Typologies of Hybrid Ventilation in Schools

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SUMMARY

This article is the result of a study on how to close the “gap” between architects and a building service consultant. Closing is necessary in order to be able to create both a better indoor climate and an interesting architectural environment. Especially for schools with natural air supply some basic physical principles of draught prevention should be checked in an early stage of the design or commissioning process. Air supply designs for the most common architectural problems should be easily available. Most of the presented design options have been evaluated with measurements and CFD-simulations. For schools with natural air exhaust (overpressure system) the results of an on-site test are presented. This system can be applied even in existing schools with single glass windows and a monumental façade.

INTRODUCTION

In The Netherlands and other European countries the air change rate in schools increases in order to prevent health problems of students. The minimum air supply in The Netherlands is 7 l/s (= ca. 25 m³/h) per student. Due to the high occupancy (generally 1 person at 2 m² = 3.5 l/sm²) prevention of draught needs much attention. Architects need ready-to-use ventilation design concepts for schools because of:
- A lack of knowledge of draught prevention,
- Individual architectural opinions,
- A low budget.

A research project is starting in The Netherlands to design options of natural, mechanical or hybrid ventilation. These systems for new or refurbished schools will be presented in a comprehensive way in a Dutch design guide and can be integrated in a REHVA-guide dealing with healthy schools in the near future. In this guide higher air change rates will be discussed as well: 35 m³/h and 45 m³/h per student = 4.9 - 6.3 l/sm².

Hybrid ventilation may have different meanings. Generally it comprises a low pressure natural ventilation system which can be supported by fans when necessary. However, a combination of natural air supply with mechanical exhaust or natural air exhaust with mechanical supply can be considered as hybrid as well.

Sometimes the building service consultant has to make design proposals for the architect. On the other hand architects can stimulate the creativity of a building service consultant to find a specific solution for a specific problem..

METHODS

The methods used during my study and subjects discussed with architects are:

a. Research of physical principles
b. Architectural research
c. Airflow measurements
a. Research of physical principles
The research provides a variety of options to deal with air flows and heat transfer:
- Mixing of cold air
Mixing of cold air with the surrounding warm air in order to prevent draught, without or with a false ceiling.
Research at the Delft Technological University [1] shows that it is possible to prevent draught (3.5 ls/m²) by means of natural air supply without a ceiling. When the air is supplied just beneath the ceiling with an Archimedes-number of 0,001 (figure 1, II) the DR-value will be maximal 20%. However, it is possible to have an acceptable thermal comfort as well with other Archimedes numbers when the air will be supplied with a wide air inlet with the same size as the width of the room. When the velocity is low (figure 1, I) or very high (figure 1, III) the air velocity above the floor will increase. Concrete core and (floor) heating can - to a certain extend - compensate draught-risks by higher local operative temperatures near the floor.

![Figure 1: Air supply options without a false ceiling.](image)

The integration of the air inlet at the ceiling needs much attention [2, 4], because of the fact that the narrow inlet-slit should be close under the ceiling.

In case of a false ceiling there are more possibilities of draught prevention and integration of an air inlet into the façade is more easy [4].

- An outlet via a double window
There is no information of the combined performance of an air outlet and a double window. The thermal qualities of the window and air flows are analyzed with CFD-simulations. The outlet system is tested in a police academy in Apeldoorn by measuring the air flow and pressure differences during the heating season.

- Heating systems
The most common heating systems are a radiator under windows, floor or concrete core heating and preheating of air of an air inlet. It is very important to understand the difference of the convection flow characteristic of radiator heating and floor heating. This has been evaluated with CFD-simulations (Phoenics, Flair).

b. Architectural research
Two systems are discussed:
1. Systems of natural air supply, mechanical exhaust and several combinations with ceilings for three different façade typologies (positions of windows).
After analysing the most general typologies of façades, design principles for architects are developed to support their design processes.
2. A system of natural air exhaust via a double window and mechanical air supply for existing monuments. A design option has been developed for an existing building in which physical, aesthetic, practical and economic requirements are combined.

c. Airflow measurements and CFD-simulations
The presented natural air supply and natural exhaust systems have been measured or simulated. The performance of the outlet system has been evaluated with the following equations:

The maximum air velocity through a vent with a very low air resistance is [1]:

\[ U_{\text{max}} = \sqrt{\frac{2 \cdot \Delta P}{\rho}} \] (1)

Where \( U_{\text{max}} \) = the maximum air velocity (m/s), \( \Delta P \) = the pressure difference in (Pa) and \( \rho \) is the volumetric mass of air (kg/m\(^3\)).

For instance, the maximum air velocity at 4 Pa and 20°C will be 2.6 m/s. The measured air velocity of the system can be divided by the maximum air velocity. This is the airflow-efficiency, \( \varepsilon_{\text{airflow}} \) (-):

\[ \varepsilon_{\text{airflow}} = \frac{U_{\text{measured}}}{U_{\text{max}}} \] (2)

The air velocity is measured with a hot wire anemometer (Envic AFT-1D, 0-10 m/s, 3% tolerance) in the opening of the air exhaust system. The pressure difference is measured at both sides of the window (SETRA 267, +50 - -50 Pa, 1% tolerance). The measurements have a sample time of 1 minute.

RESULTS

a. Physical principles
In case of a false ceiling there are other options to prevent draught (figure 2). In this situation the warm air from the room and the heat from the concrete ceiling is used to warm up the supplied cold air. The false ceiling has a large surface so there is more time for the cold air to mix with the warm air.

Figure 2. Presentation of some physical principles of draught prevention and promotion of mixing of cold and warm air flows, making use of a “common”-air inlet.
Figure 3. Presentation of the physical principles and comfort qualities of the system of figure 2. Draught is prevented by the false ceiling. Cold downward air flows from the air inlet are prevented by a “spoiler” connected to the air inlet.

Experience shows that a lot of discussions with architects are necessary to integrate this option in their specific design. Generally it is necessary to make draught problems visible for architects underline the draught-problem (figure 4).

Figure 4. Presentation of local thermal discomfort of the system of figure 7b.

**b. Architectural research**

Some of the most common systems of natural air supply used by architects in The Netherlands are presented with the following figures:

Figure 5. a) Air supply close to the ceiling, b) Air supply in combination with a false ceiling
An example of how architects try to integrate this knowledge in their design details is presented in figure 8:

Figure 8: Two examples of air inlets details from different Dutch architects. The supplied air can be transported via the zone above a false ceiling (system III B, figure 7).

c. Airflow measurements and CFD-simulations

Results are design options of:
- A self regulating natural air exhausts system.
- False ceilings, related to thermal and acoustic parameters.
- Different heating systems: Concrete core or radiator heating and options of preheating supplied air.

An example of a self regulating natural air exhausts system is given below:
For a monumental building - the police academy in Apeldoorn - an air outlet system has been tested. In this case the air outlet of a self regulating vent is combined with a double window system (figure 9). Some advantages are:
- reduction of the amount of ducts in the building
- reduction of fan energy
- prevention of downdraught by increasing the temperature of the glass at the inner side
- reduction of infiltration of cold outdoor air

CFD-simulations show that a high position of the outlet is most favourable to prevent downdraught: the temperature of the window at the room side rises and the cold air between the windows cannot flow back into the room.

![Figure 9](image)

Figure 9: Presentation of the principle of a self-regulating air outlet (system 1, table 1) and a picture with the outlet at the upper side of the window.

The self regulating system prevents the wind to influence the airflow too much. Moreover, when the air supply fan is shut off, the heat loss due to ventilation is small (figure 10 and table 1).

![Figure 10](image)

Figure 10: Measurement results of air outlet system 1
Table 1. Comparison of two natural air outlet-systems (1.72 m long, opening ca. 1.38 m long) with a repulse valve combined with a double window system. The measurements of system 1 and 2 are executed at the same time in a different window in the same classroom (Apeldoorn, 17-25 November 2005)

<table>
<thead>
<tr>
<th></th>
<th>System 1</th>
<th></th>
<th>System 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air velocity (m/s)</td>
<td>Pressure difference (Pa)</td>
<td>Flow (m³/h)</td>
<td>Air flow efficiency (-) System</td>
</tr>
<tr>
<td>average</td>
<td>1.89</td>
<td>5.49</td>
<td>282</td>
<td>62 %</td>
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<tr>
<td>standard deviation</td>
<td>0.13</td>
<td>0.73</td>
<td>19</td>
<td>0.11</td>
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<tr>
<td>maximum</td>
<td>2.28</td>
<td>21.07</td>
<td>340</td>
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</tr>
<tr>
<td>minimum</td>
<td>0.06</td>
<td>2.01</td>
<td>9</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Air velocity (m/s)</td>
<td>Pressure difference (Pa)</td>
<td>Flow (m³/h)</td>
<td>Air flow efficiency (-)</td>
</tr>
<tr>
<td>average</td>
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<td>6.20</td>
<td>207</td>
<td>47 %</td>
</tr>
<tr>
<td>standard deviation</td>
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<td>0.72</td>
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</tr>
<tr>
<td>maximum</td>
<td>1.86</td>
<td>27.91</td>
<td>256</td>
<td></td>
</tr>
<tr>
<td>minimum</td>
<td>0.05</td>
<td>2.10</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 shows a better efficiency of system 1 compared to system 2. The main reason is that the area of the smallest opening in system 1 is larger than of system 2 and the aerodynamic properties of system 1 are better than system 2. However, even the efficiency of system 1 can be improved avoiding sharp edges of the inlet, outlet and bends and creating a smooth channel without disturbances that can create eddies. In that case an air flow efficiency of more than 83% can be reached [5].

False ceilings, related to thermal and acoustic parameters:
To have the right reverberation time and good speech intelligibility it is necessary to create 25% absorption on the whole inner surface of a class room. For reasons of air quality the floors need a smooth surface and a large part of the walls and the ceiling should be available for acoustic materials. Acoustic elements can diffuse fresh air. They should not hinder the heat transfer and cleaning of these elements should be possible. At his moment there is a database of design options and a calculation model is developed to predict the acoustical properties of a classroom [6].

Floor or radiator heating and CFD-simulations:

Figure 11: Comparison of convection flows of natural air supply, combined with a false ceiling and different heating systems (derived from CFD-simulations).

Figure 11 shows that it is much easier for radiator heating than for floor heating to prevent downdraught from natural air supply and to promote the mixing of cold and warm air above a false ceiling. In case no radiator is available, heating of the ceiling - like concrete core heating - is necessary as well. However, at the opposite side of the façade there is always the risk of downdraught. This can be reduced by creating - for instance- a air permeable ceiling at the opposite side of the façade.
DISCUSSION

When natural air supply and natural exhaust-systems are compared both systems have different opportunities and can be energy effective. In table 2 some of the characteristics of both systems are compared:

<table>
<thead>
<tr>
<th></th>
<th>Air flow</th>
<th>Heat recovery</th>
<th>Heating and cooling</th>
<th>Fan energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural air supply</td>
<td>Max. 3.5 l/sm²</td>
<td>Heat pump on air exhaust</td>
<td>Heating and cooling with water</td>
<td>Very low</td>
</tr>
<tr>
<td>Natural exhaust</td>
<td>3.5 - 6.3 l/sm²</td>
<td>Aquifer preheats and cools the supplied air</td>
<td>Heating with water and air, cooling with air</td>
<td>Low</td>
</tr>
</tbody>
</table>

This table shows that larger air flows can be supplied with a system of natural exhaust than with a system of natural air supply without creating a draught risk. This is possible by using the right air inlet-systems and using the corridor as an outlet as well.

By preheating natural supplied air, larger air flows might be possible, but this has not been tested up to now.

1. For architects and other designers it is very important to have a compact database of images and knowledge to show comfort-problems and optional solutions.
2. An integral approach of all the important “indoor” physical parameters is necessary even for common design problems.

ACKNOWLEDGEMENT

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REFERENCES