Pilot study report:

Tånga
Falkenberg, Sweden

Åke Blomsterberg, J&W, ake.blomsterberg@jw.se
Åsa Wahlström, SP, asa.wahlstrom@sp.se
Mats Sandberg, HIG, mats.sandberg@hig.se

Photo by Christer Nordström

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# Pilot study report: Tånga

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1 GENERAL INFORMATION

1.1.1 Report date
2002-05-03

1.1.2 Principal researchers
Åke Blomsterberg, J&W Consulting Engineers; Åsa Wahlström, SP (Swedish National Testing and Research Institute); Mats Sandberg, HIG (University of Gävle); Jörgen Eriksson, SP.

1.1.3 Other participants
Christer Nordström, CNA architects; Helena Westholm, Efem architects; Arne Liljedahl, City of Falkenberg; Freddie Övegard, J&W.

1.1.4 Project title
Refurbishment of the Tånga school

1.1.5 Principal objectives
The main objective is to implement and demonstrate hybrid ventilation in a retrofit of a school. Other important objectives are:
- To support the design of the hybrid ventilation system, with advanced simulations.
- To design and integrate an advanced control system and an advanced BEMS.
- To design and integrate an advanced monitoring system, for monitoring the hybrid ventilation system.
- To performance monitor and evaluate the hybrid ventilation system, the energy use and the indoor climate.

1.1.6 Start date / End date
January 1998/December 2001

1.1.7 Number of man-hours
2100

1.1.8 Project approach
The school is included in an EC Thermie demonstration project MEDUCA (Model EDUCAtional buildings for integrated energy efficient design), started in 1997 and finished in 2001. The common work within MEDUCA was divided into three work groups: analysis, performance monitoring and dissemination. For the Tånga school this was expanded thanks to the work within IEA Annex 35 HybVent and resulted in:
Analysis supporting the design
- development of detailed performance requirements on indoor climate, energy use and building energy management system
- analysis of architectural features incl. Tenants consultation
- detailed energy simulations using advanced energy model, to optimise energy use and indoor climate
- detailed air flow simulation using a multi-zone air flow models, to optimise the combined natural and mechanical exhaust ventilation system
- daylight calculations to optimise daylight
- indoor environment questionnaire before and after retrofit

Performance monitoring
Detailed performance monitoring and evaluation were carried out to evaluate the effect of each energy saving measure in order to be able to conclude which of these measures are efficient. An
important objective was to evaluate the hybrid ventilation system with respect to ventilation (air flow rates, air change efficiency), IAQ; thermal comfort, use of electricity for ventilation and energy use for space heating.

The monitoring period was started with one time tests to discover if the installed heating and ventilation system was functioning as designed and to determine certain values (air flows in mechanical ventilation system and in hybrid ventilation system, thermal comfort, sound pressure levels, daylight levels etc). The actual monitoring phase, lasting 2 years, included continuous measurements of outdoor environment, indoor environment, energy use and system operation for one year. The monitoring system was integrated with the building energy management system (BEMS).

The above measurements were complemented with a standard indoor climate questionnaire to find out how the users perceive the indoor climate, heating and ventilation system and how the building is used (e. g. occupancy profiles). This was done before refurbishment and when the refurbished school had been used for one year.

1.1.9 Building selection
Almost 50 % of the schools in Sweden were built during 1961 and 1975. It is the group of schools with the highest use of energy i.e. 170 kWh/m²/year for heating.

The Tånga school was built in 1968 and is a complete school with 20 classrooms, 10 workshops, dining hall, kitchen, gymnasium and offices with a total floor area of 9350 m². The building and the HVAC technology are somewhat better than what is typical for the period. The school was due for renovation and the owners were interested in implementing energy saving features and hybrid ventilation.

1.1.10 References


Hellberg, A., etc., 1996, Att se, höra och andas i skolor – en handbok om inommiljö (To see, hear and breathe in schools - A handbook on the indoor environment), report from the National Board of housing, building and planning and the National Swedish Board of Occupational Safety and Health, Sweden.


1.1.11 Comments

2 TEST SITE DESCRIPTION

2.1 Geographic information

2.1.1 Location
The school is located in Falkenberg (longitude 12° 30’ E and latitude 56° 55’ N), on the west coast of Sweden, 100 km south of Göteborg.

2.1.2 Elevation (height above sea level)
10 m

2.1.3 Terrain; Site plan
The school is located in a mostly residential area. The immediate surroundings are flat with some scattered trees to the south. At some distance there are some residential buildings.

2.1.4 Orientation
See figure 3.2.

2.1.5 Comments

2.2 Climate information (Summary)

For the energy and climate simulation a climate data file representing a typical year for the west coast of Sweden, Göteborg 1988, was used. The file is available from SMHI (Swedish institutet for meteorology and hydrology). The weather file contains hourly values of: outdoor dry bulb temperature, outdoor humidity (kg/kg), diffuse solar and sky radiation on a horizontal surface, normal solar radiation, sky temperature. The format of the file is: I4, 3i3, 1x, f6.2, 1x, f5.4, 2(1x, f7.2), 1x, f6.2 representing year, month, day, hour, outdoor temperature, outdoor humidity, diffuse solar and sky radiation, normal solar radiation, sky temperature.

2.2.1 Location of meteorological station

2.2.2 % frequency wind speed versus wind direction
Average meteorological wind speed 3 m/s.

2.2.3 Air temperature
The average outdoor temperature for January is 1.6 °C and for July 16.1 °C. The annual average temperature is 7.2 °C. The temperatures are averages for the period 1961-90 for Halmstad, 30 km south of Falkenberg.

2.2.4 Degree day information
Yearly heating degree days 3325, based on an indoor temperature of 17 °C i.e. assuming that the difference between the actual indoor temperature and 17 °C is generated by internal gains. This standard procedure by the Swedish Institute for meteorology and hydrology (SMHI).

2.2.5 Daylight / insolation
The global solar radiation on a horizontal plane is 161.2 kWh/m² (July), 11.3 kWh/m² (January) and 957.9 kWh/m² (annual). The solar radiation levels are averages for the period 1961-90 for Göteborg, 100 km north of Falkenberg.

2.2.6 Cloud factor

2.2.7 Relative humidity & precipitation
N/a

2.2.8 Barometric pressure
N/a
2.2.9 Soil temperature
N/a

2.2.10 Other meteorological parameters

2.2.11 Comments

3 BUILDING DESCRIPTION

3.1 General description

3.1.1 Building name
Tånga

3.1.2 Building type
School for 7th – 9th grade.

3.1.3 History
The school is located in the city of Falkenberg and was built in 1968 containing 20 classrooms, 10 workshops, dining hall, kitchen, gymnasium and offices with a total floor area of 9350 m². The school consists of four buildings (A, B, C and D), all of them with two storeys. Building A contains a kitchen, a dining hall, offices etc., building B mainly classrooms, building C mainly workshops and building D a gymnasium. The building and the HVAC technology were rather typical for the period 1961-1975 (see table 3.1 and table 3.2). Some improvements were carried out in 1989 (new windows) and 1991 (added thermal insulation). The school needed a general renovation due to wear and tear.

Table 3.1 Building construction before refurbishment, Tånga school.

<table>
<thead>
<tr>
<th>Building component</th>
<th>Construction</th>
<th>U-value, W/m²K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>Flat with 25 cm mineral wool</td>
<td>0.15 (loose fill insulation was added in 1991)</td>
</tr>
<tr>
<td>Windows</td>
<td>Some double pane, mostly triple pane windows (installed in 1989)</td>
<td>3.1 and 2.0</td>
</tr>
<tr>
<td>Exterior walls</td>
<td>Bricks + 12 cm mineral wool</td>
<td>0.4</td>
</tr>
<tr>
<td>Interior walls</td>
<td>Bricks</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2 HVAC system before refurbishment, Tånga school.

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristics</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating system</td>
<td>Conventional radiators with thermostatic valves</td>
<td></td>
</tr>
<tr>
<td>Energy for space and hot water heating</td>
<td>District heating</td>
<td>Estimated specific use of electricity of is 3 kW/m³/s.</td>
</tr>
<tr>
<td>Ventilation system</td>
<td>Mechanical exhaust and supply ventilation without heat recovery in building B and C, in building A partly with heat recovery installed in 1993</td>
<td>Operating times is controlled by a timer set on start 7.00 and stop 17.00. The ventilation rate is 6 l/(s and person) in classrooms</td>
</tr>
</tbody>
</table>

3.1.4 Design philosophy for IAQ and thermal comfort, energy efficiency and other issues of concern

The overall use of electricity for ventilation in building B is to be reduced by installing a demand control hybrid ventilation system combining natural (passive stack and solar chimney) and mechanical (fan assistance) driving forces, instead of the existing balanced ventilation system without heat recovery. In building A and C the existing balanced ventilation systems will be upgraded to energy efficient ones. The demand controlled hybrid ventilation system should basically be an fan assisted passive stack ventilation system, where window airing is possible. In the classrooms the ventilation system should supply a basic ventilation rate during the lessons and then during breaks the ventilation can if necessary be forced. The idea is that breaks should take place regularly. CO₂ (and ev. Temperature sensors) for ventilation control are to control the ventilation, but with possibility for manual override. These sensors should enable the ventilation rates during the heating season to be lowered by 25 %. The users should be able to override the automatic control of the ventilation system. The users will be given user-friendly instructions of their possibilities to interact with the heating and ventilation system. The outdoor supply air is to be preheated by convectors below the windows.

There is to be no mechanical cooling system. Cooling should be achieved naturally by increasing the air flow through the passive stacks and/or window airing and night cooling controlled by the energy management system. To reduce high temperatures caused by sunshine appropriate shading devices should be installed. The daylighting level will be optimised by using glare control, daylighting reflectors etc. The materials (paint etc) of the interior surfaces will be chosen to optimise the indoor light climate. Energy efficient lighting devices (HF trafficent tubes combined with presence detectors) will replace the existing ones.

The following special performance specifications were developed, within the MEDUCA Thermie project, for the Tånga school.

The energy targets are to reduce the energy use for space heating from 140 kWh/m²/year to 75 kWh/m²/year and the use of electricity from 50 kWh/m²/year to 35 kWh/m²/year.
<table>
<thead>
<tr>
<th>Tånga school requirements on ventilation</th>
<th>Swedish national requirements on ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- outdoor air 0.35 l/(s m²)</td>
<td>0.35 l/(s m²)</td>
</tr>
<tr>
<td>- outdoor air 7 l/s/person (see also chapter 3.6.5)</td>
<td>7 l/s/person (recommendation)</td>
</tr>
<tr>
<td>- no recirculated air</td>
<td>no recirculated air</td>
</tr>
<tr>
<td>- air velocity within the occupied zone: winter &lt;0.15 m/s, summer &lt;0.25 m/s</td>
<td>winter &lt;0.15 m/s, summer &lt;0.25 m/s (recommendation)</td>
</tr>
<tr>
<td>- air exchange efficiency &gt;40 %</td>
<td>&gt;40 % (recommendation)</td>
</tr>
<tr>
<td>- airtightness of building envelope &lt; 1.6 l/(s m²) at 50 Pa</td>
<td>1.6 l/(s m²) at 50 Pa</td>
</tr>
<tr>
<td>- outdoor air intake located in order to minimize the influence of pollutants from cars and other outdoor sources</td>
<td></td>
</tr>
<tr>
<td>- indoor air outlet from the school located at a safe distance from the outdoor air intake, in order to prevent recirculation</td>
<td></td>
</tr>
<tr>
<td>- ducts should be accessible for cleaning</td>
<td>ducts should be accessible for cleaning</td>
</tr>
<tr>
<td>- particles &lt;60 µg/m³ (&gt; 5 µm)</td>
<td></td>
</tr>
<tr>
<td>- TVOC &lt;200 µg/m³</td>
<td></td>
</tr>
<tr>
<td>- carbon dioxide &lt;1000 ppm (indicator of IAQ) with normal occupancy</td>
<td>&lt;1000 ppm</td>
</tr>
<tr>
<td>- recommended relative humidity 30 – 60 % at normal indoor temperature</td>
<td></td>
</tr>
<tr>
<td>- formaldehyde &lt;50 microgram/m³</td>
<td></td>
</tr>
<tr>
<td>- no humidifier</td>
<td></td>
</tr>
<tr>
<td>- flexible ventilation system, which can be adapted to the needs of the occupants</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tånga school requirements on heat</th>
<th>Swedish national requirements on heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>With normal occupancy (valid for the occupied zone)</td>
<td>Directive operative temperature &gt; + 18 °C (recommendation)</td>
</tr>
<tr>
<td>- operative temperature between 20 °C and 26 °C with normal occupancy</td>
<td></td>
</tr>
<tr>
<td>- the vertical temperature difference between 1,1 m and 0,1 m above floor shall be less than 3 °C</td>
<td></td>
</tr>
<tr>
<td>- the surface temperature of the floor shall normally be between 19 and 26 °C</td>
<td>&gt; + 16 °C (recommendation)</td>
</tr>
<tr>
<td>- the radiant temperature asymmetry from windows or other cold vertical surfaces shall be less than 5 °C</td>
<td>Difference in directive operative temperature &lt; 5 K (recommendation)</td>
</tr>
</tbody>
</table>
### Tånga school requirements on noise

<table>
<thead>
<tr>
<th>Room</th>
<th>From HVAC</th>
<th>Swedish national requirements on noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office, meeting etc.</td>
<td>$L_{pAeq}$ dB</td>
<td>$&lt;35$</td>
</tr>
<tr>
<td>Classroom</td>
<td>$&lt;30$</td>
<td>$&lt;30$</td>
</tr>
<tr>
<td>Room (noise &lt;200 Hz)</td>
<td>From HVAC $L_{pAeq}$ dB</td>
<td>$&lt;50$</td>
</tr>
<tr>
<td>Classroom</td>
<td>From outside (traffic etc) $L_{pAeq}$ dB</td>
<td>$&lt;50$ (recommendation)</td>
</tr>
<tr>
<td>Room</td>
<td>From HVAC $L_{pAeq}$ dB</td>
<td>$&lt;35$</td>
</tr>
<tr>
<td>Office, meeting etc</td>
<td>$&lt;35$</td>
<td>$&lt;40$ (recommendation)</td>
</tr>
<tr>
<td>Classroom</td>
<td>$&lt;30$</td>
<td>$&lt;30$ (recommendation)</td>
</tr>
</tbody>
</table>

Airborne sound insulation between classroom and:
- other classroom, conference room $>48$ dB ($>40$ dB for wall with door) $>48$ dB (recommendation)
- corridor $>44$ dB ($>35$ dB for wall with door) $>48$ dB (recommendation)
- music room, assembly hall, fan room, kitchen, gymnasium, and the like with noisy activities $>60$ dB

Reverberation time, classroom 0.6 s (refers to room average 125-4000 Hz)

### Tånga school requirements on lighting

**Classrooms** 300 – 500 lux

**Corridor** >150 lux

### Tånga school requirements on Electricity

<table>
<thead>
<tr>
<th>Lighting</th>
<th>In general terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>- classrooms $&lt;13$ W/m²</td>
<td></td>
</tr>
<tr>
<td>- corridor $&lt;8$ W/m²</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ventilation</th>
<th>In general terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust only $&lt;1.0$ kW/m³/s</td>
<td></td>
</tr>
<tr>
<td>Exhaust and supply $&lt;2.0$ kW/m³/s</td>
<td></td>
</tr>
</tbody>
</table>

### Tånga school requirements on moisture

- dry construction materials i.e. wood $<18$ (weight-) % moisture content and concrete $<85$ % R.H. before application of floor covering.
- dry construction methods
- moisture safe constructions

### Swedish National requirements on noise

- Classrooms $300 – 500$ lux
- Corridor $>150$ lux

### Swedish National requirements on electricity

- Lighting
- Ventilation
- Exhaust only $<1.0$ kW/m³/s
- Exhaust and supply $<2.0$ kW/m³/s

### Swedish National requirements on moisture

- dry construction materials i.e. wood $<18$ (weight-) % moisture content and concrete $<85$ % R.H. before application of floor covering.
- dry construction methods
- moisture safe constructions
3.2 Building geometry & materials

3.2.1 Plan
See below a plan of the first floor of one of the wings of building B. On the plan is shown the inlets and ducts of the hybrid ventilation system. Also shown is the balanced ventilation system for the restrooms.

3.2.2 Elevation
See below the south façade of building B. Below the windows are shown the inlets of the hybrid ventilation system and on the roof the solar chimney.
3.2.3 Building form

The school consists of four different buildings:

A - with auditorium, dining hall, kitchen, offices. The building has two stories, is almost rectangular and has a flat roof.
B - with mainly classrooms. The building has two stories, is E-shaped and has a flat roof.
C - with mainly workshops. The building has two stories, is rectangular and has a flat roof.
D with a gym.

Buildings A, B and C are being retrofitted. The hybrid ventilation system will be installed in building B.

The height of building B is 7.5 m. The other buildings have a similar height.

3.2.4 Volume

Heated volumes:
Building A, 8628 m³
Building B, 12031 m³
Building C, 3672 m³

3.2.5 Floor area & materials

The gross floor areas:
Building A, 1363 m²
Building B, 3672 m²
Building C, 1096 m²
### Building A

<table>
<thead>
<tr>
<th>U-value</th>
<th>Area, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>0.34</td>
</tr>
<tr>
<td>Roof</td>
<td>0.12</td>
</tr>
<tr>
<td>Glazing</td>
<td>1.90</td>
</tr>
<tr>
<td>Floor</td>
<td>0.34</td>
</tr>
</tbody>
</table>

**Notes:**
- Including frame and casement.

### Building B

<table>
<thead>
<tr>
<th>U-value</th>
<th>Area, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>0.47</td>
</tr>
<tr>
<td>Roof</td>
<td>0.12</td>
</tr>
<tr>
<td>Glazing</td>
<td>1.76</td>
</tr>
<tr>
<td>Floor</td>
<td>0.34</td>
</tr>
</tbody>
</table>

### Building C

<table>
<thead>
<tr>
<th>U-value</th>
<th>Area, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td>0.41</td>
</tr>
<tr>
<td>Roof</td>
<td>0.12</td>
</tr>
<tr>
<td>Glazing</td>
<td>1.90</td>
</tr>
<tr>
<td>Floor</td>
<td>0.34</td>
</tr>
</tbody>
</table>

**Notes:**
- Including frame and casement.

### Building Materials

<table>
<thead>
<tr>
<th>Building</th>
<th>Wall</th>
<th>Roof</th>
<th>Glazing</th>
<th>Floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building A</td>
<td>6 cm brick + 12 cm mineral wool + 6 cm brick</td>
<td>25 cm loose fill insulation + 13 cm mineral wool + 2 cm wood</td>
<td>Double pane</td>
<td>2 cm mineral wool + 10 cm concrete</td>
</tr>
<tr>
<td>Building B</td>
<td>6 cm brick + 12 cm mineral wool + 6 cm brick</td>
<td>25 cm loose fill insulation + 13 cm mineral wool + 2 cm wood</td>
<td>Double pane, one of the three wings is retrofitted with low energy windows (U-value 1 W/m²K)</td>
<td>2 cm mineral wool + 10 cm concrete</td>
</tr>
<tr>
<td>Building C</td>
<td>6 cm brick + 12 cm mineral wool + 6 cm brick</td>
<td>25 cm loose fill insulation + 13 cm mineral wool + 2 cm wood</td>
<td>Double pane</td>
<td>2 cm mineral wool + 10 cm concrete</td>
</tr>
</tbody>
</table>

### 3.2.6 Ceiling height

The room height is 3.3 m.

### 3.2.7 Facades (external walls)

See chapter 3.2.5 Floor materials

### 3.2.8 Windows

See chapter 3.2.5 Floor materials
3.2.9 External doors or hatches
   Conventional Swedish doors

3.2.10 Number, volume and layout of rooms

3.2.11 Attic, basement, crawlspace

3.2.12 Interior walls, including moveable partitions

3.2.13 Interior doors and devices

3.2.14 Stairwells

3.2.15 Service risers

3.2.16 Comments

3.3 Air leakage data (type, location and crack length for each component)
The air leakage was not measured, but the building should be reasonably airtight taking into account type of construction including modern airtight windows.

3.3.1 Doors

3.3.2 Windows

3.3.3 Ventilation openings & stacks

3.3.4 Chimneys & flues

3.3.5 Communicating walls, such as cavity walls

3.3.6 Structural joints: sole-plate, ceilings, corners, skirting boards, vapour and air barrier treatments

3.3.7 Service routes: plumbing outlets, drains, electrical outlets, etc.

3.3.8 Other air leakage zones such as stairwells & service risers

3.3.9 Background leakage

3.3.10 Neutral pressure level

3.3.11 Comments

3.4 Wind pressure coefficients

3.4.1 Wind tunnel
The wind tunnel used was a building aerodynamic windtunnel of the closed-circuit type with a test section 3 m wide, 1.5 m high and 11 m long.

3.4.2 Simulation of the natural wind
The atmospheric boundary layer over outside of a town terrain was simulated by means of spires at the upstream end of the test section and an 7 m fetch of floor roughness, consisting of 40 mm cubes in a regular array with a density 10%. The height of the boundary layer was about 1 m.

3.4.3 Model
The model of the Tånga school was built in scale 1:200 and made by wood. The instrumented model was supplied with 130 pressure taps of 1.0 mm diameter.
3.4.4 Instrumentation and procedure

The pressure taps were connected by plastic tubes to a 48-port Scanivalve provided with a Druck PDCR22 pressure transducer. The time-mean pressures were determined by averaging instantaneous pressure values sampled with a frequency 10 Hz over a period of 30 seconds. The tests were carried out at a wind speed of approximately 11 m/s at the model rooftop level.

The dynamic pressure at that level, used at reference pressure for the pressure coefficients, was measured at the location of the instrumented model – with no model present – and calibrated against the dynamic free-stream pressure measured by a fixed pilot-static tube placed 1.5 m above the centre of the turntable. This tube was also used for the measurement of the static (reference) free-stream pressure.

3.4.5 Definition of the Pressure coefficient

The local pressure coefficient is defined as

\[ C_p = \frac{(p - p_0)}{q_0} \]

- \( p \) = local static pressure (time-mean) on building surface
- \( p_0 \) = static free stream pressure
- \( q_0 \) = dynamic free stream pressure at roof-top level; \( q_0 = \rho \cdot u^2/2 \)
- \( \rho \) = density of air.
- \( u \) = mean wind velocity at roof top level.

3.4.6 Location of the measuring points

The pressure was recorded at the ventilation inlets and at the outlets on the solar chimneys. On the facades (denoted by capital letters) the measuring points were located below the windows.
3.4.7 Recorded pressure coefficients

Below are two diagrams summarising all the recorded pressure coefficients.

Figure 3.2 Numbering of the location of the measuring points (Building B)
g is ground floor and f is first floor.
Figure 3.3 Average measured wind pressure coefficients as a function of wind direction.

Figure 3.4 Measured wind pressure coefficients as a function of wind direction for different facades and roofs. The numbering of the surfaces is given in figure 3.2.

3.5 Space heating
Energy for space and hot water heating is provided for by the district heating system of Falkenberg. Every room is heated by radiators or convectors with thermostatic valves.
3.6 Ventilation

3.6.1 Ventilation principle

The main principle of ventilation of building B school is passive stack ventilation. When stack effects don’t provide a sufficient differential pressure, assisting fans will maintain it at a sufficient level. In the Tånga school the outdoor air is distributed to the rooms through several air intakes below the windows in the exterior walls into a stub duct from where it is distributed to the room. The outdoor air is preheated by convectors under the stub duct. This should bring about mixing ventilation in the classrooms. The extract air is evacuated through air terminal devices below the ceiling on the opposite side of the room into vertical ventilation ducts. Local dampers are mounted both in the air intakes and in the exhaust duct of each room to allow individual control of the flow rate. To reduce the risk of air from going backward through the duct system all of the classrooms have their air intakes against the predominant wind direction.

To increase the stack effects, 6 m high solar chimneys (see also figure 3.7 and 3.8) have been installed on the roof with assisting exhaust fans and central dampers mounted in parallel. In addition to extending the length of the exhaust ducts, the solar chimneys consist of a flat plate solar air collector that heats the air in the chimney and increases the stack effect the last 6 m of the exhaust ducts. There are in total three solar chimneys, each one serving a separate part of the building. It is desirable to get equal stack effects on both floors and when needed having the exhaust fans working simultaneously. To achieve this the design is to reduce the cross-section area of the exhaust ducts from the first floor.

![Diagram](image)

*Figure 3.5 The principle of the new hybrid ventilation system with supply air through convectors in the facade and exhaust through the passive stack.*

Building A and C is ventilated by an efficient balanced ventilation system incorporating air-to-air heat recovery.
3.6.2 Components
Low pressure vents in the facade and low pressure exhaust air terminal devices.

3.6.2.1 Fresh air inlets
The outdoor air is distributed to the rooms through air inlets below the windows (three per classroom) in the exterior walls into a stub duct from where it is distributed to the room. The outdoor air is preheated by convectors under the stub duct. This provides mixing ventilation in the classrooms.

![Figure 3.6 The window sill in a classroom, where the outdoor air enters and is preheated by a convector. Notice the new upper window for bringing daylight to the inner parts of the room. Between the upper and lower window reflecting shelves will be installed. Photo by Christer Nordström.](image)

3.6.2.2 Fans
The fan is frequency controlled

3.6.2.3 Heat recovery
The requirements for energy conservation should for the building as a whole meet the national requirements. For the demand controlled hybrid ventilation system in building B this means that the mean energy consumption should be 50% lower than for a constant air volume (CAV) system without heat recovery, and where the air flow rates meet the national requirement during occupancy. As the actual system does not incorporate any means for heat recovery of the exhaust air, energy conservation for the ventilation system is instead achieved by using an advanced variable air volume (VAV) control system. It should also be noted that for a large part of the year there is no heat demand in a classroom when it is in use and therefore there is no need for heat recovery during periods of high air flow rates.

3.6.2.4 Filtration
As the school is situated in a quite clean environment it has been considered acceptable to use no filters to decrease the pressure drop through the air intakes. Louvers and mosquito net are however used to prevent rain and snow as well as insects and larger particles as leaves to enter the duct. The air intakes and the stub duct are easily accessible and can be cleaned by hand.
3.6.2.5 **Ducts**
Round sheet metal ducts.

3.6.2.6 **Room supply & extract devices**
See chapter 3.6.2.1

3.6.2.7 **Air exhaust outlets**
See figure 3.7 and 3.8 below, and figure 3.5.

*Figure 3.7 Photo of the solar chimney. Photo by Christer Nordström.*

*Figure 3.8 Cross section of the solar chimney.*
3.6.3 Frequency of operation, duration of operating cycle

3.6.4 Balancing report

3.6.5 Ventilation rate (outdoor airflow supplied by system)
The national requirements for minimum ventilation air flow rates is 7 l/s/person during periods of occupancy and 0.35 l/s/m² during periods of non-occupancy. The design air flow rate for the actual hybrid ventilation system is however only 4.5 l/s/person based on maximum occupancy in the classrooms. The arguments for this design value is that there seldom is maximum occupancy, children have lower metabolism than adults and that one for shorter periods of time can allow a higher CO2 level than 1000 ppm. However if the hybrid ventilation system for some reason does not give an acceptable indoor air quality it should always be possible to manually change to a third CAV operation mode with the fans running to ensure an airflow rate of 7 l/s/person based on maximum occupancy in the whole building.

3.6.6 Any recirculation between rooms due to HVAC system

3.6.7 Space cooling
Most windows can be opened. Night cooling is also possible.

3.6.8 Comments

3.7 Internal loads

3.7.1 Pattern of occupancy
The buildings are basically occupied 195 weekdays/year between 7.00 and 16.00. Typically classrooms are occupied by 25 pupils and on teacher i.e. 2.3 m²/person. All in all there is 413 pupils and a staff of 60 persons.

3.7.2 Lighting
Daylighting is improved in three classrooms in building B with upper windows and internal daylight reflectors, and improved existing skylights. Energy efficient lighting devices (installed electric power in classrooms 13 W/m², in corridors 8 W/m²) i.e. HF fluorescent tubes are installed in building A, B and C. The artificial lighting is automatically controlled by presence detectors i.e. switched off.

3.7.3 Other internal gains
The internal gains from persons and PC’s for a classroom have been determined to be 1.95 kW between 7.00 and 16.00 for weekdays.
The internal gains from the new HF fluorescent tubes have been estimated to be 12 W/m² weekdays between 7.00 and 16.00 for week 1 to 14 and week 41 to 52.

3.8 Control system and control strategy for ventilation and space conditioning

3.8.1 Type of system
A building energy management system (BEMS) controls the HVAC system of the Tånga school. The control of the school is characterised by a high degree of automatic control.

The BEMS operates in a Windows environment. The system communicates by analogue or digital telephone networks with respect to data transfer and alarm handling. The system allows logging in from external computers. The file format of monitored/measured data is standardised to enable file transfer of data to external environments. The system enables operation from both external terminals and the sub centrals in addition to the monitoring central. The system monitors the energy (district heating and electricity) use in detail (separately space heating, hot water, electricity for ventilation and lighting, the building is divided into three different parts). Temperature, relative humidity and CO2 in classrooms are also monitored.

The BEMS is designed to ensure good thermal comfort and good indoor air quality with a low use of energy. The system is also designed with a minimum of user control and only the technical manager of the school has access to the automatic control system. The air flow in the classrooms
with hybrid ventilation can however be adjusted by the teacher. The dampers in the inlets and outlets can be adjusted continuously by the teacher.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Automatic by BEMS</th>
<th>User Controlled</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation air flow</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Air quality control</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td></td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Reading of energy meters</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fire</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Shading</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
<tr>
<td>Solar chimney Control</td>
<td></td>
<td></td>
<td>✔</td>
</tr>
</tbody>
</table>

The BEMS system consists of a main computer and substations placed around the school. A diagram of the principle of the building services engineering system is shown in chapter 3.6.1.

The ventilation control system at the Tånga school is a combination of individual and central control. The space heating is mainly controlled by the outdoor temperature i.e. the forward temperature is controlled by the outdoor temperature. Each radiator and convector is also equipped with a thermostatic valve.

3.8.2 Parameters monitored

CO₂ content of the indoor air, and indoor, outdoor and solar chimney temperature.

3.8.3 Sensors

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Classrooms, 1,2 m above floor</td>
</tr>
<tr>
<td>Indoor air temperature</td>
<td>Classrooms, 1,2 m above floor</td>
</tr>
<tr>
<td>Outdoor air temperature</td>
<td>Roof</td>
</tr>
<tr>
<td>Solar chimney air temperature</td>
<td>Behind the solar collector, in the middle</td>
</tr>
</tbody>
</table>

3.8.4 Control strategy & internal design conditions

The ventilation control system in the Tånga School is a combination of individual and central control. A CO₂ sensor in each room controls the local inlet and outlet dampers. At a CO₂ level of 1000 ppm or less the local dampers are set to a minimum open position, controlled by a timer between 6 and 18 o’clock weekdays. During the first year of operation the dampers were also open for 10 minutes every hour during the remaining time. The minimum position can be varied as a function of the outdoor air temperature. At low outdoor temperatures and/or high wind velocities the airflow rate is therefore automatically limited to prevent excessive energy consumption and problems with dry indoor air. If the CO₂ level exceeds 1000 ppm this is indicated by a signal lamp in the classroom. At CO₂ levels above 1500 ppm the local dampers open 100 %. The teacher can however always override the local control system and manually change the position of the local dampers between 50 and 100 %.

In summertime the stack effect decreases. Below a certain temperature difference between the outdoor air and the air in the solar chimney the stack effect is no longer sufficient to maintain the design airflow rates. The central dampers are then closed and the exhaust fan simultaneously started. To avoid a high frequency of starting and stopping of the fan the dampers are opened and the fan is stopped at a somewhat higher temperature difference. When running, the exhaust fan is controlled by the pressure difference over the fan. The exhaust fan increases the pressure difference continuously as the temperature difference decreases. Window airing is possible at any time. In summertime the stack effect can also be utilised for night cooling of the building. At a centrally located control panel the personnel can if necessary override both the local and the
central control strategy and set a fan controlled design air flow rate of 7 l/s per person in the whole building.

The heating system of the school is connected to the district heating system of Falkenberg. The flow temperature to the radiator is controlled by the outdoor temperature. The flow through the radiator or convector is pre-set and each radiator is equipped with a thermostatic valve.

### 3.8.5 Lessons Learned

The results of the Tånga school show that it is possible to control the indoor climate in a school building with a hybrid ventilation system with a fairly simple automatic and manual control system and that the possibility to override the automatic control and manually operate the hybrid ventilation system is appreciated by the staff.

However improvements are possible and should be made. The control system should be reprogrammed e.g. by including a timer on the manual control of the hybrid ventilation. Other improvements would be to raise the ventilation rates of the ground floor to the level of the rates of the first floor. The building with hybrid ventilation has also a balanced mechanical ventilation with heat recovery for the restrooms operating continuously. This system might be replaced with a simple exhaust fan system controlled by a timer and thereby further reducing the use of electricity.

Better coupling between the control of the convectors and the temperature of the outdoor air entering the classroom would be desirable. At times there are problems with cold draught.

At times it would probably make sense if the automatic control of the hybrid ventilation was not influenced only by the CO₂ content in the classroom, but also by the air temperature of the classroom.

### 3.9 Pollutant sources

#### 3.9.1 Interior sources

#### 3.9.2 Exterior sources

Normal for a small city in Sweden i.e. no real problems.

### 3.10 Furniture, interior fittings

### 3.11 Costs

#### 3.11.1 Building

The total building costs (manufacturing and installation in year 2000) for the refurbishment of Tånga school are 23 000 000 SEK (2 556 kEuro), out of which the costs of the retrofit measures influencing the energy use and the indoor climate is 2 350 000 SEK (260 kEuro) for building B (hybrid ventilation) and 875 000 SEK (95 kEuro) for building C (new energy efficient mechanical ventilation) (see breakdown in table below).

#### 3.11.2 Plant

If the combined energy saving measures only are considered then the payback time would be 17 years for building B, assuming the price of electricity to be 1.00 SEK/kWh (0.11 Euro/kWh) and district heating 0.50 SEK/kWh (0.06 Euro/kWh). As this is a retrofit situation, in most cases the installation of the new ventilation would have been carried out due to wear and tear. This means that the marginal cost compared with a renovation to the original standard of the building should be considered i.e. how much more expensive are e.g. a new hybrid ventilation system compared with a traditional mechanical ventilation system without heat recovery. The payback time is likely to be much shorter in this perspective. Many of the energy saving measures also improve the indoor climate, which is difficult to price.
Table 3.3 Building cost (manufacturing and installation) for the Tånga school, price level of 2000.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
<th>Costs, SEK</th>
<th>Total, SEK/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low energy windows, building B</td>
<td>Exchange of old windows in one wing (1/4 of the floor area of building B)</td>
<td>149000</td>
<td></td>
</tr>
<tr>
<td>BMS</td>
<td>Additional cost for hybrid ventilation</td>
<td>672000</td>
<td>587 (65 Euro) total hybrid ventilation system</td>
</tr>
<tr>
<td>Hybrid ventilation, building B</td>
<td>Three solar chimneys</td>
<td>624000</td>
<td></td>
</tr>
<tr>
<td>Hybrid ventilation, building B</td>
<td>Duct system etc.</td>
<td>722741</td>
<td></td>
</tr>
<tr>
<td>Energy efficient balanced ventilation, building B</td>
<td>Exchange of old system</td>
<td>137158</td>
<td></td>
</tr>
<tr>
<td>Energy efficient balanced ventilation, building C</td>
<td>Exchange of old system</td>
<td>862000</td>
<td>787 (90 Euro)</td>
</tr>
<tr>
<td>Lighting</td>
<td>Additional cost for energy efficient lighting</td>
<td>50000</td>
<td></td>
</tr>
<tr>
<td>Solar shading, building B</td>
<td>Additional cost for shading devices</td>
<td>10500</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>3227399</strong></td>
<td></td>
</tr>
</tbody>
</table>

For building C the costs of the retrofit measures i.e. the new ventilation system and additional costs for energy efficient lighting, influencing the energy use and the indoor climate is 875 000 SEK (97 kEuro) (see breakdown in table above). The payback time for these two measures combined would be 13 years, assuming the price of electricity to be 1.00 SEK/kWh (0.11 Euro/kWh) and district heating 0.50 SEK/kWh (0.06 Euro/kWh). As this is a retrofit situation, in most cases the measures would have been carried out due to wear and tear.

Building C is not fully comparable with building B due to different floor areas and different use. The B building contains mainly classrooms, while the C building contains mainly workshops. As to the classrooms there are implications that the indoor climate is better in the classrooms of the B building, which is difficult to price.

A comparison between the costs of a retrofit with a demand controlled hybrid ventilation and renewed and improved existing mechanical ventilation controlled by a timer for this school, can only result in orders of magnitude. The chosen system for hybrid ventilation does not only have an impact on the energy use, but does also lower the sound level from ventilation compared with the new improved mechanical ventilation system. The hybrid ventilation system might also have lower maintenance costs.

The savings in energy use for space heating thanks to the demand and time controlled hybrid ventilation system and the time controlled mechanical ventilation systems with heat recovery are of the same order of magnitude in the Tånga school and so are the investment costs. The reference for the energy savings is a conventional balanced mechanical ventilation system without heat recovery. The advantage of the hybrid ventilation system is that it is demand and user controlled, that the use of electricity is very low and that the sound level from ventilation is lower, it is basically quiet. However sound from outside the building can be a problem.
3.11.3 Control system
See previous chapter.

3.12 Monitoring programme

3.12.1 Measurement Objectives
The objective is to evaluate the hybrid ventilation system with respect to ventilation (air flow rates, air change efficiency), IAQ; thermal comfort, use of electricity for ventilation and energy use for space heating.

3.12.2 Parameters to be measured, Measurement plan

<table>
<thead>
<tr>
<th>Monitoring</th>
<th>Monitoring period: 99-12-01 to 01-12-31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrumentation description: The monitoring system incl. sensors are integrated with the BEMS according to specially developed MEDUCA technical specifications.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measured quantity</th>
<th>No. of sensors</th>
<th>Frequency of data reporting</th>
<th>Measurement uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold water use</td>
<td>4</td>
<td></td>
<td>± 5 %</td>
</tr>
<tr>
<td>Energy use for space and tapwater heating</td>
<td>6</td>
<td>Every hour</td>
<td>± 5 %</td>
</tr>
<tr>
<td>Use of electricity (ventilation, lighting, pumps, wall outlets, miscellaneous)</td>
<td>20</td>
<td>Every hour</td>
<td>± 2 %</td>
</tr>
<tr>
<td>Air temperature in classrooms and ducts</td>
<td>70</td>
<td>Every 5 minutes</td>
<td>± 0.5 K</td>
</tr>
<tr>
<td>Relative humidity in classrooms in bldg B</td>
<td>6</td>
<td>Every 5 minutes</td>
<td>± 5 %</td>
</tr>
<tr>
<td>CO$_2$ in classrooms</td>
<td>30</td>
<td>Every 5 minutes</td>
<td>± 100 ppm</td>
</tr>
<tr>
<td>Air velocity in ducts in classrooms in bldg B</td>
<td>6</td>
<td>Every 5 minutes</td>
<td>± 0.1 m/s</td>
</tr>
<tr>
<td>Air flow direction in ducts in classrooms in bldg B</td>
<td>6</td>
<td>Every 5 minutes</td>
<td></td>
</tr>
<tr>
<td>Local and central damper opening</td>
<td>24</td>
<td>Every 5 minutes</td>
<td>± 5 degrees</td>
</tr>
<tr>
<td>Operational times manual/auto for ventilation systems in classrooms in bldg B</td>
<td>6</td>
<td>Every change</td>
<td>± 5 min</td>
</tr>
<tr>
<td>Outdoor air temperature</td>
<td>1</td>
<td>Every hour</td>
<td>± 0.5 K</td>
</tr>
<tr>
<td>Global horizontal solar radiation</td>
<td>1</td>
<td>Every 5 minutes</td>
<td>± 5 %</td>
</tr>
<tr>
<td>Relative humidity, outside</td>
<td>1</td>
<td>Every 5 minutes</td>
<td>± 5 %</td>
</tr>
<tr>
<td>Wind speed</td>
<td>1</td>
<td>Every 5 minutes</td>
<td>± 0.5 m/s</td>
</tr>
<tr>
<td>Wind direction</td>
<td>1</td>
<td>Every 5 minutes</td>
<td>± 5 degrees</td>
</tr>
</tbody>
</table>
3.13 Results from monitoring programme

3.13.1 Evaluation of indoor environment

The thermal comfort, the sound levels, the lighting and the indoor air quality fulfil the Tånga school requirements, which are more stringent than the Swedish national requirements.

The indoor temperature weekdays (6.00 – 18.00) during the period March 2000 to February 2001 (excl. June 15 – August 15 when the school is empty) varied between 20 and 24 °C in the six classrooms with hybrid ventilation, according to continuous detailed monitoring. Only a few days when the outdoor temperature was above 25 °C did the indoor temperature exceed 24 °C. The air temperature at floor level (measured at 0.1 meter height) has been above 19 °C except for a few days then the temperature was around 18 °C.

The vertical temperature difference fulfilled the requirement of less than 3 °C during the same period.

Detailed measurements of thermal comfort were carried out in two classrooms with hybrid ventilation during a warm and sunny spring week (average outdoor temperature of 13.0 °C). The operative temperature differed less than 1.5 °C from the air temperature and the radiant temperature asymmetry was less than 3.5 °C close to the windows and close to the door less than 0.5 °C, which is below the requirements of 5 °C. The operative temperature is between 20 °C and 22.0 °C, but can be up to 24 °C for short periods (20-30 minutes) at points close to the windows. The air velocity was less than 0.10 m/s close to the windows and less than 0.06 m/s close to the doors. The air velocity was also below the requirement of 0.15 m/s during measurement done when the outside temperature was 4 °C.

Measurements of sound in classrooms with hybrid ventilation show that the sound level caused by noise outside is acceptable except directly beside the air intakes that are facing the road, where 41 dB LpA was measured. The requirement on noise from HVAC was exceeded at 2 meters height in classrooms with balanced ventilated building (building C). However, most of the noise was due to other installations since nearly the same noise level was measured when the ventilation system was turned off.

The lighting was measured both before and after refurbishment. The lighting requirements are fulfilled except for a few cases where the installed lighting power per square meter is slightly too high. The daylight level and quality is in one case slightly less than what is reasonable to require. The clerestories in the corridors make a real improvement of the daylight.

Ventilation rates and indoor air quality have been measured in detail in six class rooms with hybrid ventilation, during the period March 2000 to February 2001. The CO2 concentration is mostly around 1000 ppm or lower and only for short periods (10-20 minutes) higher, but very seldom above 1500 ppm.

The relative humidity has been between 30 and 60% as required except at very cold days, below -6 °C, when the humidity has been 25%. The ventilation rates are higher in the classrooms on the first floor than on the ground floor. At fan assisted operation and fully opened dampers the ventilation flow reach the design values of 210 liter per second and without fan assistance the ventilation flow can reach the design value of 132 liter per second. At times the airflows are quite low but on the other hand the CO2 concentrations are above 1000 ppm only for short periods.

The particle concentration was measured during two days and as expected the concentration is nearly the same as the outside concentration since the air intakes has no filters. The concentration in the classroom that has air intakes close to the road is somewhat higher than in the classroom facing the yard.

A questionnaire before and after refurbishment shows that the personnel perceived the indoor climate as rather good already before the refurbishment with regard to air and ventilation, heat and temperature, daylight and lighting, sound and noise, and cleaning and well-being. Thanks to the refurbishment the indoor climate was further improved.

In general the indoor climate can be considered as approved if the frequencies of complaints for the answering alternative “often” is lower than 20 %. Before refurbishment 25 % of the pupils were often troubled by stuffy air and after 16 %. Before refurbishment 28 % perceived that it is was cold mornings, which now had been improved. After refurbishment draft from air supply has become a problem, 23 % of the pupils and the personnel after refurbishment compared with 2 %
before refurbishment, often perceive troubles. Cold and sunny winter days, problems with draft can occur from the air supply devices, when the dampers are fully open due to full classrooms.

Both pupils and teachers perceive daylight and lighting as good (very good according to 28 % of the students) already before the refurbishment, but perceive that it is even better (very good according to 45 % of the pupils) after refurbishment.

Both pupils and teachers perceive the sound level before and after refurbishment as fairly good. The number of pupils often troubled by sound from ventilation has however increased from one to five percent, which anyway is a very low frequency of complaints. For classrooms with air intakes towards the road the reason can be noise from trucks passing by. However, there are only one or two trucks passing each day and this can be taken care of with sound insulation of the air intakes. The air intakes are not equipped with any special silencer. To improve the sound attenuation should not be difficult.

The personnel appreciate that the hybrid ventilation system can be operated manually and they do so fairly often.

Active tracer gas measurements have been made during one week in February 2000 in the hybrid ventilated building, which shows the amount of outdoor air that is supplied to each room. The result was that the ventilation rate was low but on the other hand the building was at that time not yet properly operated. However, the measurements showed that the continuously monitored ventilation flow in the exhaust duct represents the ventilation in the classroom very well.

### 3.13.2 Control of ventilation and indoor climate

The indoor temperature weekdays (6.00 – 18.00) during the period March 2000 to February 2001 (excl. June 15 – August 15 when the school is empty) varied between 20 and 24 °C in the six classrooms with hybrid ventilation, according to continuous detailed monitoring. Only a few days, when the outdoor temperature was above 25 °C, did the indoor temperature exceed 24 °C.

Ventilation rates in the classrooms with hybrid ventilation can at times be low. The CO₂ concentration, however, is mostly around 1000 ppm or lower and only for short periods (10-20 minutes) higher, but very seldom above 1500 ppm.

![Figure 3.9 The CO₂ level and the damper position (% open) in one of the classrooms of the Tånga School during 10th of March 2001.](image)

As can be seen in the figure above, the dampers start modulating when the CO₂ level exceeds 1000 ppm and stops modulating when the level is below. The dampers are at least 50% open during daytime to ensure a minimum level of fresh air. During the night and weekends, the dampers are opened 10 minutes every second hour.
Figure 3.10 The CO2 level and the damper position (% open) in one of the classrooms of the Tånga School during 25th – 29th April 2000.

The figure above shows a number of occasions when the control is manually overridden. The figure also shows the occasions discussed above when the dampers are opened outside working hours.

Figure 3.11 Air flows and fan operation for one of the classrooms in the Tånga school during a week in September 2000.

The figure above shows that it is difficult to reach the required levels of airflow during hot periods.
Figure 3.12 shows how the fan is controlled by the difference between the chimney and outdoor temperature.

The staff is satisfied with the indoor climate in the classrooms and particularly with the fact that the ventilation system is quiet. The staff is pleased that the system can be operated manually and they are often using the possibility.

A few times problems with draft from air intakes have occurred during very cold winter days, when the dampers are fully opened due to fully occupied classrooms.

3.13.3 Evaluation energy use

The actual energy use for space heating of the school (building A + B + C) after refurbishment is somewhat higher than predicted (expected), 114 kWh/m²/year compared with 80 kWh/m²/year. The explanation is found looking at the individual buildings. In building A additional heat recovery was never installed in the ventilation system. For building B the expectations should be met if the ventilation rates are lowered during nights and weekends. During the first year of operation the dampers of the hybrid ventilation system were fully open for ten minutes every hour during nights and weekends due to airing of building damp. For building C the expectations are even exceeded due to better efficiency than expected.

Table 3.4 Normalized energy use for space heating for building A, B (new balanced heat recovery mechanical ventilation for the restrooms and hybrid ventilation for the rest of the building) and C (new balanced heat recovery mechanical ventilation) of the Tånga school, kWh/m²/year, climate Göteborg 1988.

<table>
<thead>
<tr>
<th>Before refurbishment¹</th>
<th>Predicted for after refurbishment¹</th>
<th>Actual for after refurbishment¹²</th>
<th>Conv. new bldg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>294</td>
<td>85</td>
<td>133</td>
<td>153</td>
</tr>
</tbody>
</table>

¹ Calculated values, where the calculation model agrees with monitored values
²58 will be achieved according to calculations, if the ventilation rates are lowered during nights and weekends
The electricity use of fans are lowered in all buildings, but building A, where nothing was changed. For building B and C the expectations were exceeded thanks to a conservative prediction and better than expected performance. The prediction for the building B did not really take into account the potential of hybrid ventilation. The prediction was based on an energy efficient demand controlled mechanical ventilation system.

The electricity use for lighting has been reduced to a level lower than the predictions.

Table 3.5 Annual use of electricity (kWh/m²). Tånga school, for: 2000-2001

<table>
<thead>
<tr>
<th>Building</th>
<th>Before refurbishment¹</th>
<th>Predicted for after refurbishment</th>
<th>Actual for after refurbishment</th>
<th>Conv. new bldg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td> </td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Lighting</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Operation</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

¹ estimated from measurements of the total use of electricity for the whole school
² 0.5 represents the hybrid ventilation fans, 10 also includes the balanced heat recovery ventilation system for the restrooms and the fans for the fume cupboards.

Overall the energy use for space heating has been reduced by 20 %. For building B the reduction is 30 % and for building C 50 %. The two buildings are not completely comparable, as the area and type of activity are different. Building B has primarily classrooms and building C workshops. The overall electricity use for ventilation has been reduced by 55 % and the overall electricity use for lighting by 45 %.

3.14 Lessons Learned

The overall reduction in energy use for space heating is 20 % i.e. for building A, B and C combined. For building B (with new demand controlled hybrid ventilation without heat recovery) the savings is 30% and for building C (with new time controlled mechanical ventilation with heat recovery) 50%. The energy use for space heating of a building like Tånga school can be of the same order of magnitude for demand and time controlled hybrid ventilation and time controlled mechanical ventilation with heat recovery. The use of electricity for ventilation will be lower with hybrid ventilation and so will the sound level from ventilation. The sound level from outside was however higher in the Tånga school and should preferably be lowered by designing and installing sound absorbers in the outdoor air vents of the hybrid ventilation system. The control system should be reprogrammed e.g. by including a timer on the manual control of the hybrid ventilation. Other improvements would be to raise the ventilation rates of the ground floor to the level of the rates of the first floor. The possibility to manually operate the hybrid ventilation was appreciated by the staff. The building with hybrid ventilation has also a balanced mechanical ventilation with heat recovery for the restrooms operating continuously. This system should be replaced with a simple exhaust fan system controlled by a timer and thereby further reducing the use of electricity.

The overall reduction in use of electricity for ventilation is 55 % and the overall reduction in use of electricity for lighting 45 %. The reduction in use of electricity for ventilation in building B was 55 % (but could be 95 %) and in building C 70 %.
The indoor climate was improved. However, better coupling between the control of the convector and the temperature of the outdoor air entering the classroom, would be desirable. At times there are problems with cold draught.

At times it would probably make sense if the automatic control of the hybrid ventilation was not influenced only by CO₂ content in the classroom, but also by the air temperature of the classroom.

The overall energy savings do not pay for the whole investment. However the renewal of the ventilation system is mostly due to wear and tear and the indoor climate is improved, which is difficult to price. The energy savings can most likely pay for the marginal cost compared with a traditional refurbishment.