ventilation rates are prescribed by the Dutch Building law:

Exhaust values
- Kitchen : 75 m^3/hour
- Bathroom : 50 m^3/hour
- Toilet : 25 m^3/hour

Supply values
- Living room : 50 m^3/hour
- Sleeping rooms : 100 m^3/hour

The maximum infiltration rates may not exceed a prescribed level. For buildings with a maximum volume of 500 m^3 the leakage rate must be less then 0.2 m^3/hour (720 m^3/hour) measured at 10 Pa wind presure. For this building blower door tests were carried out in the past. Some minor leakages were discovered and after repairing these leakage spots again blower door test will be carried out to determine the exact infiltration rates. In the groundfloor, using mechanical ventilation there are 2 supply ducts (in the living room) and two exhaust places (toilet and kitchen).
The upper floor, bathroom and sleeping rooms, does have air supply in each sleeping room and an exhaust in the bathroom.

Room	Ventilation rate (ACH)	Supply	Exhaust
		From outside	To other rooms
Living room	0.5	0.36	0.14
Sleeping room 1	0.3	0.3	0.3
Sleeping room 2	0.2	0.2	0.2
Sleeping room 3	0.3	0.2	0.3

Table 2: *Air flow and supply source*

Room	Ventilation rate (ACH)	Exhaust	Supply
		To outside	From other rooms
Kitchen	2.5	2.5	2.5
Toilet	8	8	8
Bathroom	3	3	3

Table 3: *Air flow and exhaust source*

DEMAND CONTROLLED VENTILATING SYSTEM

Demand controlled ventilation in the heating season is implemented in the building by using movement detection in each room including the entrance of the building. If in a room movement is detected for a longer time than the room controller switches the room inlet/outlet ventilation valve in the ventilation system duct system from a minimum supply/exhaust rate to the rate required by the Dutch Building code

Reducing the heat losses resulting from the necessary ventilation is implemented in two ways:
- By using heat recovery on the exhaust ventilation flow is a major step to reduce the overall losses of these low energy houses.
- Reducing the heat losses by demand controlled ventilation is a next step in rooms on presence.

Normally building ventilation rates are 24 hours a day set at the prescribed level even if nobody is in the building. If the building or part of the building (living room or sleeping rooms) are not occupied the ventilation rate to that room can be reduced. At night time when everybody is asleep ventilation supply to the living room can be reduced and in daytime when nobody (normally) is present in the sleeping rooms the exhaust from that rooms can be reduced too. Supply rates can be reduced but room air humidity must be taken into account. Minimum supply rates should have a value so that air humidity in access of 70% is avoided.

SIMULATION PROGRAM

The TRNSYS 14.2 code was used for simulation calculations. In another project TRNSYS 14.2 and other simulation programs as ESPr, VA114, COMIS, ADELINE and Energy10 will be used to match simulation results with the measured data from the test facility. The simulation programs will not only be validated with measuring data but also the outcome of the different models will be compared with each other.

WEATHER DATA

For simulation purposes the Dutch Test Reference year is used as input data for the simulation model

GROUND FLOOR BOUNDARY TEMPERATURE

The temperature beneath the ground floor will fluctuate during the year. Depending on the heat conduction coefficient of the soil type beneath the building and the solar gains on the ground next to the building the temperature in the crawl space will very during the year. The dashed line in figure 5 represents the ambient temperature; the solid line is the temperature outside the groundfloor in the crawling space

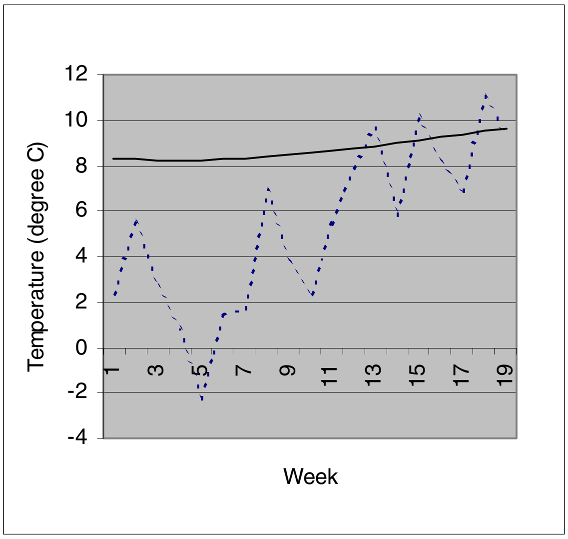

Figure 5: *Temperature beneath ground floor during the first 4 month in wintertime*

INTERNAL GAINS

Table 4 represents the internal heat gained by people, machines and lighting. These data are taken from a calculation model which is used in the Netherlands when a building permit has to be awarded. Different schedules are used for the living room and the sleeping rooms. The used values are mean values and are typical for Dutch situations.

Time [hr]	*7:00 till 17:00* W/m^2	*17:00 till 23:00* W/m^2	*23:00 till 7:00* W/m^2
Living (7 days)	8	20	2
Sleeping rooms (2 days)	2	4	6
Sleeping rooms (5 days)	1	1	6

Table 4: *Internal heat loads used in simulation For the sleeping rooms a different schedule applies for weekdays and weekends*

HEATING SCHEDULE

Time [hr]	*7:00 till 17:00 W/m^2*	*17:00 till 23:00 W/m^2*	*23:00 till 7:00 W/m^2*
Living (7 days)	19	20	15
Sleeping rooms (2 days)	19	20	15
Sleeping rooms (5 days)	15	15	14

Table 5: *Heating schedule used in simulation For the sleeping rooms different schedules are alplied for weekdays and weekends*

Heating schedule is assumed to be active from 1 october till 30th of april each year. In the weekend for the sleeping rooms different schedules are applied. Heating power used in simulations is set at 36.000 KJ.

VENTILATION AND INFILTRATION RATES

Infiltration is kept to a minimum by using double sealings for doors and windows and much attention is paid to seal off the connections between facade and ground floor.

Reference situation.

In the reference situation ventilation rates are as prescibed by the Dutch Building Law. Day and night the amout of air chanfges per hour have the same values as shown in table 6.

The ventilation system has the prescribed rate of some 300 m^3/hour. Based on the Dutch building code the ventilation rates were determined to be 0,5 and infiltration rates were calculated at 0,2 air changes per hour. Heat recovery is applied with an efficiency of 90%.

With this inputs the heat balance is calculated by the program. This with be the reference case. Results with the demand controlled ventilation will be compared with this data.

	Ventilation Rate (ACH)	
Location	Day time	Night time
Living room	0.5	0.5
Kitchen	2.5	2.5
Toilet	8	8
Entrance	0.3	0.3
Bathroom	3	3
Sleeping room South large	0.6	0.6
Sleeping room South small	0.5	0.5
Sleeping room North	0.6	0.6

Table 6: *Ventilation rates used for simulation of the reference state*

For simulations with demand controlled ventilation 2 cases were calculated:

- Case 1: Night time reduction: ventilation rates at the ground floor at night (from 23.00 – 07.00 hour) are 50% less than during daytime hours. For the sleeping zone rates during daytime are 50% less than during night time.
- Case 2: Occupancy reduction: Based on common pattern of using the dwelling by a 4 person family presence in the different rooms (living room, kitchen, toilet, bathroom and sleeping rooms) is determined. No presence in a room means that the ventilation rates are lowered to 50% of the rates at room presence.

	Ventilation Rate (ACH)	
Location	Day time	Night time
Living room	0.5	0.25
Kitchen	2.5	1.25
Toilet	8	4
Entrance	0.3	0.15
Bathroom	3	1.5
Sleeping room South large	0.3	0.6
Sleeping room South small	0.2	0.5
Sleeping room North	0.3	0.6

Table 7: *Ventilation rates demand controlled ventilation case 1 (night time reduction)*

RESULTS

Reference case: continious ventilation rates during day and night

Based on the room volume the Dutch Building code the ventilation rates in the rooms are shown in table 6. Simulations carried out with the above mentioned values for the reference case, i.e. the ventilation rates as prescribed by the building code.
With these values a yearly heat demand of this building of 15.1 GJ was calculated.

The overall heat balance of the dwelling is presented in the next figures. The heat balance consist of the following parts:

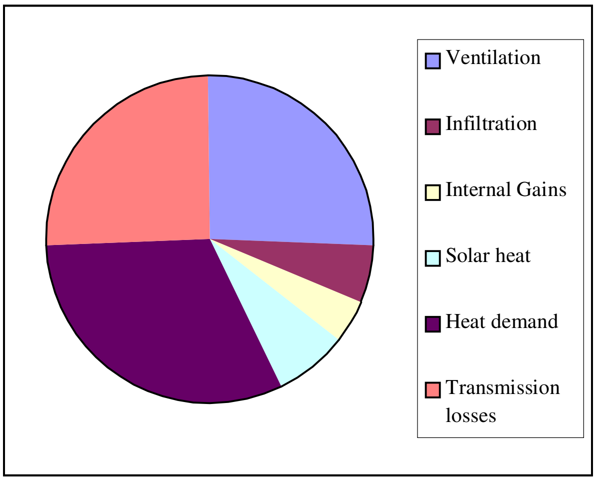

Figure 6: *Reference case heat balance (%)*

Gains:
- Incoming solar radiation
- Internal gains
- Heat demand

Losses are:
- Ventilation losses
- Infiltration losses
- Transmission losses

HEAT RECOVERY

In table 5 the heating schedules of the dwelling are shown. No heating is applied to the sleeping rooms during daytime hours in the first 5 days of the week. The outlet air from this rooms will be mixed (via the exhaust in the bathroom) with the warmer air from the ground floor at the inlet pipe of the heat recovery unit. Simulations where carried out to see the effect of this mixing on the fresh supply air to the sleeping rooms.
Temperatures of the supply air to the rooms is calculated based on room temperature and outside temperatures:
From each floor the air temperature to the rooms is determined by:
Tsupply = Ta+ 0.9*(Troom- Ta).

Whereby Ta is the ambient temperatures as read by the simulation program, Troom is the room temperature as determined by the program and Tsupply is the new supply temperature of fresh air.

Due to the fact that the exhaust from the ground floor is mixed with the exhaust form the first (sleeping) floor and the heating schedule in the sleeping rooms differ during weekdays from that of the ground floor rooms and then fed to the heat recovery unit, one might expect that the sleeping rooms are slightly heated up by the relatively warm supply air. Simulations where carried out to see if that is true

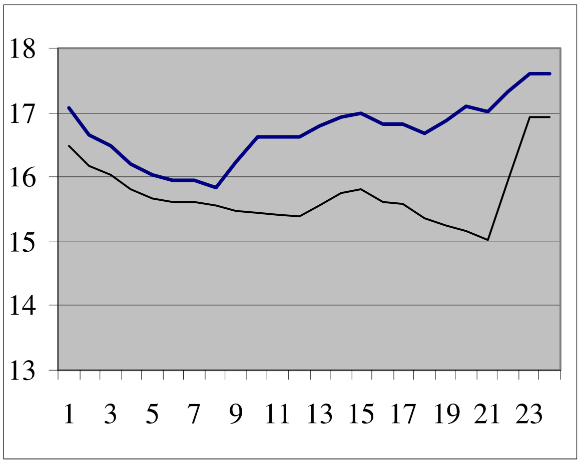

Figure 7*: Inlet air temperatures rooms*

The thick line in figure 7 at the top of the figure represent the temperatures of the inlet air if the exhaust air from the ground floor and the sleeping zones are mixed and fed to the heat recovery unit. The thinner lower line is the air temperature to the sleeping zone if it had an own heat recovery unit. From this figure it can be concluded that in case of a mixture of warm exhaust air form the ground floor and "colder" air from the sleeping zone the sleeping zones will be warmed up a little bit.
In case of a mixed flow the temperature of the air entering the sleeping zones is at maximum 3,5 ^{o}C. higher then with a "separate" heat recovery unit for this zone. This results in fact in a slow heatup of the sleeping rooms.

DEMAND CONTROLLED VENTILATION CASE 1

Simulation carried out with to 50% reduced ventilation rates during daytime or nighttime revealed an annual heat demand of 13.0 GJ.
This means an annally energy conservation of nearly 15%

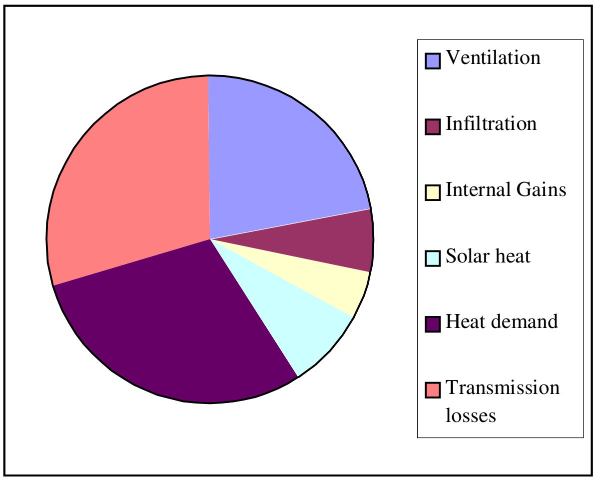

Figure 8: *Reduced ventilation case heat balance (%)*

DEMAND CONTROLLED VENTILATION CASE 2

To investigate if demand controlled ventilation during daytime, when using living room, kitchen and in the morning leads to an additional energy conservation, the occupation of the rooms must be determined. Furthermore the type of occupants must be determined. It is determined that the occupants of the dwelling is a 4 person family (2 adults and 2 children).

Room occupation:

Kitchen	07.00 – 08.00	17.00 – 19.00
Living room	07.00 – 23.00	
Bathroom	06.30- 08.00	22.00- 23.00
Sleeping room 1		23.00- 06.30
Sleeping room 2		22.00 –07.00
Sleeping room 3		21.00- 07.00
Toilet	*)	

*) The effective occupation time i.e. the time during a day that an increased ventilation rate is necessary has been determined as 1 hours daily.

During this time the ventilation rates are increased to the prescribed levels and during the unoccupied times the levels are 50% lower assuming this ventilation rates are sufficient to keep the air quality at an acceptable level.
These values are used for calculations.
The outcome of this calculations are that an extra 5% of energy conservation is achieved compared to the reference case (0,5 GJ).

CONCLUSIONS

A growing number of new built dwellings in the Netherlands are equipped with balanced ventilation with heat recovery (upto 10% in 2000). New to build dwellings are subjected to strong energy consumption rules. Even with this strong rules and low energy dwellings it is possible to reduce the energy demand of the building even more. The major losses in this type of buildings are the ventilation losses. Reducing them, even after using heat recovery, is possible by introducing demand controlled ventilation. Demand controlled ventilation means that the ventilation rates in the different rooms are only switched to the prescribed levels if the occupants are in the rooms.

In this reseach, using the thermal simulation model TRNSYS 14.2 the energy conservation is calculated to be some 15%. If daytime and nighttime ventilation rates are reduced to 50% of the prescribed level and even to some 20% if use pattern of rooms (bathroom, toilet and kitchen) are introduced.
The energy conservation reached strongly depends on the heating schedules used. In this reseach the common Dutch habit to only heat the sleeping rooms during evening or weekend times was used.

The energy conservation calculated is the decrease in heat demand of the building. Not taken into account is the electricity used to operate the home network which controls the ventilation systems. Research in the years to come will reveal the actual value for this electricity use. At this moment it is estimated to be some 200 kWh a year, roughly corresponding with 1,44 GJ.

Putting demand controlled ventilation into work sets some constraints on the ventilation system. In balanced ventilation systems the exhaust fan controls the output of the supply fan. They act in "balance". Reducing the opening of an exhaust valve will therefore reduce also the supply to the sleeping rooms or the living room. For demand controlled ventilation systems the ventilation rates should always be sufficient enough to ventilate rooms not in use The control of the exhaust rates and the supply rates should therefore be determined on basis of the pressure in the ducts near the heat recovery unit. In this case closing an exhaust valve or a supply valve will not influence the rest of the system.

Another result from this study is that, when sleeping rooms during daytime are not heated with the same schedule as the living room, the balanced ventilation system will slowly heat up the sleeping rooms during day time. During the next two years, experiments will be carried out to determine the heat balance of the building during the different seasons. First the reference situation heat balance (continious ventilation air supply) will be measured. Electricity consumption will be determined. In the next winter season the occupancy controlled ventilation will be subject of experiments. Air quality during this experimenst will be monitored.

Final results are expected to be available at the end of 2002.

ACKNOWLEDGEMENTS

This project is financially supported by the regional government of the Northern Netherlands. Much help in the construction of the ventilation systems used was received from mr. De Graaff of StorkAir.
The author further wishes to express his gratitude to dr. Wim van Helden for his advices during the work.