DIFFUSE CEILING VENTILATION FOR FRESH CLASSROOMS

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ABSTRACT

In most Dutch classrooms draught results in insufficient ventilation and poor air quality during the heating season, adversely affecting the well being and performance of pupils. Also a considerable part of the year the risk of overheating is high due to the high internal heat load. New analyses show that over 85% of time the heat load and not minimum indoor air quality is the determining factor for the required amount of ventilation. That is if passive cooling is to be preferred above mechanical cooling, with regard to energy conservation. This finding has been added in the latest Dutch guidelines for school ventilation.
Because high flow rates are desired without preheating, new draught free air distribution concepts are required. This paper describes the development of such a new concept. Fresh air is supplied through small perforations, scattered over the whole ceiling surface. During the heating season two pilot studies were held to evaluate the practical implementation of the concept in existing schools. To show the application in different existing schools also two design studies are described. The results show that with modest investment costs, extremely low fan energy consumption and a low noise level the indoor environment in classrooms may be improved considerably.

KEYWORDS

Diffuse ceiling ventilation, Healthy classrooms, Indoor Air Quality, passive cooling

THE NEED FOR PASSIVE COOLING

The high occupancy rate of classrooms results in high ventilation demands. Draught occurs if the kinetic energy of this large air flow is not absorbed correctly in the room air volume. This is often the case in present ventilation systems, with highly concentrated air inlets. Therefore, users do restrict the ventilation, which results in a poor indoor air quality during the heating season.
Outside the heating season in most schools overheating problems exists. Minimizing the overheating problem (T_i < 22 ºC) with increased ventilation (passive cooling), as illustrated by Figure 1, requires a ventilation system with a ventilation range typically between 170 and 700 dm^3s^{-1} per class room. At outside temperatures over approximately 5°C the flow rate has to rise. As shown in Figure 2 in the Dutch climate the probability is about 85% that the outside temperature during the day is higher

than 5°C. So most of the time the flow control is based on temperature instead of air quality. For practical reasons, to prevent noise, in Figure 2 the flow rate during the day has been limited to 340 dm^3s^{-1}. During the summer period this may be combined with 500 dm^3s^{-1} night ventilation, to better control the day temperature. This passive cooling approach has been adopted in the latest Dutch guidelines for school ventilation NPR 1090.

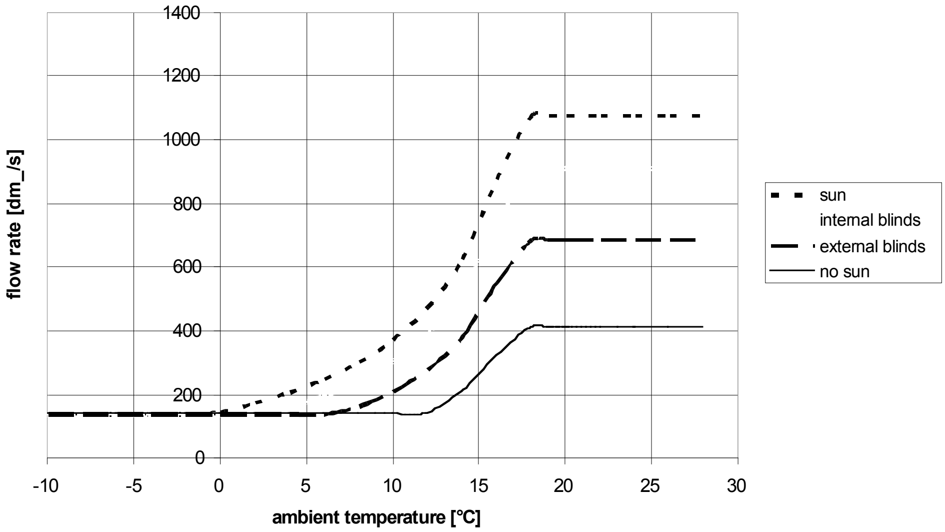

Figure 1: Required ventilation flow per classroom for maintaining air quality and prevention of overheating, as a function of the outdoor temperature and solar radiation and measures.

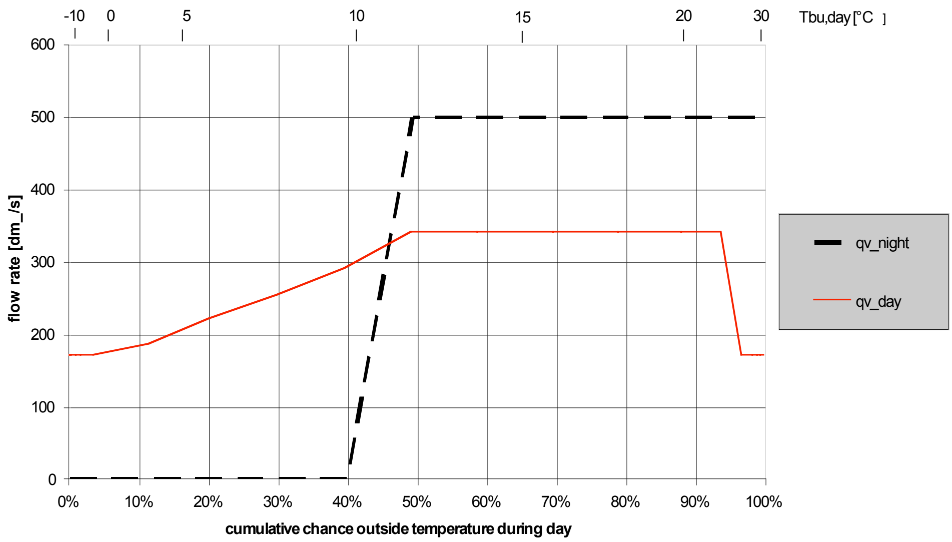

Figure 2: Required ventilation settings per classroom.

An alternative to the passive cooling approach would be the use of mechanical cooling. With a simple model an estimation has been made of the effect of insulation and air tightness on the energy consumption of a typical Dutch classroom, see Figure 3 (cooling COP = 3, HRU efficiency = 90%). With regard to heat recovery (HRU) an interesting trend is visible. The HRU-saving potential is small and even decreases

with increasing building quality. This is because the heat load of pupils, lighting and sun will highly cover the ventilation heat demand during the higher day time temperatures. To save ventilation energy, a good demand control on ventilation is more important than an HRU.
Another interesting observation is that the cooling costs for a well insulated, air tight class room do exceed the heating costs. These cooling costs may be avoided by using passive cooling systems, as suggested in this article. Apart from a wide ventilation range with automated thermostatic control, this asks for sufficient buffer capacity of the building construction or aids like phase change materials.

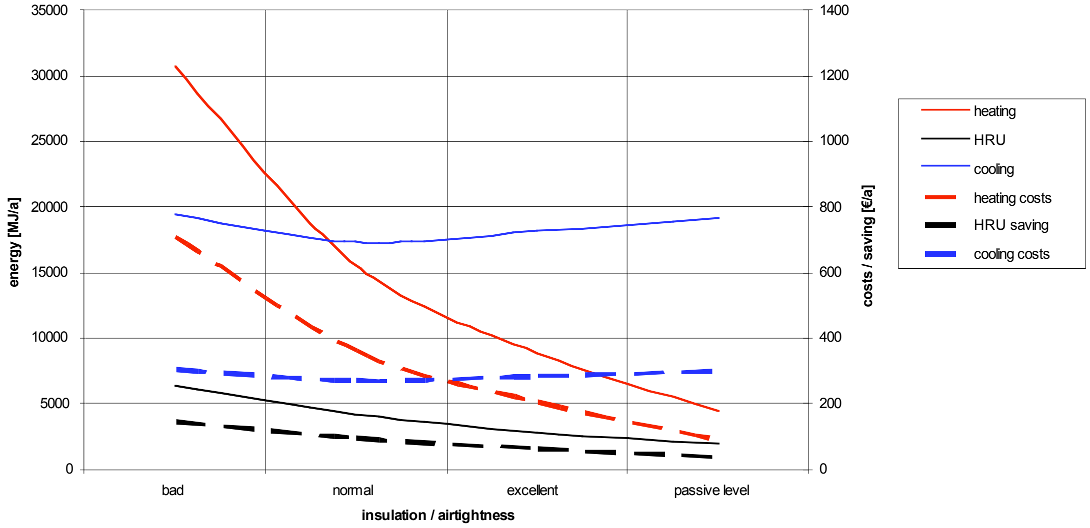

Figure 3: Energy use and energy costs for a classroom as function of the insulation.

DIFFUSIVE CEILING VENTILATION

As argued in the previous section fairly high flow rates are required without preheating. Without preheating it is hardly possible to supply these amounts of air through concentrated inlets in the façade without causing draught. Therefore a new patented air supply concept has been proposed, in which the whole ceiling surface is used to evenly distribute the fresh air: diffuse ceiling ventilation ® (Jacobs et al. (2008)). Figure 4 presents the principle of the concept: a ventilator (5) sucks outside air through the façade or roof. The space above the lowered ceiling (2) is used as an air distribution plenum. The fresh air is blown in the classroom through small holes (7) with a speed of 0.5 – 2 ms^{-1}. Enough mutual distance between the holes allows the formation of individual jets. Due to induction of room air in these jets, the temperature difference and air velocity are sufficiently reduced to prevent draught, before entering the living area.

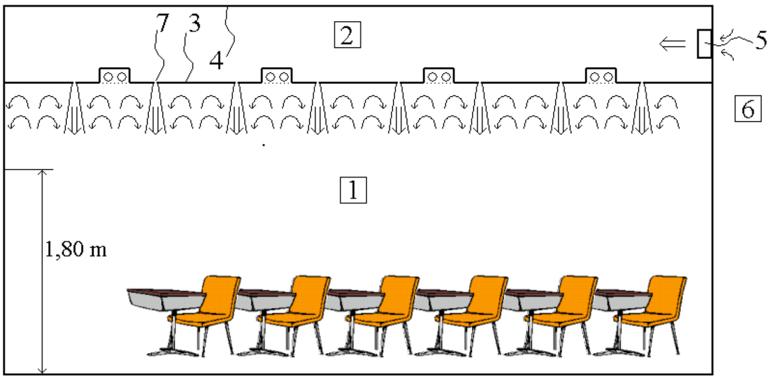

Figure 4: Principle of the diffuse ceiling ventilation concept ®.

Figure 4 shows a design with supply through the façade. In practice every classroom has its own possibilities for the supply and discharge of ventilation air. Furthermore, the glazed area, the insulation level, the building mass and the solar exposure varies, causing differences in the overheating problem case by case. Therefore this paper describes the further exploration of this concept by the results of two pilots and two design studies.

PILOT AND DESIGN STUDIES

Decentral supply and discharge through the façade

On the ground floor of a primary school in Sliedrecht the first pilot was situated, see Figure 5. To prevent drastic building measures for ductwork, a decentral supply and discharge through the façade has been chosen, see Figure 6. Outside air was sucked in by a radial ventilator (diameter 310 mm) and then blown in the space above the lowered ceiling through 6 parallel 1 m long silencers (diameter 180 mm). The air was distributed by 25 mm holes, pitch 300 mm drilled in the existing 600 x 600 mm ceiling plates. All dimensions were chosen to keep the air velocity in the order of 1 - 2 m/s at 200 dm^3s^{-1}. This resulted in a very low energy use and low noise level, see table 1. As existing building elements, such as the plenum above the ceiling plates and no ducts were used, the investment costs were relatively low.

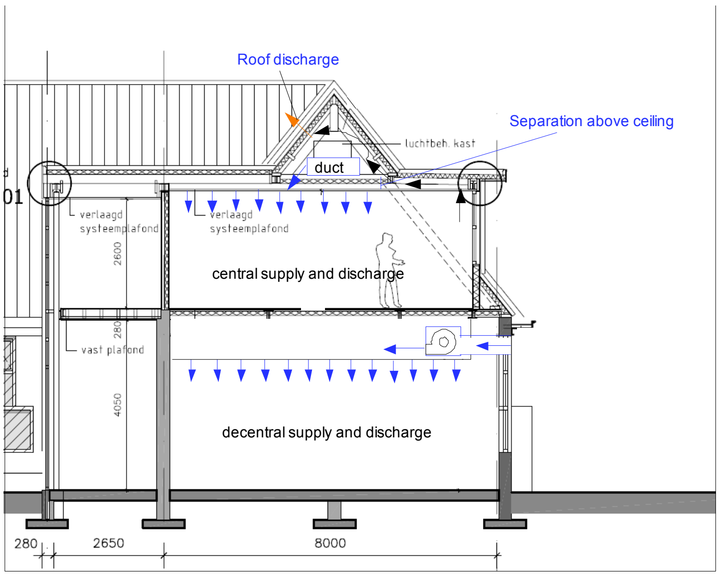

Figure 5: Sliedrecht, ground floor: decentral supply and discharge through façade. First floor: central supply duct and discharge through attic.

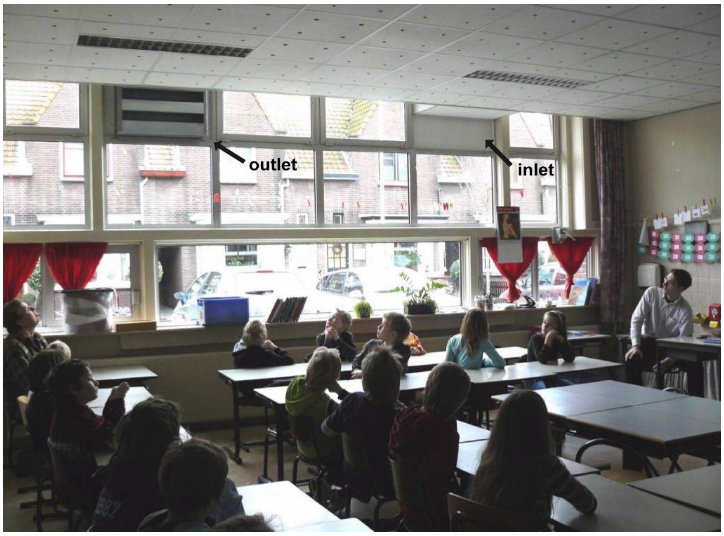

Figure 6 : Sliedrecht ground floor, decentral supply and discharge, perforated ceiling.

TABLE 1: Performance of decentral supply and discharge pilot (Figure 5, ground floor).

	Flow rate [dm^3s^{-1}]	L_p [dB(A)]	Pressure drop [Pa]	Energy [W]
Low	180	28	6	8
Medium	390	41	60	50
High	610	53	144	172

Central supply and central discharge

For the same primary school in Sliedrecht a design has been made to ventilate 5 classrooms at the first floor. The upper part of Figure 5 gives the cross section of the situation. Due to a restricted ceiling height a built-in ventilator box is difficult to realize. For this reason one decided to choose a central supply duct, situated in the small attic above. A typical problem of the floor below the roof is the solar heat load. For this reason it has been decided to use only two third of the ceiling for supply and to use the ceiling above the dormer as air discharge. Subsequently the air flows to the attic and through a central roof discharge. Simulations have shown that this routing of the discharge air reduces the heat load with 500 W per class room.

Decentral supply and discharge through the roof

Dutch schools are often foreseen with a so-called 'lessenaardak' (lectern roof), see Figure 7 for a primary school in Breugel. This roof consists of two parts. Using the whole roof as supply would require two supply fans or a duct between the two parts. However simulations indicate that it is possible to use only one part of the roof as supply. As the left part is south facing this part will be used for the air discharge. In this way the discharge air removes the solar heat load.

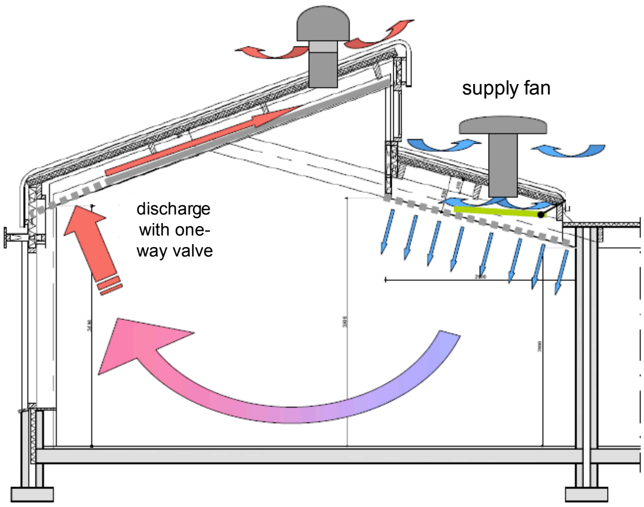

Figure 7: Breugel, decentral supply and discharge through roof.

Decentral supply through the roof and discharge to the atrium

At the highest floor of a primary school in Tilburg the second pilot has been held. As the classroom is situated directly below the roof a roof fan (2) has been applied, see Figure 8. Upstream the fan a filter (1) is placed. Directly downstream the fan a silencer (3) is placed. The existing roof tiles (4) have been perforated with 25 mm holes. The fan is CO_2 controlled. The used air flows across a grill (6) above the door to an atrium.

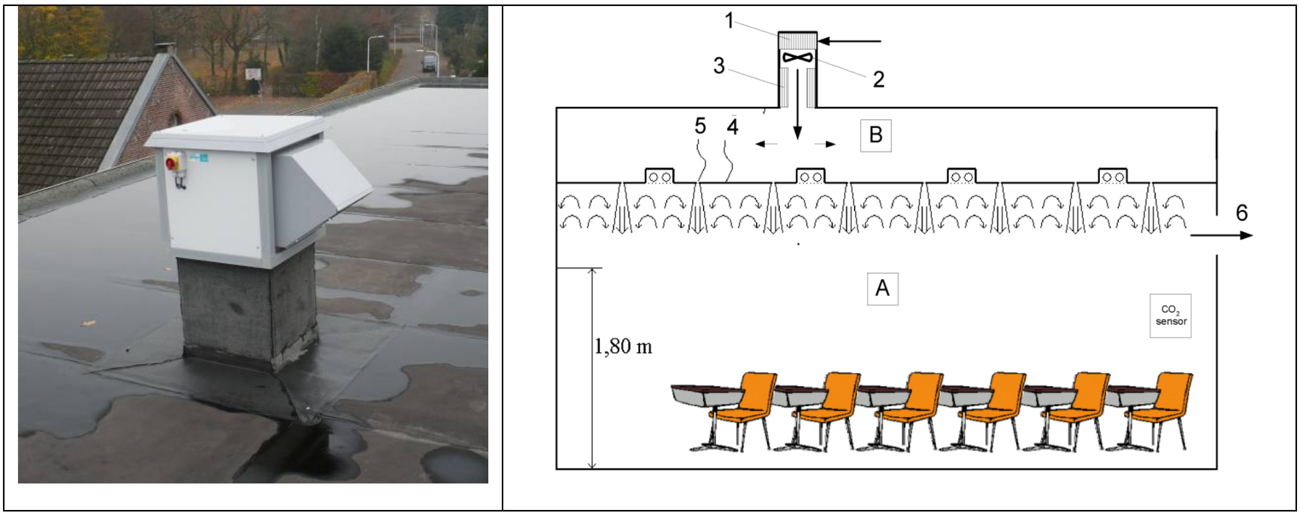

Figure 8 : Tilburg, decentral supply through the roof and discharge towards the atrium.

EFFECT ON ENERGY CONSUMPTION

The energy consumption of class rooms is relatively low compared to office buildings. One of the reasons is the absence of mechanical ventilation and cooling systems. In Holland the average electricity use of a classroom is 18 kWh/m^2. This costs about € 200 per year per classroom. The implementation of a traditional ventilation system, see table 2, could double the electrical energy use. This shows the importance of low pressure ventilation systems.

TABLE 2: Comparison of Specific Fan Power (SPF) and electricity consumption of different ventilation systems. Occupancy 1040 h/a, flow rate 200 dm^3s^{-1}, electricity costs 0.2 €/kWh.

	SPF [kW/m^3]	Electricity costs [€/a]
Traditional system[1]	5 – 10	290
Modern system[1]	2 – 2.5	90
Primary school Sliedrecht	0.04	2
Primary school Tilburg	0.5	20

[1]Railio and Makinen 2007

CONCLUSIONS

Because of the high heat load passive cooling is essential in schools. For the passive cooling high flow rates are needed and thus a low pressure and draught free design is required. Especially in existing schools this is a challenging task. As this article illustrates with a number of examples diffusive ceiling ventilation is a promising concept. As nearly each school has a different lay-out the design of the supply and discharge of the air has to be done in an intelligent way. There is not one solution which fits all.

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