DK2

Replacing mechanical ventilation with natural ventilation at Enghøjskolen school in Denmark

1 Photos

Figure 1a: Photo showing the facade of Enghøjskolen

Figure 1b: Photo showing the interior of Enghøjskolen

2 Project summary

The purpose of the project was to document the effect of the school renovation. Low emission surfaces were introduced and mechanical ventilation was replaced by increased volume in classrooms as well as natural ventilation through windows, providing increased user-control.
Problems in schools where indoor climate is controlled by building services, include lack of responsibility among occupants, recurring unsatisfactory conditions whereby load exceeds the capacity of installations and high-energy consumption caused by insufficient demand control. Problems in user-controlled schools are often different. Attention to indoor climate control creates disturbances and climate requirements are only met when users intervene.
An intervention study was performed in a poorly maintained school for children of preschool age up to grade 10. The intervention included removal of mechanical ventilation, increased ceiling height and larger hinged windows controlled by users, temperature sensors and a timer to open them during recess. Results from the renovated school show significantly reduced energy consumption, increased user satisfaction and slightly improved values for air pollution and temperature. Since users could better control conditions in the renovated school, occasional poor air quality or temperature levels did not cause notable dissatisfaction.

3 Site

Denmark, latitude: 56.5°N, longitude: 8.5°E, altitude: 10 m.
Temperate coastal climate. Mean annual temperature: 8°C,
mean winter temperature: 4°C.

4 Building description /typology

4.1 Typology / Age

Typology/Age	Pre 1910	1910–1930	1930–1950	1950–1970	1970–
The side corridor school					● (before)
The cluster school					● (after)

Educational level: School (pre-school to grade 10)

4.2 General information

Year of construction: 1974
Year of renovation (as described here): 1997–99
Total floor area (m^2)*:* 10,000
Number of pupils: 500
Number of classrooms: 16
Typical classroom
size (m^2) *:* 69
number of pupils: 28

4.3 Architectural drawings

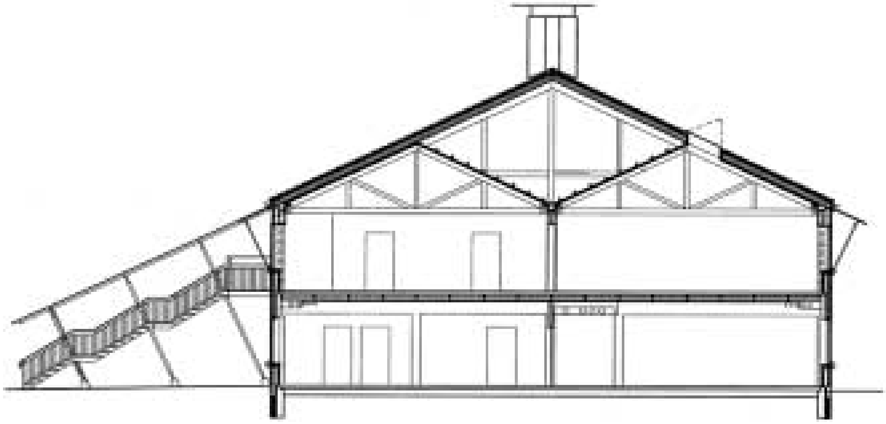

Figure 2: Cross-section of the school after renovation.

5 Previous heating, ventilation, cooling and lighting systems

The school was supplied with district heating. The district heating system was directly connected to the radiator system and the heating coils in the ventilation system without any heat exchanger. The ventilation system needed replacement.
Originally the radiator system was the only source of heating. In order to obtain a greater heating capacity when outdoor temperatures droped below 0°C, the ventilation system was used as an auxiliary source of heat.
The school was supplied with a building management system (BMS).
The previous lighting system had fluorescent luminaires.

6 Retrofit energy saving features

6.1 Energy saving concept

Worn-out installations and structures in Enghøjskolen, a Danish school in Hvidovre, situated just outside Copenhagen, made it necessary to carry out a comprehensive renovation. Façades, roofs, windows and all materials for inner surfaces were replaced. Teachers, students, parents, consultants and school maintenance staff decided in co-operation that the old ventilation system should be replaced by hinged windows only. This would allow school users to open the windows when required. Furthermore some of the ceiling and façade windows should open by motor control when temperatures increase and when the school bell sounds for recess. This way, windows would be open at least 10 minutes every hour of the school day. Moreover the ceiling height was increased in classrooms by replacing the original flat roofs with pitched roofs parallel with the ceilings. Prior to the renovation, walls had acrylic paint and floors were covered with linoleum. New and similar materials were used in the renovated school.

6.2 Building

The insulation of the thermal envelope in the refurbished building was improved. The U-values of the new windows comply with the Danish Building Regulations. Furthermore the ceiling height was increased in classrooms by replacing the original flat roof with pitched roofs.

6.3 Heating

Radiators with thermostats heat the classrooms. The heat output from the radiators covers transmission plus ventilation losses. The theoretical ventilation loss is set to 5 l/s per person plus 0.4 l/s per m^2 when there are people in the room.

6.4 Ventilation

Natural ventilation with hinged windows. The renovated school is not sized for 28 pupils per classroom as the old one, but for 24 and this means a bigger volume per person (at least 12 m^3). This is the minimum volume demand if mechanical ventilation is to be avoided.

6.5 Lighting

The new lighting system has luminaires with compact fluorescent lamp types (CFLs) and occupancy sensors.

6.6 Other environmental design elements

Construction products are selected to be robust and durable and have a minimal impact on the environment when made and disposed of.

7 Resulting Energy Savings

Table 1 shows that average heat consumption from 1992 to 1995 before renovation was 2.9 times higher than in 1998-99. Average electricity consumption before renovation was 1.7 times higher than after. Much energy was used in the old ventilation systems. Furthermore, the renovation provided better insulation of the school as required in the current Danish building legislation from 1995.

Table 1: Energy consumption for heat (convectors, ventilation systems and hot tap water) and electricity (fans, pumps, lighting and other equipment).

In kWh/(m^2 year)	1992-3	1993-4	1994-5	1998-9
Heat	166	191	284	73
Electricity	64	63	72	39

Large differences in ventilation rates existed between the rooms prior to renovation. This was probably a result of poor system maintenance. Re-circulation was reported to be out of action during the final years before renovation. Nevertheless the investigator found some examples of re-circulation dampers with their actuators disconnected. This probably caused some re-circulated air to be included in reported values. Air change measurements failed in two of the three rooms without mechanical ventilation in the renovated school. In the rooms with closed windows, air changes, as expected, were extremely low.

Table 2: Information on size, occupancy and ventilation with outside air for the classrooms investigated before and after renovation.

	Class	Area m^2	Volume m^3	Number of students	Air change h^{-1}	Air flow per person l / (s person)
Before	6a / 7a	69	200	20	2.45	6.81
	7b / 8b	69	200	19	1.22	3.58
	7g / 8g	69	200	21	0.68	1.80
	8a / 9a	69	200	24	–	–
After	6a / 7a	69	286	21	–	–
	7b / 8b	69	297	23	–	–
	7g / 8g	69	286	19	0.07	0.29
	* 8a / 9a	90	270	19	0.85	3.36

* *This room was on the first floor and had mechanical ventilation also after renovation.*

	Class	Mean temp. Horizontal °C	Std. dev. Temp. Horizontal °C	Mean temp. increase. Horizontal °C/h	Std. Dev. temp. Vertical °C	Mean CO_2 conc. mg/m^3	Mean hydro–carbon conc. microgm/m^3
Before	6a / 7a	23.8	0.49	0.89	1.09	1730	4.8
	7b / 8b	–	–	–	–	1705	6.5
	7g / 8g	22.7	–	0.30	1.59	2251	55.1
	8a / 9a	21.2	0.97	0.50	1.03	1983	36.3
Mean before		**22.6**	**0.73**	**0.56**	**1.24**	**1917**	**25.7**
After	6a / 7a	21.3	0.29	0.54	0.75	–	–
	7b / 8b	21.9	0.20	0.48	0.45	–	–
	7g / 8g	21.3	0.19	0.50	1.01	1838	9.6
	* 8a / 9a	19.9	0.16	0.42	1.31	1583	5.6
Mean after		**21.1**	**0.21**	**0.49**	**0.88**	**1711**	**7.6**

* *This room was on the first floor and had mechanical ventilation also after renovation.*

Table 3: Statistics for measurements of temperature, CO_2 and the index of total hydrocarbons before and after renovation.

Table 3 shows descriptive statistics for measurements of temperatures in a horizontal layer, temperatures along a vertical line from floor to ceiling and measurements of CO_2 concentration and index of total hydrocarbons in a horizontal layer. Standard deviations were calculated for each set of measurements and then averaged. Reported values are based on measurements taken from 8.00 to 14.00 hours on two consecutive school days. Values tend to be somewhat better in the renovated school. Temperatures in the renovated school show less variation between positions and over time as indicated by standard deviations and the temperature increase. Through comparison of measured ventilation rates to occupancy and CO_2 concentration, it seems obvious that re-circulation was applied before renovation and that ventilation in the renovated school was higher on average than during measurements with closed windows. The high index for hydrocarbon concentration before renovation may indicate significant air pollution sources among the old surface materials.

8 User evaluation

Figures 3 to 5 show information from an investigative questionnaire made just before the renovation and one year after. Approximately 80% of the replies

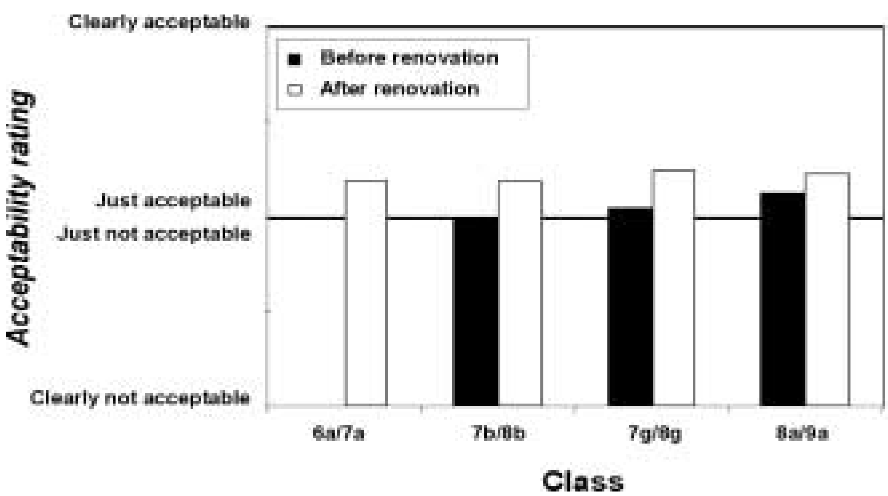

Figure 3: Acceptability of air quality before and after renovation.

were from students, who participated in both years, while the remaining 20% came from students who only participated once. Perception of air quality was rated on the acceptability scale ranging from 'Clearly not acceptable' to 'Clearly acceptable' shown in figure 3. Acceptability increased significantly (p<0.5) for the two classes where mechanical ventilation was removed. The increase was less than significant for class 8a/9a that had a homeroom with mechanical ventilation also after renovation.

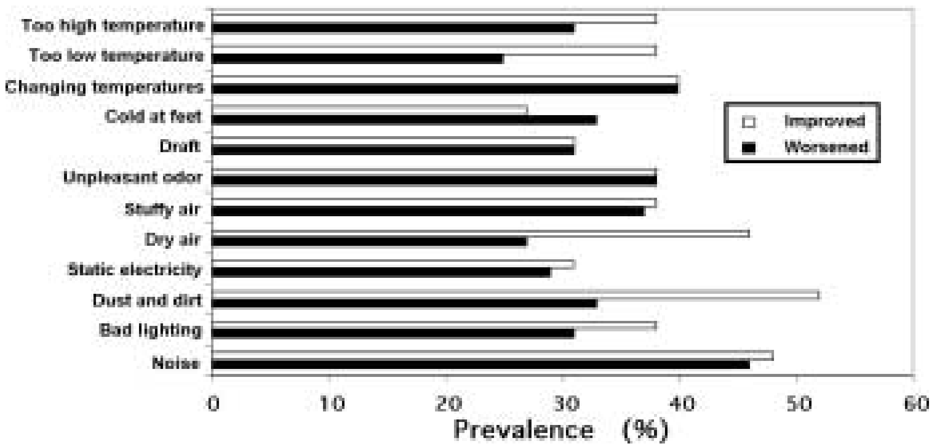

Figure 4: Perceived change of some unpleasant conditions after the school renovation.

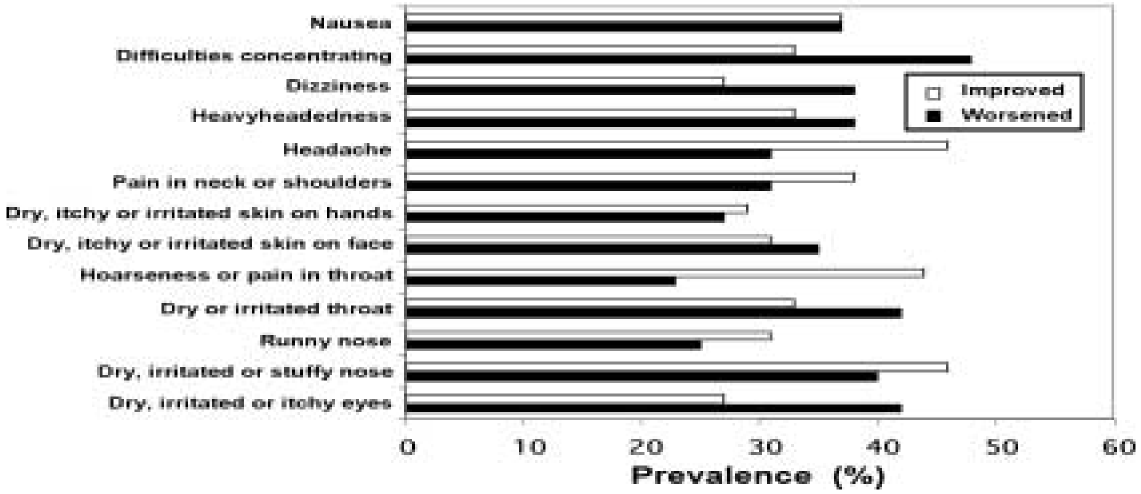

Figure 5: Perceived change of some symptoms after the school renovation.

Figure 4 shows the responses concerning improvement or worsening of unpleasant conditions. The sum is less than 100 % since some replies were unchanged. Most conditions improved after the renovation. Improvements were significant (p< 0.10) for 'Too high temperature' and 'Too low temperature' and significant (p<0.05) for 'Dry air' and 'Dust and dirt'. Other changes were lower than significant. The only annoying condition that worsened was 'Cold at feet'. This was probably caused by cold air entering the room during periods of airing.

9 Renovation costs

No information is available.

10 Experiences/Lessons learned

10.1 Energy use

The average heating consumption before renovation was approx 3 times higher than after. A great part of the savings was due to increased insulation as required in the current building regulation. Much energy has been saved by hinged windows replacing mechanical ventilation.

10.2 Impact on indoor climate

The school was in a poor condition before renovation. The mere fact that the school was finally renovated may have had a positive influence on the users. New and undamaged indoor surfaces, together with much improved daylight and contact with the surroundings through new and larger windows, may also have contributed to improved satisfaction. In spite of the very low ventilation rates and significant energy savings in the renovated school, measurements indicate that control of temperature and air quality improved slightly. The acceptability of the air quality improved significantly. It is quite possible that low emission construction products, increased room volume and demand control exercised by users, all together improved air quality. Despite rather low external temperatures during the measurement process, ventilation through windows was effective.

The school is now running with significantly reduced environmental impact. Maintaining adequate air quality requires students to act regularly. This is in line with the idea that schools should prepare students to be able to take responsibility for their own health in an eco-conscious manner. Average CO_2 concentrations of around 1800 mg/m^3 or 1000 ppm both before and after renovation are rather high values. The users' choice between air quality and the inconvenience of opening the windows determines the results. The air quality in the school is comparable to most other Danish schools.

10.3 Economics

The gross construction costs including all the renovation done (insulation of thermal envelope and new constructions) were 6,027 DKK/m^2 (804 EURO/m^2).

The total costs including design fees were 7,241 DKK/m^2 (965 EURO/m^2).

10.4 Practical experiences of interest for a broader audience

The school users were as good, or better, at obtaining comfortable temperature and air quality as the poorly maintained mechanical ventilation system with central automation.

10.5 Resulting design guidance

- Much energy may be saved in a school if hinged windows replace ventilation systems, automated control of window openings ensure frequent use and school users devote themselves to a coordinated effort for a good indoor climate.
- Increased ceiling height, use of materials with greater storage capacity for heat and air pollution, users motivated to share the responsibility for the quality of the indoor climate, and understandable and responsive buildings and installations are key issues in improving the indoor climate and reducing energy consumption in schools.

11 General data

11.1 Address of project

Enghøjskolen, Hvidovre, Denmark

11.2 Existing or new case study

Project initiation:
Design completed: 1996
Renovation construction completed: 1999
Monitoring and evaluation completed: 2000

11.3 Date of report / revision no.

August 2003.

12 Acknowledgements

Builder: Hvidovre Municipality
Architects: Thure Nielsen and Rubow A/S.
Consulting engineers: Birch & Krogboe A/S and Dominia A/S
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Author (of this description): Lars Gunnarsen & Kirsten Engelund Thomsen, Danish Building and Urban Research

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