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Poster 1

Improved Indoor Environment and Ventilation in Schools. A Case Study in Växjö, Sweden.

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SYNOPSIS

During the last decade several surveys in Sweden have indicated that the indoor climate in existing schools is unsatisfactory, therefore a thorough project was carried out in Växjö.

The indoor climate was investigated in three schools during 1989. Detailed measurements were made of ventilation (e.g. rates, air exchange efficiency), indoor air quality (e.g. CO_2) and thermal comfort (e.g. air velocity). The main results were: high indoor temperatures, low air velocities and high concentration of CO_2. Improvements were made in all three schools during 1990. One of the classrooms was rebuilt to have its own separate ventilation system with the possibility to use either ceiling diffusers or floor supply air terminal devices.

After the improvements the measurements were repeated. The CO_2 concentration and the air temperature were measured at different locations within the classroom, at different air flow rates and at different supply air temperatures. The air exchange efficiency was determined for different air flow rates and different air supply systems.

The following recommendations were made for the schools in order to obtain

- an optimum indoor air quality: air flow rate 8 l/s and person, supply air temperature 18 °C and four ceiling diffusers

- a satisfactory thermal comfort: automatic exterior shading, circulation fan in the classroom, night cooling with outdoor air during fall and spring.

The results of this project will be used to produce a manual "Indoor Climate in Schools".

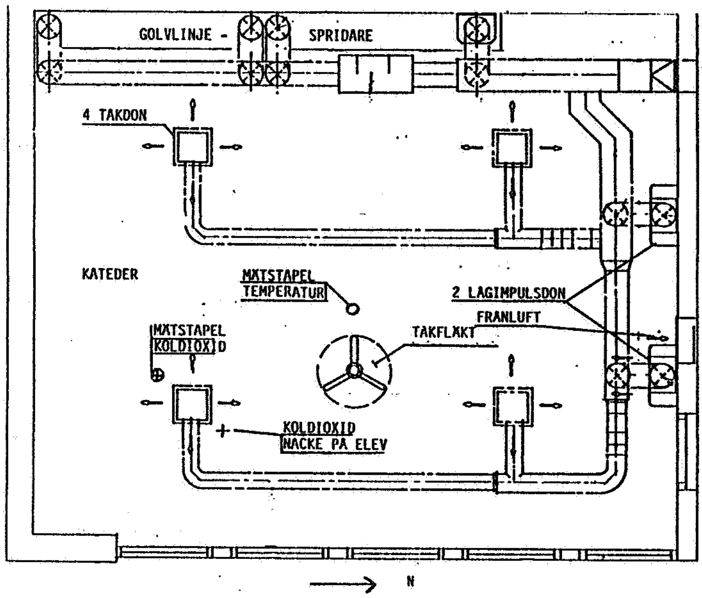
1. INTRODUCTION

In Sweden there are many schools today which need to be rebuilt and replanned. The reason is changing demands regarding education, the age of the buildings, and problems with the indoor climate and the air quality.

In Växjö a project has been carried out, partly financed by the Swedish Council for Building Research. The project concerns the indoor climate in schools, and three schools of various types have been chosen. During the school year 89/90 measurements were made to clarify the situation. During the summer and autumn -90 certain reconstructions were made. Measurements and evaluations were concluded in the summer 1992.

The aim of this project is to clarify the influence of the HVAC systems on the indoor climate in the classrooms before and after the measures were taken. The purpose is to be able to come up with explicit proposals for systems and design guidelines for classrooms with principles for air flows, temperatures etc.

The three schools are Bokelund (primary and middle school), built in 1968, Fagrabäck (high school), built in 1966, and Katedral (senior high school), built during 1958/1977. The schools have different building constructions and HVAC systems.



Plan of classroom in Fagrabäck showing location and type of air terminal device, and location of measuring point for CO_2 and air temperature.

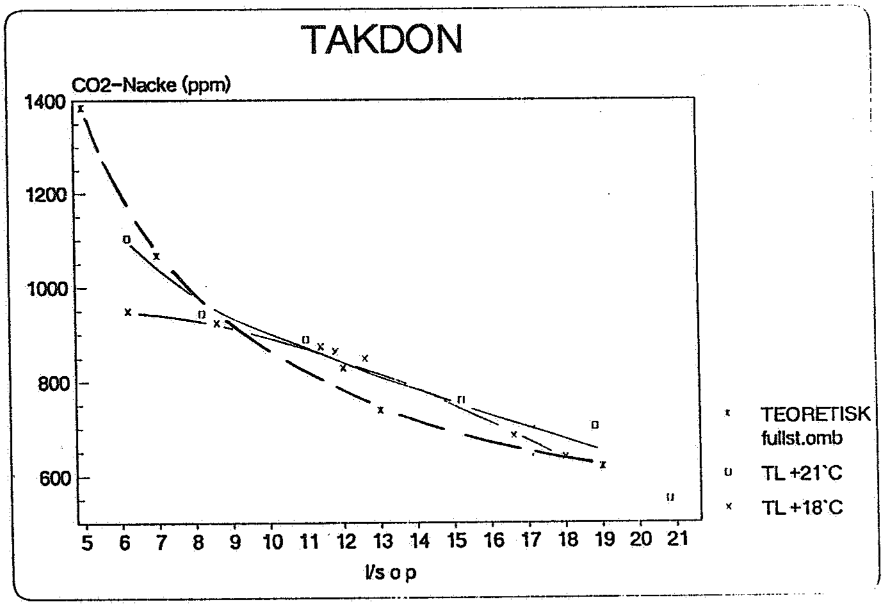


Figure 1. CO_2-content at the neck of the pupil as a function of air flow (l/s and person) at different supply air temperatures. Each point corresponds to one set of measurements, i.e. one lesson. The dotted line is a theoretical calculation. Takdon = ceiling air terminal device.

The figure shows very clearly the reduction of the CO_2 content at an increasing flow. Furthermore, you can see that the supply air temperature has a noticeable influence on the CO_2 content at flows lower than appr. 8-9 l/s per person.

2. RESULTS BEFORE MEASURES

The most important results from the preliminary measurements (during the school year 1989/90) are the following:

- High indoor temperatures (winter +24 °C, summer +30 °C)
- Low air velocities in the room (<0.1 m/s)
- Low contents of chemical substances in the air (tot. voc < 100 µg/m^3)
- High contents of carbon dioxide (only at Bokelund lower than 1000 ppm)
- Low contents of formaldehyde (<40 mg/°C, m^3)
- Low contents of radon
- No unnormal presence of mould
- High contents of cat´s hair in dust

The measurements proved that the most obvious problem is the high indoor temperatures. In order to reduce this problem the strategy was to install sun shading like sun-blinds and Venetian blinds, and cool night-air to cool the building.

At Katedralskolan a questionnaire was added to the investigations. This questionnaire showed low values as to well-being and social status and. The conclusion was that improvements on the visual surroundings like colouring etc were motivated.

3. MEASURES OF REBUILDING CARRIED OUT

The following measures have been taken during the autumn of 1990 in the school buildings:

Bokelund
A sun-blind has been installed as well as control equipment for night cooling.

Fagrabäck
In one class-room three different systems for supplying air have been installed. The class room has also been equipped with a fan and a sun-blind, and possibilities of inreasing the airflow. Most of the measurements will take place here. There are possibilities of varying a great number of parameters making comparisons.

Katedral
Three classrooms have been redecorated and the old windows habe been changed to new, tighter windows with blinds. The ventilation system has been cleaned and equipped with a control function for night cooling.

4. MEASUREMENTS OF CARBON DIOXIDE AND TEMPERATURES

Measurements were made during winter conditions in 1991. Figure 1 shows the contents of CO_2 by one pupil´s neck in the classroom (at the end of the lesson) as a function of the specific flow (l/s and person) when ceiling supply air terminal devices are being used. The ceiling supply air terminal devices consisted of four symmetrically located perforated supply air terminal devices.

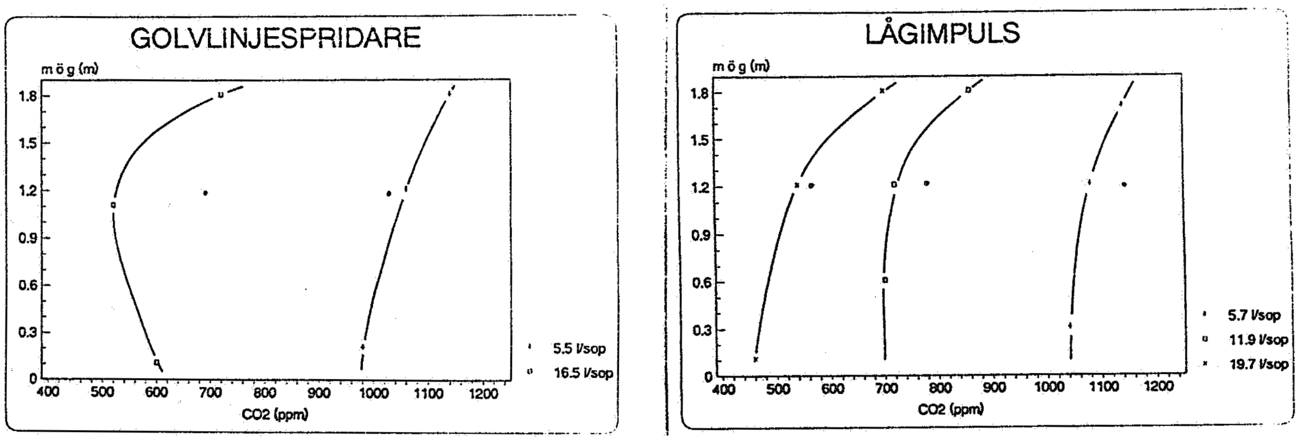


Figure 4. CO_2-content at different heights for different air flows. Supply air temperature +18 °C. The dot at 1.2 m above floor level represents the C_2-content at the neck. Lågimpuls = low velocity. Golvlinjespridare = line floor supply.

For the measurements shown in figure 3 and 4, the corresponding temperature gradients are shown in figure 5 and 6. Figure 5 and 6 show that the ceiling air terminal devices with greater flows (12 and 16.5 l/s per person respectively) give an insignificant temperature gradient (<0.5 °C). Other alternatives (including ceiling air terminal devices with small flows) give a temperature gradient which is 1 - 2 °C, i. e. no temperature gradient of importance.

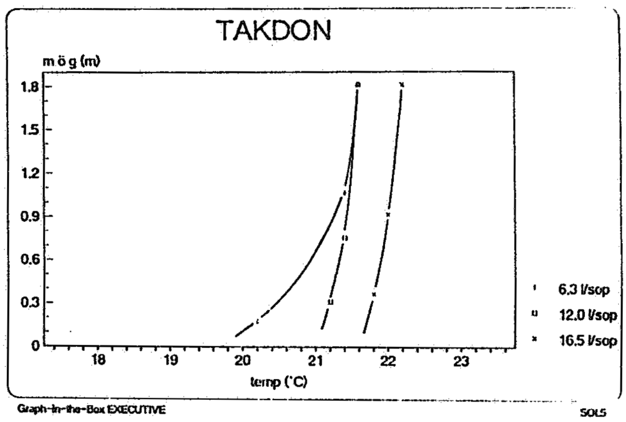


Figure 5. Temperature gradient for different air flows with ceiling air terminal devices. Supply air temperature +18 °C.

The measurements show that you can meet the requirement on 1 000 ppm CO_2 by the neck with the four supply air terminal devices with a supply air temperature of 18 °C and flows of 6 - 7 l/s per person. The calculated content of CO_2 for complete mixing at these flows is about 1100 ppm. The results from the measurements with low velocity air terminal devices (two behind pupils) throwing the air in a bow and with a line low velocity air terminal device (appr. 6 m long) show at the lower flows somewhat higher (100 - 200 ppm) contents of CO_2 than the ceiling air terminal devices (see figure 2)

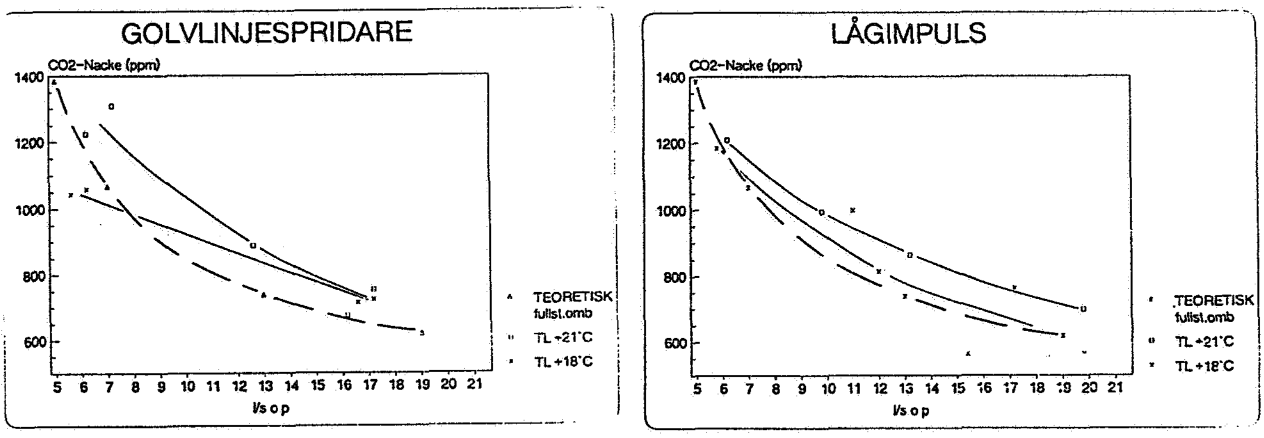


Figure 2. CO_2-content at the neck of a pupil as a function of air flow (l/s and person) at different supply air temperatures. The dotted line = theoretical calculation with complete mixing. TL = supply air. Lågimpuls = low velocity. Golvlinjespridare = line floor supply

Figure 3 and 4 show the vertical gradient of the CO_2 content with different air terminal devices and flows at 18 °C supply air temperaure. It apperars very clearly that ceiling air terminal devices give a lower gradient (a negligible divergence vertically) than the low velocity air terminal devices and the line floor supply air terminal device. It is also interesting to observe that the CO_2 content at the neck is somewhat higher when using low velocity air terminal devices than at points measured in the aisle between the desks (the gradient).

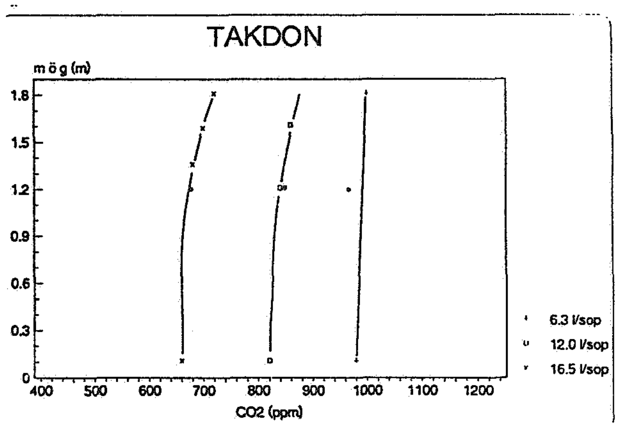


Figure 3. CO_2-content at different heights for different ceiling air terminal devices. Supply air temperature + 18 °C. The dot at 1.2 m above floor level represents the CO_2-content at the neck.

Furthermore, using night cooling is a simple and cheap way to cool the classroom during the night. It is well known that the surface temperature is as important as the air temperature for the experienced temperature, and with night cooling you can lower the surface temperature of the room.

Another circumstance effecting the experienced temperature is the air speed. When the speed increases, the experienced temperature is reduced. A ceiling fan, managed by teachers and pupils with a thyristor in the class-room, will get the air circulating, which leads to a feeling of the temperature being lower. The ceiling fan has been very much appreciated by the teachers and pupils, who have accepted astonishingly high air speeds (0.25 - 0.30 m/s).

7. AIR EXCHANGE EFFICIENCY BEFORE MEASURES

During August 1989 to March 1990 a series of different measurements was carried out regarding the air exchange efficiency in the different class-rooms. The measurements were made both with and without pupils. The results show that in most cases, regardless of the type of ventilation system, you will get close to a complete mixing ventilation when the class-rooms are being used (see figure 7). On the contrary, the result may be very varying when the class-rooms are empty, depending on the kind of ventilating system. During the measurements the airflow and supply temperatures have been kept constant. The reason for the mixing effect when pupils are present is the air movements caused by free convection from the pupils.

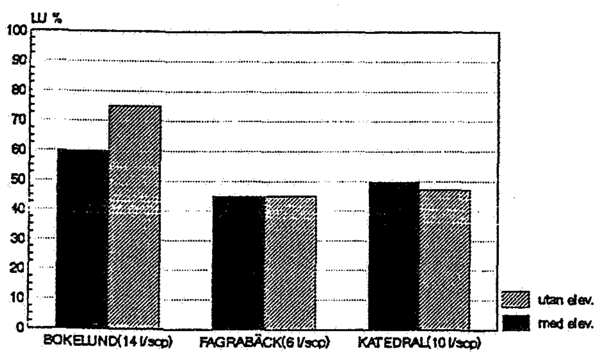


Figure 7. Air exchange efficiency before measures. Supply air temperature 2-3 °C lower than room temperature.

8. THREE DIFFERENT SYSTEMS

During the summer and autumn 1990 three different systems were installed in a class-room at Fagrabäck. Several measurements were made during January and February 1991, always with pupils in the class-room.

There were some difficulties in achieving identical conditions during the different measurements, e.g. the same number of pupils, the same activity by the pupils The difference between measurements with identical boundary conditions is caused by small disturbances due to normal activity in the classroom, like opening and closing doors. The measurements show that there are big differences in air exchange efficiency mainly due to the supply air temperatures and flows being used, but also to some extent due to the ventilation system.

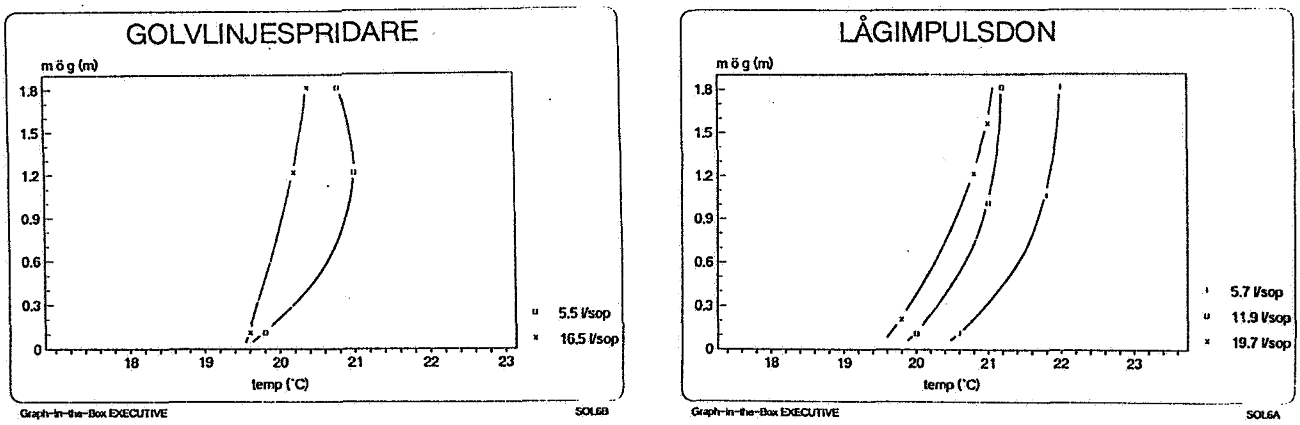


Figure 6. Temperature gradient for different air flows with low velocity supply air terminal devices and line supply air terminal devices. Lågimpuls = low velocity. Golvlinjespridare = line floor supply.

The low velocity air terminal devices and the floor line supply air terminal device are rather large for the lower flows, which results in a low temperature gradient.
The measurements described above were made during the winter season.

5. CORRELATION BETWEEN VENTILATION AND CO_2

The measurements during May have proved that both the low velocity air terminal devices and the floor line supply air terminal device give a lower content of CO_2 by the neck than the ceiling air terminal devices do. The level is between 100 to 200 ppm lower compared to ceiling air terminal devices at the flow 6 - 7 l/s per person. The explanation why the low impulse/floor line supply air terminal device does not give better values than ceiling air terminal devices during winter may be that the temperature on the inside of the two-glass windows was low (appr. 10 °C lower than the indoor temperature) and also that the surface temperature of the walls is somewhat lower than the indoor temperature. These low surface temperatures cause free convection (the thermostatic valve on the radiator closed) which gives an airflow causing a stirring of the air around the room, thus disturbing the deplacing effect. This airflow, caused by free convection has been estimated to around 50 - 100 % of the ventilation flow.

The measurements during May further showed that while the low velocity air terminal device/floor line supply air terminal device gave a better result by the pupil ´s neck, the CO_2 content was considerably higher by the teacher standing up. This also caused complaints.

6. HIGH TEMPERATURES

We can conclude that an exterior sun shading (like a blind) is necessary in order to lower the indoor temperature. The blind should be automatically controlled by a solar radiation sensor so that it also goes down early in the morning and later when no people are in school. Our measurements showed that a classroom with windows facing east already is warmed up (to 25 - 27 °C) at 8 o´clock in the morning when the teachers and pupils arrive. After that it does not help to air the room all day long.

A big airflow into the class-room makes the air whirl around, causing a mixing ventilation. This happens irrespective of what kind of ventilation system is being used. The supply temperature versus room temperature is not of any greater importance in this case (within the temperature range considered to be reasonable, i.e. somewhat below room temperature).

A low flow into the class-room can give a tendency to short circuit. In this case however, the type of ventilation system and supply temperature are of great importance.

In figure 8 you can see a tendency to piston flow for low air flows. This tendency appears both with ceiling air terminal devices and line floor supply air devices, at flows between 6 and 10 l/s per person. For low velocity air terminal devices there is a tendency towards piston flow at low air flows and loads. The inaccuracy in the measurement of the air exchange efficiency is estimated to be ±10 %. The local mean age of air was measured at nine different locations. The difference in local men age between different locations was negligable.

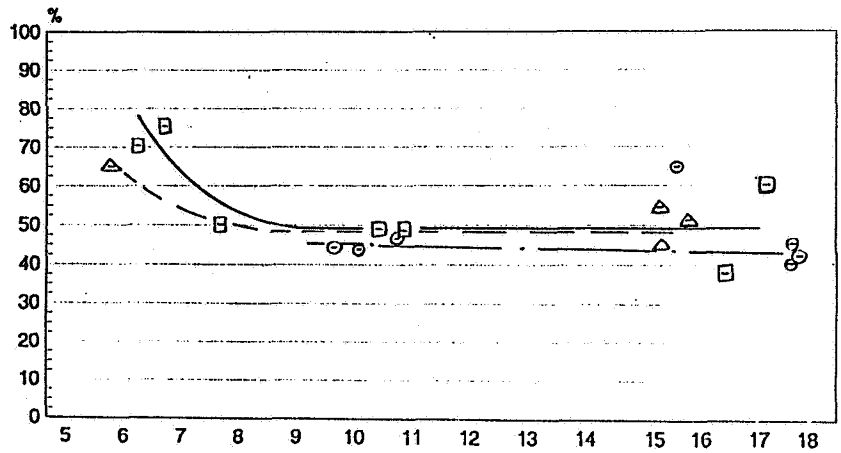


Figure 8. Air exchange efficiency as a function of air flow and supply air system. Measured after measures were taken in Fagrabäck.

⊟ = ceiling air terminal device with a supply air temperature lower than room temperature (1 - 3 °C)

⊖ = low velocity air terminal device with a suply air temerature lower than room temperature (1 - 3 °C)

△ = line flow air terminal device with a supply air temerature lower than room temperature (0 - 1.5 °C)

9. CONCLUSIONS

Ceiling air terminal devices, correctly designed as to number and location, will meet the requirement within the breathing zone 1000 ppm carbon dioxide content, with low air speeds and a small temperature gradient at a flow of 6 to 8 l/s per person. To obtain 800 ppm you will have to double the flow.

The measurements show that during the winter (with warm radiators and cold double-pane windows) the low impulse devices and line floor supply air terminal devices will give a somewhat higher content of CO_2 by the neck than the ceiling air terminal devices would at flows of 6 to 8 l/s per person. At spring conditions (with the radiator and window temperature about the same as the room temperature) the low impulse device and line floor supply air terminal will obtain 800 ppm CO_2 content within the breathing zone, with the flow 6 to 8 l/s per person.

The air speed at the feet of the pupils (close to the air terminal device) was appr. 0.2 m/s. In spite of this there has not been a single complaint of draught! The measurements also show that a teacher standing up will get a higher content of CO_2 (>1000 ppm) within the breathing zone with this solution, compared to ceiling air terminal devices.

Exterior sun shading, tyristor controlled ceiling fan and night cooling together are an effective way of reducing the indoor temperature without using comfort cooling.

The measurements of the air exchange efficiency and the mean age of air in the room show that even at relatively low flows you can achieve a moderate mean age compared to a higher airspeed. By a more effective airchange the flow can be kept down maintaining a low mean age. Relatively low flows (6 - 8 l/s per person) give a good air exchange efficiency and an acceptable mean age, and there is no reason for using higher flows (>10 l/s per person).

There is also no reason for rebuilding ventilation systems with ceiling air terminal devices to low impulse devices. It is more important to see to that the ventilation system has the correct supply air flow compared to the number of persons, the correct supply air temperature, and that the flow is distributed from a sufficient number of ceiling air terminal devices. It is also important that thermostatic valves on the radiators are set to a maximum temperature, to avoid an unnecessary increase of the indoor temperature.

Our recommendations are:

Airflow: 8 l/s per person. Supply air:18 °C (preferably lower in spring and autumn). Number of ceiling air terminal devices: 4 pcs. Max-reduction of thermostatic valve: closed at 20 °C. An automatic exterior shading, ceiling fan, and night cooling to reduce the indoor temperature.

10. REFERENCES

1. LARSSON, R. and OLSSON, S.
"Indoor Climate in Schools".
Swedish Council for Building Research RXX:1992