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DEMAND-CONTROLLED VENTILATION IN A SCHOOL

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Summary

The performance of a system for demand-controlled ventilation was investigated for a period of 1.5 years. Presence sensors of the passive infrared type are used to control the ventilation rate in each classroom. The signal from the presence sensors was recorded, as well as the CO_2 concentration in the classrooms.

One of the classrooms was equipped with displacement ventilation. A comparison was made between displacement and mixing ventilation to investigate the CO_2 concentration in the stay zone. A significantly lower CO_2 concentration was measured in the case of displacement ventilation.

Project description

In 1988, the rebuilding and renovation of an elementary school was planned in the Municipality of Nacka outside Stockholm, Sweden.

Fig 1. Järla school in Nacka

The most important part of the renovation project concerned an improvement of the ventilation in the school. One objective was to provide good air quality in the classrooms. A low energy consumption was also desired.

The purpose of this project was to demonstrate that it is possible to maintain better air quality in the classrooms by means of demand-controlled ventilation when the rooms are in use, and that this can be achieved at lower energy consumption, compared with the dimensioning of fresh air flows in accordance with current building codes.

Measurements and calculations also showed that this was a profitable measure.

The installation and test measurements were funded by the Swedish Council for Building Research (BFR).

Building form

The schools consists of two buildings joined together by a common stairwell. The buildings were constructed at different times. The older section, which has four floors and contains six classrooms, a cafeteria and administrative offices, was built in the 1920s, while the newer building dates from the beginning of the 1940s and has three floors and six classrooms.

The classrooms face the south and southeast. The height from floor to ceiling is approximately 360 cm in the older section, and 310 cm in the newer section. The floor measures 9 m x 6.5 m in the classrooms.

Building services.
Heating and ventilation before renovation.

The school has a radiator system for heating that is connected to the Nacka district heating system. When the school was renovated, the radiators were equipped with thermostat valves. Before the renovation, the ventilation system consisted of a natural draft system in the older section of the school. The new building had a mechanical exhaust air system, in which the fan operated 24 hours a day.

Before the renovation, tests were conducted to test the tightness of the buildings and the air change situation. In the building with the natural draft system, as well as in the section with mechanical exhaust air ventilation, carbon dioxide measurements were conducted in the classrooms to determine how the air was changed. At the end of a lesson, the CO_2 concentration was between 2000 and 3000 ppm.

In the newer section of the school, the CO_2 concentration normally stayed below 2000 ppm, provided that windows were opened during recesses.

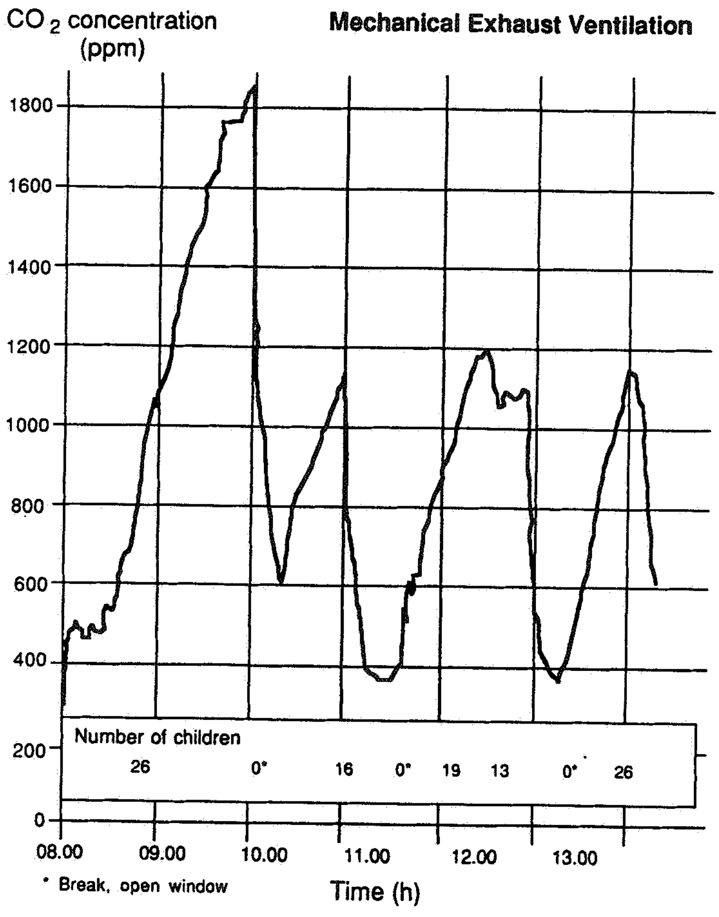


Fig 2. CO_2-concentration in a classroom before renovation

Air flow tests indicated air changes corresponding to a fresh air flow of approximately 2 l/s per student. Thus, earlier complaints about the ventilation system were justified.

Heating and ventilation after renovation

The existing radiator system was kept. The radiators were equipped with thermostat valves. When the school was renovated, the six classrooms in the older section were equipped with a supply and exhaust air system that was dimensioned in compliance with existing building codes (5 l/s of fresh air per student).

The six classrooms in the newer wing were equipped with a demand-controlled ventilation system connected to a separate AHU, as shown in Fig. 3. The objective was to prevent the carbon dioxide concentration from exceeding 1000 ppm in the stay zone.

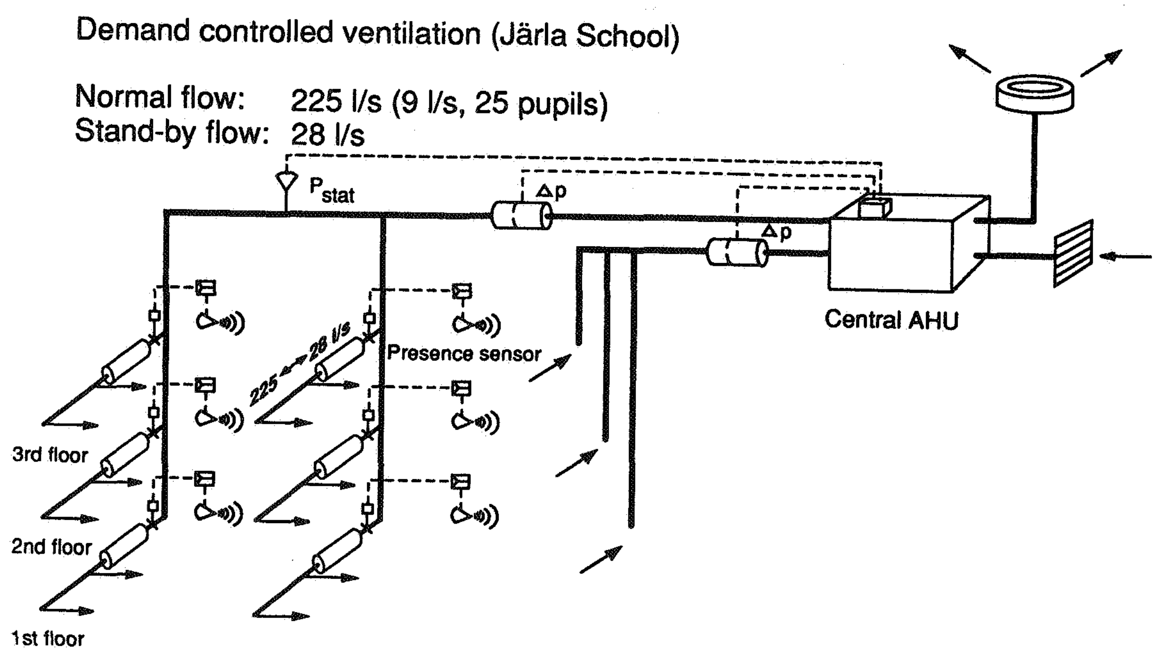


Fig 3. System principle

The system functions as follows:

- Each classroom is equipped with a presence sensor of the passive infrared type. When the device senses that someone is in the classroom, a supply air damper opens and closes ten minutes after the presence sensor picks up the last movement in the room.

- When the damper opens, the supply air to the classroom increases from approximately 28 l/s to about 225 l/s. This corresponds to 7.5 l/s per student, with 30 students in the class (grades 4-6), or 9 l/s per student, with 25 students in the classroom (grades 1-3).

- The general ventilation (basic flow) system operates 24 hours a day.

- Air exhausted into the corridor outside the classrooms is evacuated through exhaust air devices on each floor.

- The central air handling unit for supply and exhaust air is equipped with fans with guide vane control. The supply air is controlled by maintaining a constant pressure in the supply air duct system The exhaust air follows the supply air flow.

- The AHU is equipped with a plate heat exchanger for heat recovery, as well as a microprocessor-based controller that makes it possible to easily monitor the AHU's function. No air is recirculated.

- Five classrooms have traditional mixing air distribution with air being supplied at the front end of the ceiling. One room has displacement ventilation, with the supply air terminals positioned at floor level at the two corners in the front of the classroom. The supply air temperature is 18°C.

Measurements after the renovation

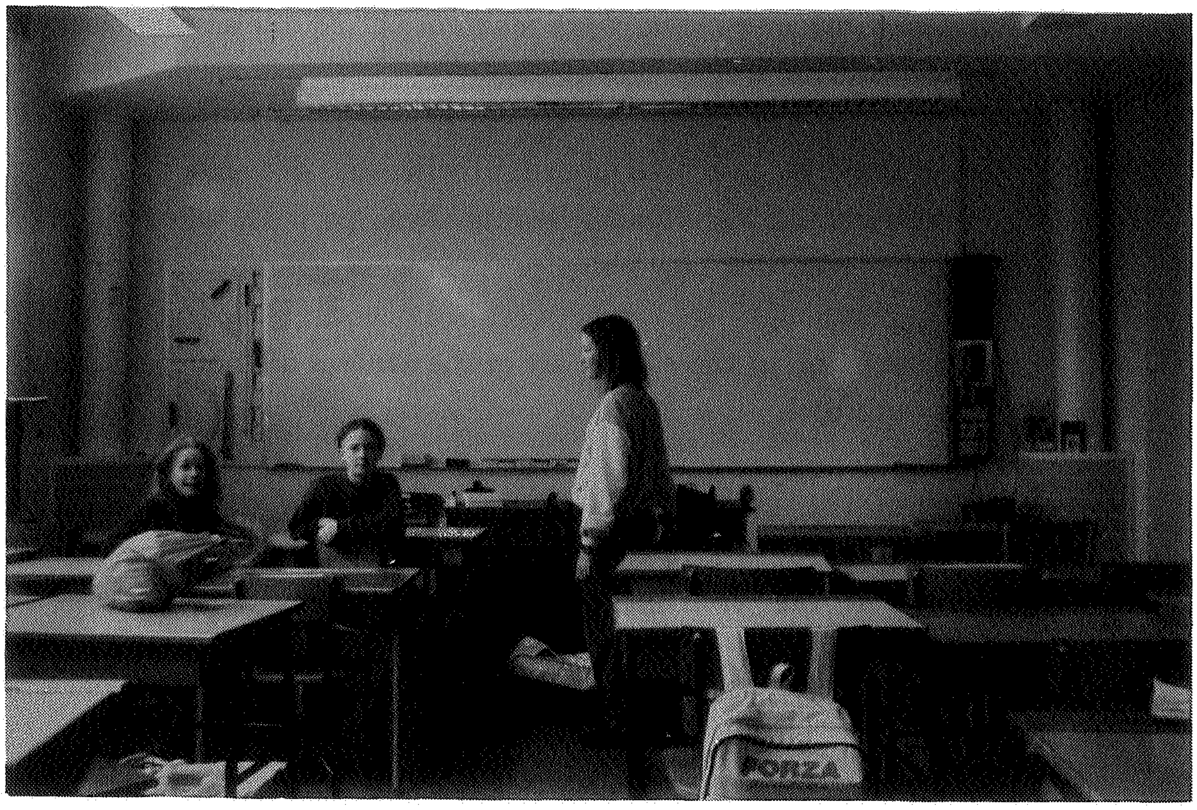


Fig 4. Classroom (306) with displacement ventilation

Measurements were conducted in three classrooms after the renovation was completed. One classroom had displacement ventilation and five had mixing air distribution.

The following measurements were made during 1990-91.

- The CO_2 concentration was recorded on a continuous basis for about two months.

- The signals (supply air flow) from the presence sensors were recorded in conjunction with the CO_2 measurements.

- Fresh air and exhaust air temperatures were recorded.
- Detailed measurements were made of horizontal and vertical CO_2 gradients in two classrooms over a period of several days.
- The supply air flow was measured when the detailed measurements were made. During these periods, teachers or students recorded how many persons were present in the room.
- The variation in the supply air in the central air handling unit was recorded.

Results of the measurements

Function of the ventilation system. Room function.

During the 1.5 years the system has been in operation, the measurements have shown that the demand-controlled system has functioned as planned. An example of this is shown in Fig. 5.

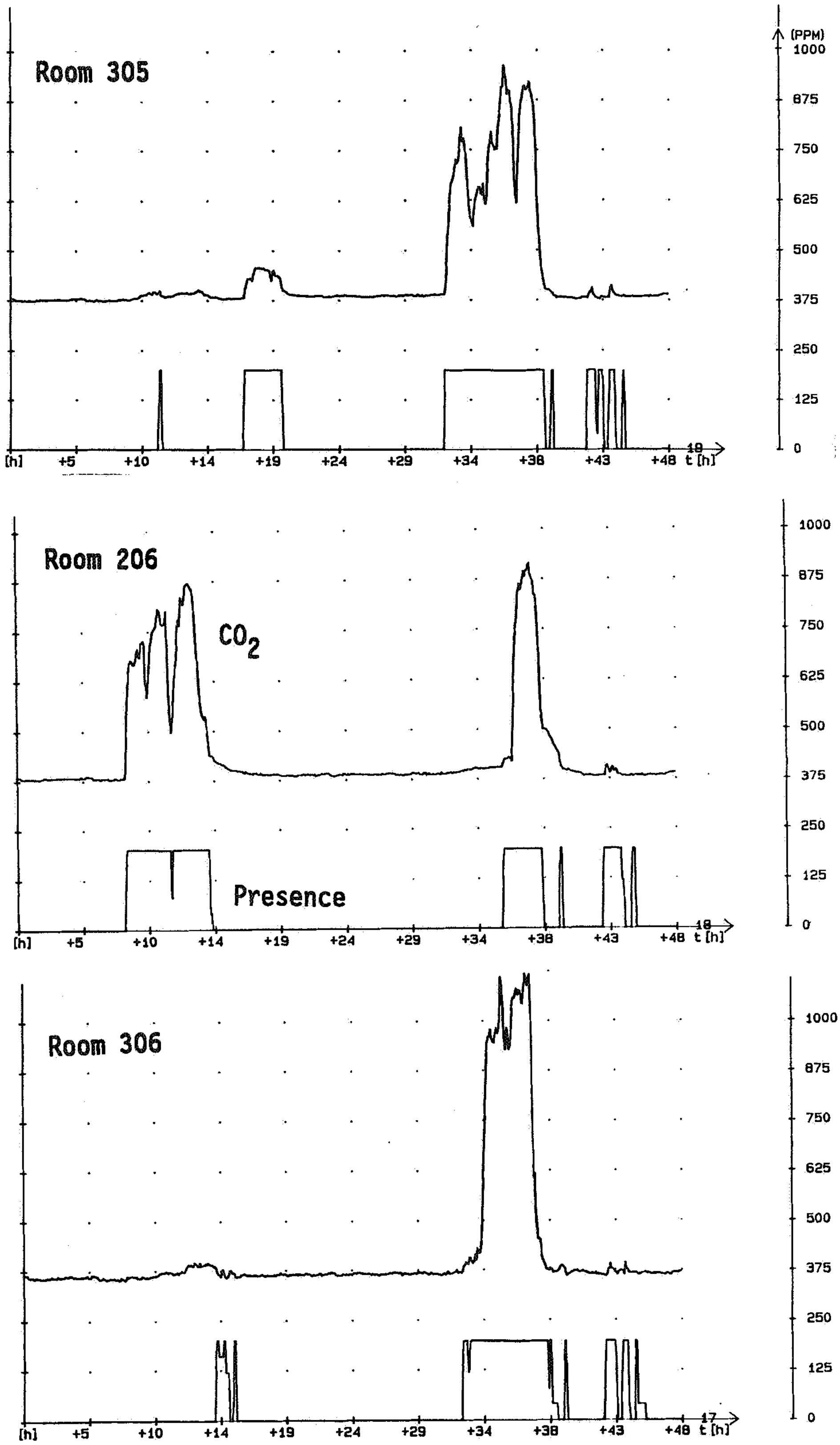


Fig 5. Presence and CO_2-concentration Monday and Tuesday, May 14th and 15th 1990

Here the carbon dioxide concentration and signal from the presence sensor have been measured for the three classrooms over a 48-hour period. The figure shows

- that only one of the three classrooms was in normal use on Monday, May 14, 1990.
- that in the other classrooms, some one entered the rooms to get books or other materials on a few occasions.
- that a small class meeting was probably held one evening in one of the classrooms.
- that the classrooms were cleaned on Tuesday evening.

The fact that two of the classrooms were not used on Monday was not in agreement with the ordinary schedule. In general, the signal of the presence sensor followed the respective class schedules closely.

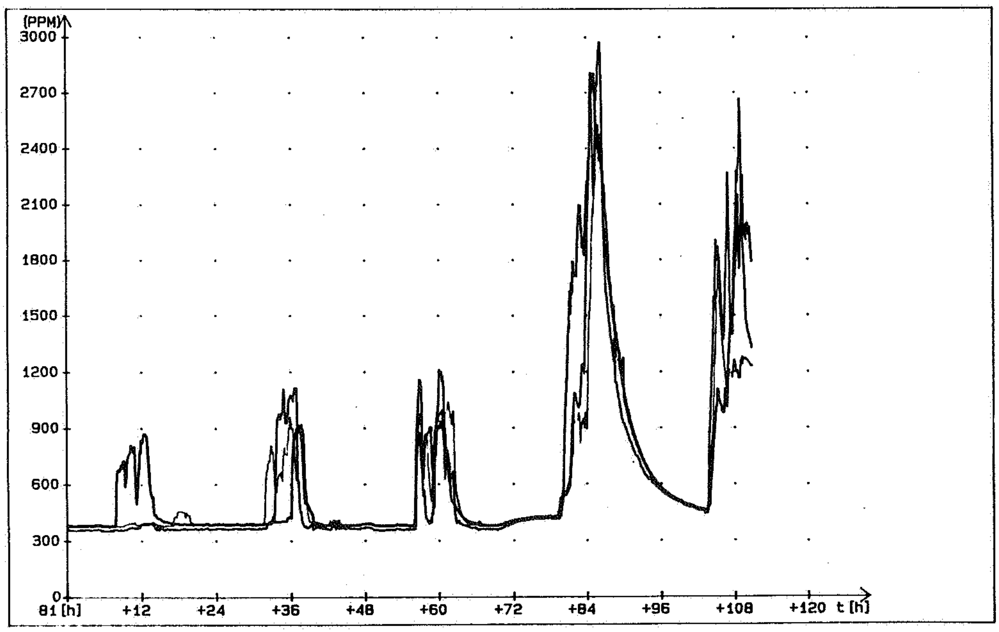


Fig 6. Power supply cut off

During the same week referred to above, the operation of the ventilation system was disturbed at the end of the week, due to the ongoing renovation work in the school. On Thursday and Friday the power was cut off completely to the AHU. The consequences of this disturbance are shown in Fig. 6.

Central Air Handling Unit

The following was recorded in the central air handling unit:

- the control signal to the guide vanes for supply air: 100% = full flow.
- the static pressure in the duct system (supply air): set value 310 Pa.
- the control signal for the air heater: 100% = open valve.
- the supply air temperature: set value = 18°C.

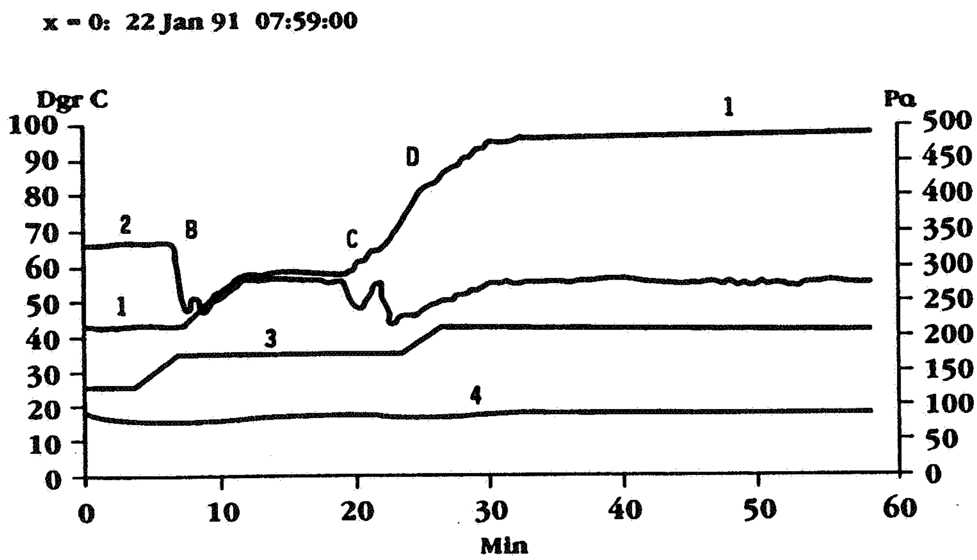


Fig 7. Measured values in central AHU

Fig. 7 shows how the air flow increases as the classroom is used. Only about 50% of the total air flow in the AHU is affected by demand control, since the remaining 50% is supplied to two workshops and to teacher rooms.

It is possible to see that:

- at 8.00 a.m. students arrive at one of the classrooms.
- the presence sensor in the classroom opens a damper.
- the pressure decreases. Guide vane B compensates the pressure drop.
- another classroom starts to be used, C and D, and the signal to the guide vane increases.
- at 100% all classrooms are being used.

Air quality

During the longer measurement periods, the CO_2 concentration was recorded in the exhaust air from the three classrooms.

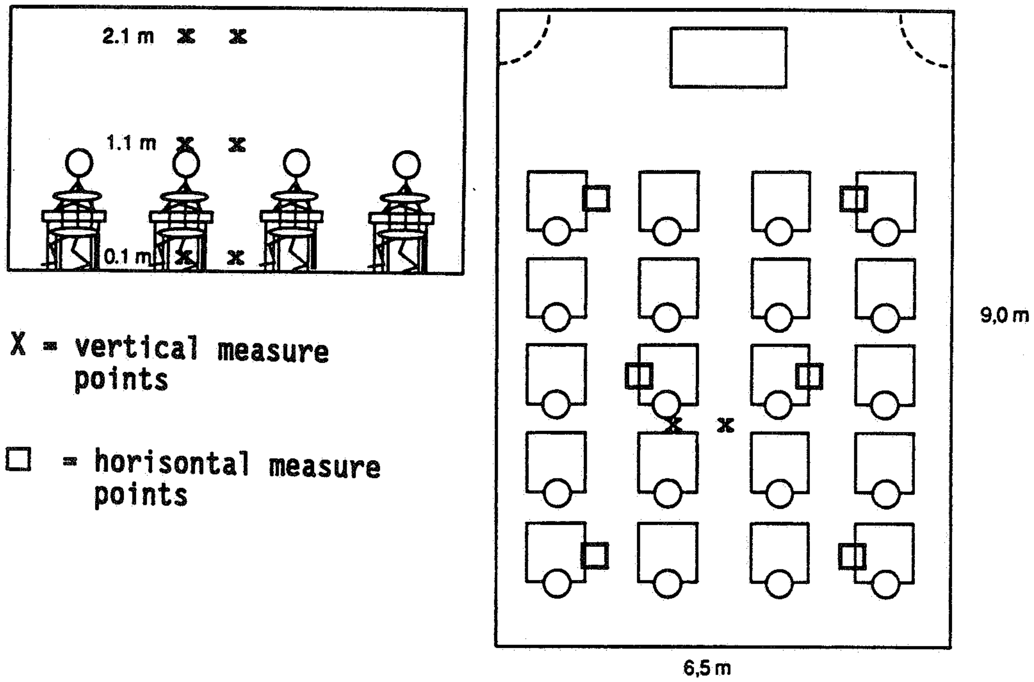
The goal to keep the CO_2 concentration below 1000 ppm in the stay zone was achieved. This could be expected, considering the actual supply air flows being used.

The air quality was also considered good by students and teachers, despite the fact that measurements were made during the outgasing period, when solvents were being emitted by new building materials. The interior of the school was also painted and fitted with an acoustic ceiling.

Comparison between mixing and displacement air distribution

In two classrooms, one with displacement air distribution (306), and one with mixing air distribution (206), detailed measurements were made of the CO_2 concentration vertically. In room 306 (displacement ventilation), the CO_2 concentration was also measured horizontally at floor level.

When measuring the CO_2 gradient vertically, two measuring bars with sensors were used at 0.1, 1.1 and 2.1 m above the floor. The bars were placed about 2 m from the rear wall of the classroom as shown in Fig. 8. Thus, measurements were made at six points in all.



During the measurements, activity was normal in the classroom, meaning that students moved between their desks and the blackboard, and between groups.

The results from the two *vertical* measurements are shown in Fig. 9. After a recess, the measurements were carried out over a double lesson (about 90 minutes in length).

Depending on the actual number of students in the classrooms, the fresh air flow corresponded to 8.0 l/s per student in the room with displacement ventilation, and 9.2 l/s per student in the room with mixing ventilation. If the measurement values are corrected to take this into account, the measured concentration at the 2.1 m level coincides in both classrooms, which, theoretically, should be the case.

As can be seen from the diagrams, the CO_2 concentration in the mixing air distribution case (206) is largely the same at all measurement points. But in the classroom (306) with displacement air distribution, a clear difference can be seen between the CO_2 concentration at the three different levels.

Here, the mean concentration in the breathing zone (1.1 m) is approximately 750 ppm, while the concentration at 2.1 m is about 1000 ppm.

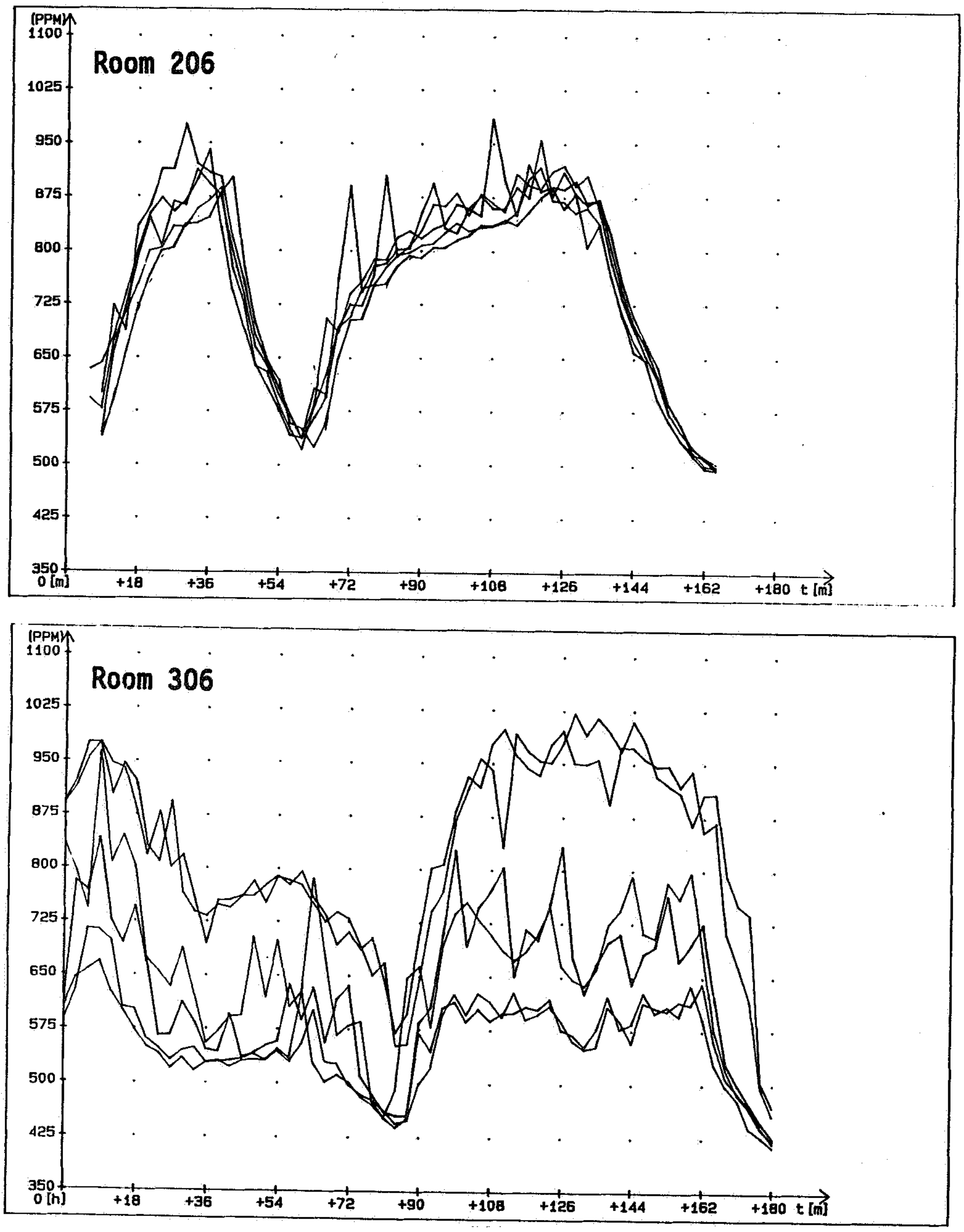


Fig 9. Mixing vs displacement ventilation

Thus in classrooms, displacement air distribution improves air quality in the breathing zone corresponding to about 250 ppm of CO_2, compared with mixing air distribution and a similar air flow.

It can also be stated that, with displacement air distribution, it is possible to decrease the fresh air flow, and thereby lower the energy requirement for heating air, by about 25 percent, and still retain air quality.

In general, it can be noted that the measured concentrations (206) indicate that the children (ages 7-13) exhale about 18 l of CO_2 per hour. This is otherwise a value considered typical for adults performing office work.

The *horizontal* measurements were also made at six points at floor level (0.1 m).

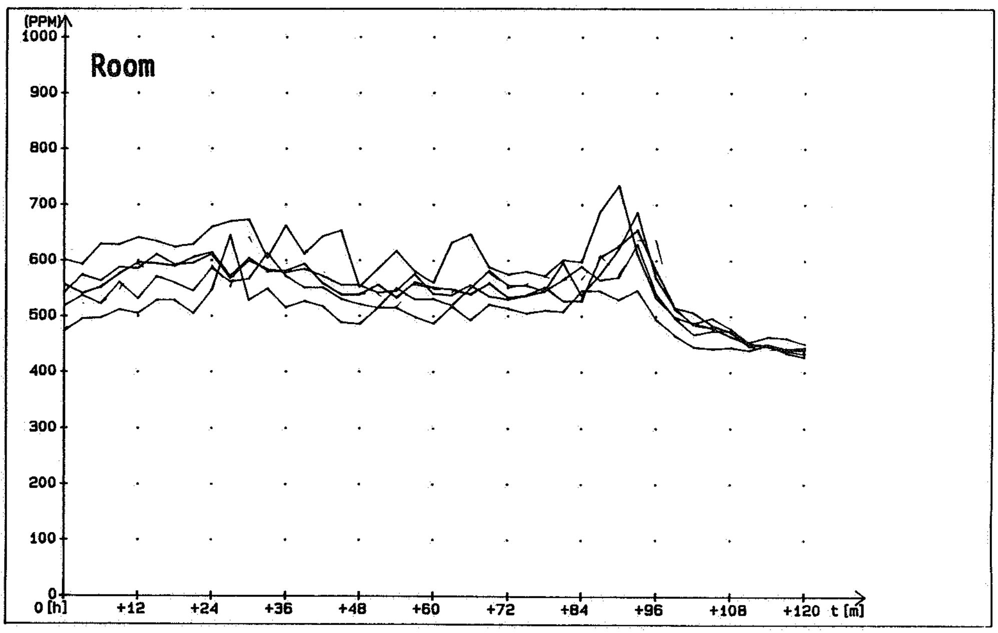
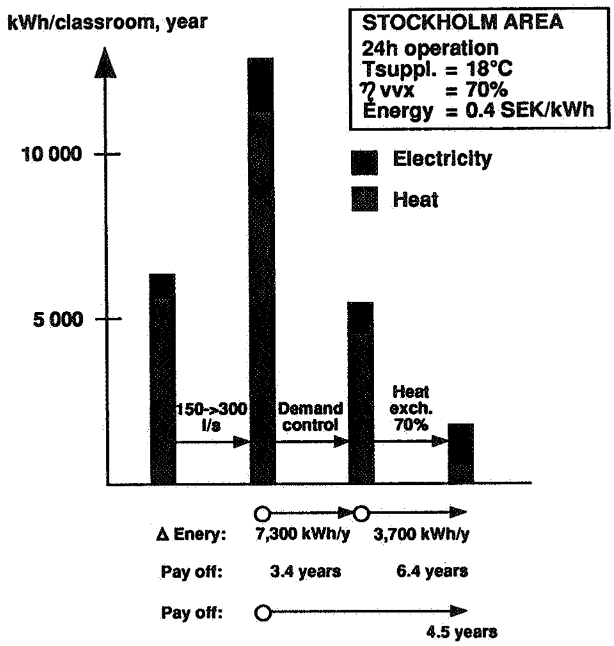


Fig 10. CO_2-concentration in 6 points at 0.1 m level

The measuring points and results are shown in Fig. 10. As indicated by the results, the supply air, which was cooler than the room air temperature, was distributed effectively throughout the classroom. The radiators were not on when the measurements were made.

Energy performance

The measurements confirmed that the air flow to the classrooms met the requirements shown on the respective schedules. Based on the schedule for the six classrooms with demand-controlled ventilation, the system's function and energy requirement for heating can be simulated. Climate data were used for Stockholm.



As shown in Fig. 11, increasing the fresh air flow specified in the existing building code (5 l/s per student, 150 l per class) to a fresh air floor guaranteeing good air quality – for example, a maximum of 800 ppm of CO_2 (10 l/s per student, 300 l per class), doubles the energy requirement for air handling.

By using demand-controlled ventilation, however, the energy requirement is reduced by more than half. The use of heat recovery further decreases the amount of energy required. Based on the demand-controlled ventilation and heat recovery system used in this project, the payoff period has been estimated at about 4.5 years for both measures.

Conclusions

When the air flow is 8-9 l/s per student, the student feel the air quality is sufficient during those months of the year when the room temperature is at an acceptable level.

In the autumn and spring, an increase in the fresh air flow, using air cooler than room air, is desirable to keep the room temperature down. It is not always possible to open windows to air out the classrooms because of noise, or because of pollen, for example. A high room temperature is one of the main reasons why the students feel the air is dry and of "poor" quality.

In a VAV system controlled on the basis of air quality, the air flow can vary between 100-10% at any time of the year.

This places special demands on the control of the heating coil in the central air handling unit.

The classroom ventilation system controlled by presence sensors has functioned reliably. The estimated energy savings were confirmed. In a centralized ventilation system, equivalent savings can almost be achieved by using a more efficient heat recovery system. This should be a more profitable solution in systems with short operating times, such as in schools.