Egebjerg School, Ballerup, Denmark

DK1

1 Photo

Figure 1: Photo of the school, north view showing retofitted rooflights.

2 Project summary

The object of the Danish MEDUCA project is the refurbishment of a school built in the seventies in the Municipality of Ballerup, Egebjerg School. The overall aim of the project is to demonstrate that an energy efficient and ecological refurbishment of a common school of the seventies, can be carried through to obtain a healthy indoor climate at a reasonable cost. Modern building technology, heating and ventilation technology were combined with carefully chosen materials, natural ventilation and active solar heating.

The project at Egebjerg School concerned a selected part of the school, C2 & C1, containing classrooms, connecting corridors and two double height common area rooms.

The project was completed in 1998.

3 Site

The project is located in the Egebjerg settlement area, Ballerup, Denmark.
Latitude: 56 °N., longitude; 9°E. Temperate coastal climate.

4 Building description /typology

4.1 Typology / Age

Typology/Age	Pre 1910	1910–30	1930–50	1950–70	1970–
The open-plan school					●

Educational level: Pre-school, primary and secondary school.

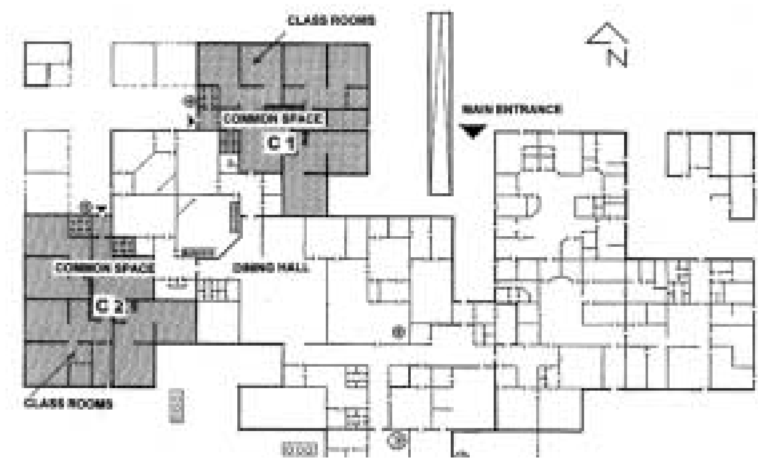
4.2 General information

Year of construction: 1973-81
Year of renovation (as described here): 1997-98
Total floor area (m2): 17825, *renovated area:* 1714
Number of pupils: 1000, *in renovated part:* 250
Number of classrooms in renovated part: 12

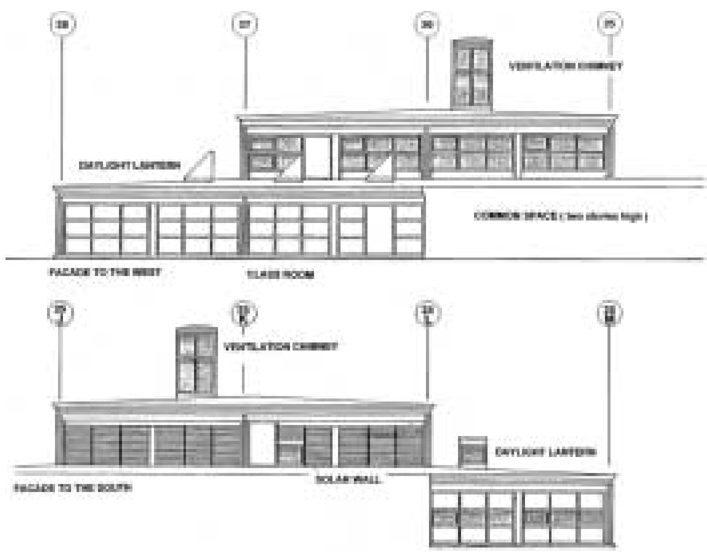
Typical classroom
size (m2) : 61
window/glass areas (m2): 255 south facing in total on renovated part
number of pupils: 25

Hours of operation (specify, e.g.: 1/1,_, _th of building): 8 (1/1).

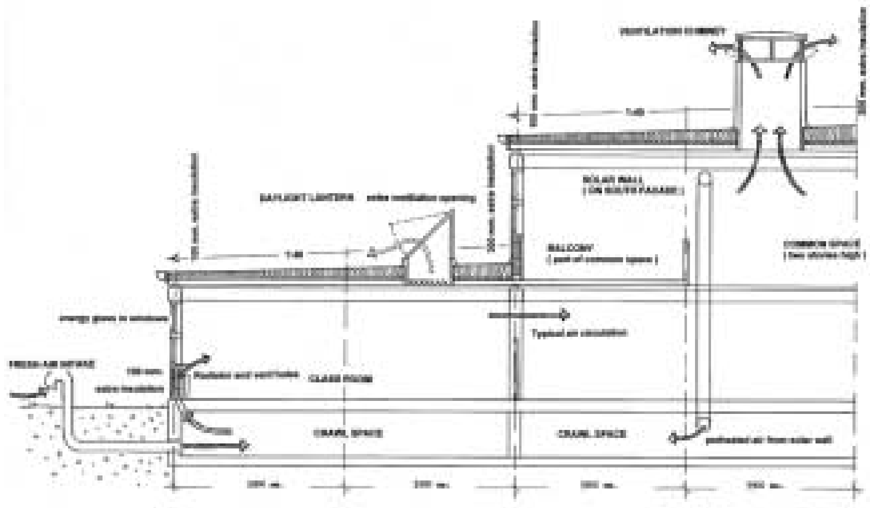
4.3 Architectural drawings



Floor plan of part of the school including the 2 renovated sections, C1 and C2.



Elevation



Technical section of the school showing the ventilation system principle.

5 Previous heating, ventilation, cooling and lighting systems

Heating system: Radiators supplied with air heating using the ventilation system, with re-circulation of the air in winter conditions.
Ventilation: The original ventilation system was a balanced mechanical ventilation system using the crawl space as an open manifold for the extract air from the classrooms.
Lighting: The lighting was traditional incandescent light bulbs with on/off switches.

6 Retrofit energy saving features

6.1 Energy saving concept

The architect of Ballerup municipality worked in close co-operation with the HVAC engineers of Cenergia Energy Consultants and the electrical and construction engineers.
The design concept focussed on replacing the existing mechanical ventilation system with a natural ventilation system and reducing heat losses through reduced U-values of roofs, façades and windows.

6.2 Building

A completely new sloped roof construction replaced the original flat roof. An average of 20 cm of mineral wool was added, giving 30 cm thick insulation overall. All façades were completely renewed including 20 cm of mineral wool insulation. All windows in the selected sections of the school were replaced by new low energy windows with a U-value of 1.7 W/m^{2}K.

6.3 Heating

New radiators optimised to the new building load were installed.

6.4 Ventilation

A completely new natural ventilation system has been designed. Fresh air is taken in through earth ducts to a crawl space below the classrooms. From the crawl space the air is led into each classroom behind convector radiators which have been designed to further preheat the air. Air leaves the classroom through corridors to the double height common assembly room, at the roof of which a combined stack effect, wind and solar chimney is placed. The chimney

is designed to work by a combination of wind pressure and ordinary stack effect. Two separate chambers are heated as solar air collectors and are opened when the temperature increases to such a degree that a considerable driving force is established. This feature is primarily designed for summer operation. A fan is located in the crawl space to generate a slight over-pressure in case the natural driving forces are too weak to generate the necessary ventilation.
A type of solar air collector called a "Canadian Solar Wall" is installed on the south façade of the double-height building. From the collector, air is taken into the crawl space instead of from the earth ducts, whenever it is preheated to a higher temperature.
The earth duct also pre-cools the fresh air in the months of the year when the outdoor temperatures are higher than that of the earth ducts.

Comfort cooling: No
Dehumidification: No
Pre-heating of ventilation air: Yes
Heat recovery: No

6.5 Lighting

Advanced roof lights. The roof lights have a vertical part for direct sunlight (primarily turned towards the south) and a sloping part towards the sky for diffuse light. In the light shaft a special arrangement of a light-diffusing grid prevents glare in the classrooms.
Artificial lighting is controlled by timeclocks and infrared presence detectors as well as daylight sensors. 10 years ago the school was equipped with energy efficient fluorescent lighting fixtures. Also some steps had been taken towards more advanced control of the lighting depending on external solar radiation levels. Now, with the refurbishment, new advanced control of the artificial lighting system will be based on indoor light levels and occupancy.

6.6 Other environmental design elements

An advanced EMS system was designed to control not only heating and lighting, but also the natural ventilation system. This includes opening of windows at the solar chimney (see below) in the leeward side from the wind and opening of fresh air intakes according to temperature and CO_2 levels. The EMS system is also used for the monitoring of the building. Air temperature and CO_2 sensors are located in each classroom and temperatures and air flows are measured at the fresh air intakes. Also energy meters in the retrofitted part of the building and the equal sized part of the building used for reference measurements are automatically read by the EMS system.

7 Resulting Energy Savings

Based on the first half year of measurements the estimated heating energy savings will be around 80 kWh/m^2 out of a pre-retrofit consumption of 180 kWh/m^2. The corresponding numbers for electricity consumption were estimated at the outset to be 18 and 36 kWh/m^2 respectively and have not been measured.

Energy consumption before and after (be as specific as possible):
Heating: 181 kWh/m^2 - 87.3 kWh/m^2
Cooling: None
Electricity for ventilation and lighting: 36 kWh/m^2 - 22 kWh/m^2

8 User evaluation

The section of the school identified for the MEDUCA project was subdivided into two parts of equal size C1 & C2. C1 was defined as a reference case for the qualitative user evaluation of C2. The user evaluation was carried through by letter: all pupils and teachers in the two sections answered a questionnaire developed by the Stockholm office of statistics and research in Sweden. 8 teachers and 120 pupils from the C2 section and 9 teachers and 72 pupils from the C1 section participated. The questionnaire had 17 main questions and several sub-questions. The figure below shows the results of one of the main questions concerning air quality. The histogram very clearly shows a "shift" in perceived air quality from acceptable to quite good and from poor to acceptable as a result of the refurbishment of the school. The general picture of all questions is an overall improvement of the indoor comfort quality in the C2 section compared to the reference.

Quality of daylight / artificial light: Very good
Sound quality: OK
General feeling:
    General well being: Very good
    Headache: Reduced
    Difficult to concentrate?: No
Technical functionality (are the technical solutions easy or difficult to operate?):
    Yes, it mainly works automatically.
Architectural quality: Highly improved by the renovation.

9 Renovation costs

The energy part of the renovation cost was app. 3.8 million DKK (0.51 million Euro) and the total renovation cost was app. 5.5 million DKK (0.74 million Euro).

10 Experiences/Lessons learned

10.1 Energy use

Heating reduced by 50%, electricity by 30%.

10.2 Impact on indoor climate

Greatly improved

10.3 Economics

Quite long payback time.

10.4 Practical experiences of interest for a broader audience

Ventilation:

Some parents of pupils with allergies have been concerned that there is no filter for pollen in the system. But it has not been possible to find any pollen in the inlet ducts or in the crawl space used as an inlet manifold by the system. Furthermore the level of pollen will never exceed the outdoor level, which the pupils are exposed to most of the time. If it proves necessary, however, it is possible to install an electrostatic filter, with little resistance to the airflow.
Natural ventilation systems are very robust against manual opening of windows – air pressure does not have to be maintained as with mechanical balanced systems. Pupils and teachers often open windows to benefit from the fresh air, not because the air quality is poor.
The pre-cooling of fresh air in the earth ducts proved very effective. In the warm spring and summer months the class rooms in the retrofitted part of the school were significantly cooler and the air fresher than in the other parts of the school.
The automatic opening and closing of windows in the solar chimney sometimes causes problems, because the motor seems to be pulling them a little out of shape. Care should be taken over the placement of the motor.

Daylighting:

The daylighting systems are designed to have a specific orientation regardless of the orientation of the classroom windows. Some of the classrooms are located so close to the main hall, which is twice as high as the classrooms, that if the correct orientation was kept, the vertical glazing would simply be in front of the hall windows, and would provide no daylighting. Therefore it was necessary to turn the daylighting systems to another orientation.

Control:

The control of the mechanical system is highly automatised. It is not possible for the user (students and teachers) to change the set points. Only the technical manager of the school has full access to the main computer of the BEMS. There is a very efficient control of the indoor climate (room temperature and ventilation airflow) and there has not been any need for the user to change the output of the radiators or other settings. The user can open windows in the façade to improve the ventilation and this is the only parameter that the user can control. The system has many new control devices which have to function correctly to obtain a satisfactory indoor climate. There have only been a few problems with two of the CO_2 sensors, which have subsequently been replaced.

At first the classroom dampers were too noisy and they sometimes opened and closed during a lesson.

The control algorithm was changed to prevent this, and for the second period, the school improved as less noisy dampers were used.

10.5 Resulting design guidance

Ventilation:

The use of a crawl space as an overall manifold for the inlet ventilation air has proven to be very useful, as it eliminates the need for preheating the ventilation air before it enters the classrooms. For this system to work, the insulation of the floor against the crawl space should be designed properly.

Earth ducts:
When placing earth ducts, care should be taken to avoid placing them too near drainage layers as this might cause some problems with water in the ducts when the ground water level is high.

Daylighting:
The louvres at the base of the daylight lanterns were designed to eliminate direct sunlight as well as have an acoustic function. Although the louvres do block direct light and do improve the acoustic, they also block some of the diffuse sunlight. There is a trade off between maximising the daylight in cloudy weather conditions with improved acoustics and no glare. This trade off should be optimised.

Control:
The monitoring results indicate that the control of the natural ventilation system could be simplified to work only on presence sensors instead of CO_2 sensors. This is cheaper and more reliable. This goes for the inlet dampers as well. An overall control routine could close the outlet windows under timeclock control, again simpler than using a CO_2 sensor.

11 General data

11.1 Address of project
Egebjerg School, 2750 Ballerup, Denmark

11.2 Project dates
Project initiation: June 1996
Design completed: February 1997
Renovation construction completed: October 1998
Monitoring and evaluation completed: January 2001

11.3 Date of report / revision no.
July 2002/version 4-reviewed.

12 Acknowledgements

Builder: The municipality of Ballerup
Architect: Frank Jacobsen, City architect.
Energy and HVAC engineers: CENERGIA ENERGY CONSULTANTS
International support programmes: THERMIE (MEDUCA project).
Author: Ove Mørck, Cenergia.

13 References

1. Summary report, thematic reports on light, ventilation, control & MEDUCA Project CD-ROM. 2002, Cenergia Energy Consultants.
2. Energy efficient design and renewable energy use in educational buildings: The MEDUCA project, Ove C. Mørck & Jens O. Hansen. UNEP Industry and Environment. Vol. 23, No. 3, July – September 2000.
3. Frisk luft på energirenoveret skole, Ove Mørck & Ole Balslev-Olesen. VVS Danvak, 35. årgang, no. 4, marts, 1999.