VENTILATION TECHNOLOGIES IN URBAN AREAS

19TH ANNUAL AIVC CONFERENCE
OSLO, NORWAY, 28-30 SEPTEMBER 1998

MODERN PASSIVE STACK VENTILATED SCHOOLS – EVALUATION OF VENTILATION AND MOISTURE CONTENT

Åke Blomsterberg[1], Eva Sikander[2] and Svein Ruud[2]

[1] J&W Consulting Engineers
Box 857
S-21120 Malmö
SWEDEN

[2] Swedish National Testing and Research Institute
Box 857
S-50115 Borås
SWEDEN

Synopsis

The aim has been to determine ventilation rates and risk of moisture damage in three modern schools with passive stack ventilation. The users are supposed to control the ventilation by using the lantern windows and the outdoor air is assumed to enter through an underground duct. The paper presents results, analysis and conclusions from the performed measurements and calculations.

The ventilation rates are sometimes low and vary with the use of the windows in the facade and the lantern. It is, however, always possible to arrive at a sufficient ventilation rate. The supply air flow through the underground duct can, without a supply fan, be low and even go backwards during warm weather. To obtain desired ventilation rates and energy conservation the building must have a good airtightness.

High relative humidities and even periods with condensation occur in the underground supply duct during spring and summer. Microbial growth has been found in two of the schools. Two important factors are choice of material and cleaning, where the knowledge is insufficient today. Moisture and microbial growth have been found in the roofs. The leakage paths, supply of moisture indoors and an interior pressurization have contributed. In order to reduce the risks the building must have a good level of airtightness.

1. INTRODUCTION

Natural ventilation (passive stack ventilation) is today a permitted ventilation system in new buildings according to the building codes in the nordic countries. The interest for passive stack ventilation is substantial in the nordic countries today. Apparently there is a resistance to mechanical ventilation systems among many architects and users. The arguments for and against are many. An important problem with passive stack ventilation is that its function is very dependent upon the current weather, which means that the user must agree to the fact that the indoor air quality and indoor comfort will very much depend upon the user's use i. e. opening and closing windows, controlling air inlets etc..

Passive stack ventilation can, but does not have to, mean risks. At low ventilation rates there is always a risk for insufficient indoor air quality and high moisture levels. If the upper part of a building is pressurized moist air can flow to the outside through air leakage paths and cause condensation and damage. This can also occur in buildings with mechanical ventilation.

During the last couple of years many passive stack ventilated schools have been built in Sweden. Most of them have a supply of outdoor air through underground ducts. In spite of the fact that this technique has been introduced in a number of projects the theoretical background is insufficient. The practical application of the technique does not seem to be founded on any extensive technical research and development work.

If the outdoor air enters the building through an underground concrete duct, the indoor air quality is at risk. Summer conditions mean that warm moist air can be cooled and condense in the duct. This condensation can cause microbial growth, which will impair the air quality.

The aim of this investigation has therefore been to determine ventilation, pressure conditions, CO_2-levels and risk of moisture damage (Blomsterberg 1997) for passive stack ventilated schools with underground supply ducts.

2. THE SCHOOLS TESTED

The investigation was carried out in three schools with similar design principles of building and ventilation system (see table 1). The differences are different designs of the underground supply duct, with or without supply fan, with or without vapour barrier of plastic foil.

Table 1 Description of investigated schools.

School	Year of construction	Location	Ventilation	Remarks
Å	1995/96	Western Sweden	Passive stack with lanterns, supply air through concrete ducts (crawl space) under the entire building	4 classrooms, no plastic vapour barrier
Y	1993/94	Southern Sweden	Passive stack with lanterns, supply air through concrete ducts (crawl space) under the building, supply fan for cooling, mechanical exhaust from WC	4 classrooms, no plastic vapour barrier
Z	1994/95	Western Sweden	Passive stack with lanterns, supply air through concrete ducts (with room height) under the building, supply fan for cooling, mechanical exhaust from kitchen and dining hall	8 classrooms

The outdoor air to the Z-school enters the building at the roof ridge through a vertical shaft. In the other schools the outdoor air enters through an underground concrete pipe, which ends up in the concrete duct under the building. The purpose of the underground duct is to be able to cool the supply air during summer and preheat during winter i. e. most of the air should go this way (Andersson 1995, Andersson 1996).

The ventilation system relies on that the users ventilate according to the actual need. The idea is that the user shall control the ventilation using the lantern windows. In some classrooms the control is automatic.

The room height is higher than in most modern schools i. e. the room volume per pupil is bigger. This larger volume acts as a ventilation buffer. The total air flow which has to be supplied is the same independent of room volume, the ventilation can however be postponed in time. This is true if the ventilation efficiency is not influenced by the room volume.

3. METHODS

The project was started with an ocular inspection of the building and the building services installations. Then measurements were carried out during a summer and a winter period:

- CO_2-concentration and air temperature in classrooms with lesson going on
- Airtightness combined with determination of the location of the leakage paths. This measurement was carried out at one occasion to document the quality of the airtightness.
- Continuous recording of the relative humidity in the underground duct, in the roof construction, in a classroom and outside
- Control of microbial growth in the underground ducts and pipes, and inside the roof
- Passive tracer gas for the determination of average ventilation rates for a couple of weeks

In order to generalize the measuring results numerical simulations of the ventilation rates were carried out, using a multi-zone air flow model, COMIS (Feustel 1990, 1995). A parametric study was made, where the following parameters were varied: temperature, wind, use of windows (in the facade and the lantern), and airtightness.

4. RESULTS AND DISCUSSION

4.1 Ventilation

The Å-school and the Z-school have a very varying ventilation rate depending upon the use of the windows in the facade and the lantern. Sometimes the ventilation is low (less than 3 l/(s and person). In the Swedish building code 7 l/(s and person) is recommended and 0.35 l/(s and m²) is required. The requirement is usually fulfilled in the Z-school (see table 2), but not always in the Å-school (see table 3).

Table 2. Measured average ventilation rates in the Z-school, 21 May - 5 June, 1997. The average outdoor temperature was + 13 °C, with a minimum of 0 °C and a maximum of + 31 °C. The average indoor temperature was + 20 °C , with a minimum of + 18 °C and a maximum of + 22 °C. The wind speed (10 m above ground) varied between 0 m/s and 7.9 m/s, with an average value of 1.7 m/s. The classrooms have an floor area of 58 m².

	Day				Night + weekend	
Room	Air changes/h	l/(s m²)	l/(s person)	l/s	Air changes/h	l/s
Cloak-room, A124						
Group-room, A129						
Classroom, A130	1.07	1.17	7	68	0.15	10
Meeting room, A131	1.29		7	75	0.26	15
Workshop, A132						
Meeting room, A133						
Cloak-room, A134						
Classroom, A135	0.43	0.47	3	27	0.24	15
Group-room, A136						
Total			171			40

Table 3. Measured average ventilation rates in the Å-school, 22 May - 6 June, 1997. The average outdoor temperature was + 14 °C, with a minimum of 4 °C and a maximum of + 29 °C. The average indoor temperature was + 21 °C , with a minimum of + 18 °C and a maximum of + 23 °C. The classrooms have an floor area of 76 m².

Rum	Day				Night + weekend	
	Air changes/h	l/(s m²)	l/(s person)	l/s	Air changes/h	l/s
Classroom, 4	0.18	0.24	2	18	-	-
Classroom, 12	0.34	0.46	4	35	0.22	23
Classroom, 17	0.36	0.49	4	37	0.07	7
Classroom, 23	0.17		2	17		
Summa exkl. 4				89		30

In the Z-school most of the time most of the outdoor air enters through the underground duct. At mild/warm weather the outdoor air enters through the underground duct thanks to the supply fan, the air flow depends upon the capacity of the fan. Without a fan air can even leave the building through the underground duct. In the Å-school half of the outdoor air enters through the underground duct (see table 4). This school has no supply fan. Besides at times a fairly big air flow leaves the building through the underground duct as well.

Table 4. Measured average outdoor air flow rates in the Å-school, 22 May - 6 June, 1997. The average outdoor temperature was + 14 °C, with a minimum of + 4 °C and a maximum of + 29 °C. The average indoor temperature was + 21 °C, with a minimum of + 18 °C and a maximum of + 23 °C.

	Diurnal	Day	Night + weekend
Air flow underground duct, l/s	89		
Total air flow, l/s	152	122	164

With this type of ventilation system the air flow can be too low if the windows in the lantern and the facade are closed. This is true above all when warm weather is prevailing. By opening windows in the lantern and the facade in a correct way there is always the possibility to obtain a sufficient ventilation rate. The user is to a great extent responsible for the ventilation, if there is no automatic control. The alternative to control the ventilation automatically often means a complicated control system, as there are many different modes of operation.

The ventilation is to a great extent influenced by wind when the weather is mild/warm. Above all the lantern must be designed and used in a correct way, so that wind and temperature driving forces do not counteract each other.

The air flow in the underground duct can be very low and even go in the wrong direction above all for warm weather. In order to guarantee that the air flows in the right direction a supply fan is needed for this kind of weather. If the supply fan is used during winter this means big risks for moisture damage in the roof construction.

If the windows in the facade and in the lantern are open, then there is a risk that the air flow through the underground duct will be very low (see table 5). With closed windows in the facade the air flow through the underground duct increases with the leakiness of the building envelope. The lowest adjustable ventilating air flow increases with increasing leakiness and can become too big during cold weather and with no one in the building i. e. nights and weekends. To obtain the correct air change rate and a low use of energy the building has to have a good level of airtightness.

Table 5. Calculated air flow rates with fan off, classroom A130, for an outdoor air temperature of + 20 °C and with a measured airtightness of 13.5 $m^3/(m^2h)$ @ 50 Pa. P-duct = percentage of outdoor air through the underground duct. The flows have been calculated for different wind speeds and directions.

	Lantern and window open			Lantern open and window closed			Lantern and window closed		
	Total, l/s	Duct, l/s	P-duct, %	Total, l/s, (l/sm^2)	Duct, l/s	P-duct, %	Totalt, l/s, (l/sm^2)	Duct, l/s	P-duct, %
NE 5 m/s	347	81	23	124	95	76	32 (0.55)	31	96
E 5 m/s	328	60	18	164	73	44	18 (0.31)	18	98
SE 5 m/s	371	66	18	296	43	14	28 (0.48)	24	85
S 5 m/s	454	47	10	339	0	0	22 (0.38)	13	59
SW 5 m/s	132	0	0	47 (0.81)	0	-1	12 (0.21)	-1	-7
No wind	153	0	0	35 (0.60)	18	51	0	0	0

The CO_2-level, which mainly is an odour indicator, can at times exceed the recommended level of 1000 ppm in the examined classrooms. In most cases this can be avoided by using the windows, manually or automatically.

An important condition for passive stack ventilated schools is that the building and its fittings and furniture does not emit any irritating substances, as there is a risk that the ventilation can be low. The main purpose of the ventilation is to ventilate for the users i. e. to remove pollutants caused by the users and of course provide the users with a sufficient amount of fresh air.

An indoor environment questionnaire in seven schools with similar passive stack ventilation systems (Hult 1997) shows that most of the seven schools 'have a relatively well perceived indoor environment and health, in spite of the fact that the air changes are lower and the CO_2-levels are higher than in schools with balanced mechanical ventilation'.

4.2 Moisture

The roofs of the three schools have in many measuring points been supplied with moisture, probably from the inside due to moisture diffusion combined with moisture convection. Air leakage of the upper parts of the building combined with a supply of moisture and an interior pressurization during certain periods will create risks for moisture damage, which also the measurements show. Damage as microbial growth have been discovered in some measuring points in the three schools. For the Z-school this probably occurred during the construction.

As an interior pressurization can occur during certain periods, the airtightness of the building envelope is crucial for avoiding damage caused by moisture convection. This kind of damage can occur also in buildings with other types or ventilation system. Buildings with mechanical supply and exhaust ventilation can experience interior pressurization due to partly clogged supply ducts. Buildings with only mechanical exhaust are best in this respect.

The values of relative humidity in the underground ducts during late spring and early summer as measured in this project show that 80 % is at times exceeded. Even periods with condensation have been measured in one of the schools. The risk of microbial growth on materials sensitive to moisture obviously exist. Damage as microbial growth has been discovered in two of the schools. The seriousness of this has to followed up during a longer period of time, a couple of years. Two important factors in this context is choice of material and cleaning. Regular cleaning must be possible and must be carried out. The knowledge of these measures is insufficiently known today.

5. CONCLUSIONS

- The ventilation and thereby the indoor air quality varies with the weather and the users use of the windows in the facade and in the lantern. It is usually possible to arrive at sufficient ventilation rate.
- As interior pressurization can occur during winter there is a risk of moisture damage in the roof construction caused by convection. In order to lower the risks the building has to have a good level of airtightness.
- The supply air flow through the underground duct can, without a supply fan, be low and even go backwards during warm weather.
- There is a risk of microbial growth in the underground supply duct during spring and summer. Two important factors are choice of material and cleaning, of which the knowledge today is however insufficient.
- An important prerequisite for obtaining a desired ventilation and energy conservation is that the building has a good level of airtightness.

During the last couple of years passive stack ventilated schools have been built and additional ones are being planned in Sweden. The technique is argued for by architects, but also engineers. The knowledge about all aspects of passive stack ventilation in modern well insulated school is today not sufficient, which this investigation has shown.

The following R&D-need exists:

- To clarify the function with respect to
  -ventilation efficiency
  -temperature and energy consequences
  -quality of supply air
  -design of outdoor air intake
- To analyze construction and life cycle costs (not commented upon in this investigation)
- To identify critical factors for good function and economy in combination
- To write an easily understandable handbook showing possibilities and risks with passive stack ventilation
- To provide design tools for the designing architect and engineer concerning passive stack ventilation

6. ACKNOWLEDGMENT

This project was initiated by the Swedish National Testing and Research Institute and funded by the Swedish Council for Building Research, The Development Fund of the Swedish Construction Industry, the Municipality of Borås and Kungsbacka.

7. REFERENCES

Andersson, T., 1995. Ventilation adapted to the seasons (in Swedish). Bygg & teknik nr 5/95.

Andersson, T., Gillbro, H., 1996. Fredkulla and Riseberga school – two of many modern passive stack ventilated schools (in Swedish). Bygg & teknik nr 6/96.

Blomsterberg, Å., Sikander, E., Ruud, S., 1997. Modern passive stack ventilated schools – Evaluation of ventilation and moisture (in Swedish). Swedish Council for Building Research, Anslagsrapport A13:1997.

Feustel, H. & Raynor-Hoosen, A., (ed.), 1990, COMIS - Fundamentals, LBL, Berkeley, USA.

Feustel, H., Smith, B., 1995. COMIS 2.1 - User's Guide. Lawrence Berkeley Laboratory, Berkeley, California, USA.

Hult, M., 1997. Schools with ventilation using passive stacks – examples of solutions and results (in Swedish). Swedish Council for Building Research, Anslagsrapport A11:1997.