Ventilation of Dutch schools presently insufficient; an integral approach to improve design

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ABSTRACT

Indoor Air Quality and thermal climate in schools is problematic in many countries. The status quo in the Netherlands is presented (e.g. average CO2 levels in schools, problems with ventilation). The goal of a first study was to evaluate the performance of exhaust-only ventilation systems. In a following study, 6 schools with different ventilation systems were studied. Main conclusions from these studies were: IAQ in the evaluated schools did not meet the requirements and more ventilation was essential for better IAQ. A new integrated approach, to design adequate solutions for ventilation of school buildings was developed,first results are described.

1. INTRODUCTION

Indoor air quality has caught attention of the Netherlands Ministry of Housing, Spatial Planning and the Environment and a large campaign was started in 2005 to make the public aware of the dangers to health as result of poor ventilation in housing. Indoor pollutant levels are often greater than the outdoors, and since Dutch people spend nearly 90% time indoors, good indoor air quality is very important. Indoor Air Quality (IAQ) at schools is of special concern since children are extremely sensitive to results of poor air quality. IAQ in schools must reach the basic requirements and should be considered as a high priority because (Landrigan, 1997):

1) Children more sensitive as they still developing physically and more likely to suffer from indoor pollutants, these growth processes are delicate and vulnerable to disruption,
2) Children are less well able than adults to metabolise and excrete most environmental toxins,
3) Children are relatively more heavily exposed to environmental toxins as they breathe higher volumes of air relative to their body weights. Good air quality in classrooms supports children's learning ability. Poor IAQ in schools influences the performance and attendance of students, primarily through health effects from indoor pollutants (Mendell and Heath, 2005).

2. VENTILATION STANDARDS

There are numerous standards and guidelines covering indoor air quality (IAQ), recommended by international health associations, industry organizations and governments. Ventilation standards state either outdoor air supply requirements (volume per time per person), or outdoor air change-rate (h^{-1}), or both. Dutch schools have to meet the Dutch Building Code (Bouwbesluit), which requires a classroom ventilation rate of 2.8 $l/s{\cdot}m^2$ at an occupancy rate with 1.3 to 3.3 m^2 floor area per person. For a standard classroom of 50 m^2 and a maximum occupation of 32 students, this results in a ventilation rate of 4.2 l/s per person. Dutch Building Code refers also to guideline NEN 1089, which requires a ventilation rate of 5.5 l/s per person based on a level of 1000 ppm CO_2-concentration with a maximum of 1200 ppm. So depending on the situation the highest ventilation rate should be used. Carbon dioxide concentrations are often used as a substitute of the rate of outside supply air per occupant (Seppänen et.al 1999). IAQ in schools is primarily evaluated by CO_2-concentrations. ASHRAE Standard 62-1999 recommends an indoor CO_2-concentration of less than 700 ppm above the outdoor concentration (~1200 ppm) to satisfy comfort criteria with respect to human bio effluents. The Dutch standard NEN 1089 asks for a maximum CO_2-concentration of 1200 ppm in classrooms (van Dijken, 2004).

In the Netherlands different investigations on indoor air quality were conducted and CO_2 levels measured. In 1987 the Agriculture University of Wageningen conducted research to indoor air quality. Measurements of CO_2 concentrations were done and in 8 out of 12 schools, CO_2 levels rose above the marginal value of 1200 ppm in more than 50% during school hours. (Sandt et al, 1987). In 1992 the local health department (GGD) in West-Brabant researched indoor air quality in secondary education buildings. Measurements of CO_2 levels were done and levels up to 4800 ppm were detected. (Leentvaart et al, 1992). In 1993 in Groningen different primary schools were inspected. In 3 out of 4 classrooms, CO_2 levels reached the marginal value of 1200 ppm. Maximums of 2400 ppm
were detected (Meijer, 1993). In 1997 IAQ measurements were done at 4 primary schools in the region of East Noord-Brabant. Peak levels of 3500 ppm were detected. (Boske, 1997). Municipality Groningen did measurements in 16 classrooms and they found median

levels of 919 to 1940 ppm (Wassing, 2003).

3. EXPERIMENTS

The goal of a first study was to evaluate the performance of exhaust-only ventilation systems. In 5 Dutch schools measurements were conducted in the heating season for a period of around 7 days. These measurements included: IAQ (CO_2), thermal comfort, airflow and outdoor conditions. A logbook and questionnaires obtained information about use of ventilation facilities and satisfaction of users. Results of the measurements showed that in 4 out of 5 evaluated classrooms the indoor air quality did not meet the requirements for good indoor air quality. CO_2-concentrations are too high indicating that ventilation is not adequate. Therefore, a first conclusion was that natural air supply in classrooms without any draught prevention is an unacceptable solution. Parallel to the research another study was done by Froukje van Dijken, she studied IAQ of 11 schools. Both results were used by the REHVA Taskforce 4 "Indoor Climate and Energy of School Buildings" in their primarily report.

In a following study, 6 schools with different ventilation systems were studied, to search for concepts, which had fewer problems. Main conclusions from this study were also: IAQ in the evaluated schools does not meet the requirements and more ventilation is essential for better IAQ. The capacity of ventilation systems has to be increased. However air supply by natural ventilation is limited to vents in the façade. In well insulated buildings the required heat supply is not sufficient to prevent draught due to the supply of cold outdoor air. Therefore, a more distributed way of supplying air is needed in these systems.

Study	**number of schools**	**CO2(ppm)** Average	Range
Joosten, 2004	5	1220	480-2400
van Dijke, 2004	11	1580	450-4700
van Bruchem, 2005	6	1355	550-3000

Figure 3. Average and range of CO_2-concentrations for Dutch schools (Joosten 2004, v.Dijken 2004, van Bruchem 2005)

4. METHODOLOGY

The results of the measurements indicated that, based on the current ventilation standards, many classrooms are not adequately ventilated. As an object for further research is an improvement of the design process. (Mendell and Heath, 2005). A first line of defense against poor IAQ in classrooms is adequate ventilation and this should be a major focus of design efforts (Daisey et.al 2003). The current design process for schools normally begins with selection of an architect. It then proceeds with programming and schematic design. Next the design engineer comes in and finally the BS (Building Services)-engineer completes the design team. But already many decisions were made in the early conceptual design that influences the development, contract documents, construction, commissioning and occupancy. Clear goals were not part of the often general programming and the design brief. The sooner goals, to ensure IAQ are brought into the design process, the easier and less costly they are to incorporate.

Up to now the building design process is more or less sequential; first the building is designed and subsequently the heating/ cooling/ ventilating system. Communication between architect and building services consultants is based on abstraction, i.e., the exchange of abstract descriptions of a design within the design process itself.

Design has normally a very dynamic nature, with a tendency to ad hoc actions, which should be supported by design aid systems. To develop the required model of design support an existing model has been extended: Methodical Design (van den Kroonenberg 1979, de Boer 1989, Blessing 1994).

Main characteristic of Methodical design is the occurrence of a four-step pattern of activities in each level of abstraction and the distinction of eight levels of functional hierarchical abstraction.

This decomposition of design the problem into necessary functions tofulfil is based on functional decomposition and is carried out hierarchically. The resulting combination structure of functions is partitioned into sets of functional subsystems. The decompositions are carried out till arrived at simple building functional components whose design is a relatively easy task, see figure 4.

In order to estimate what the restrictions imposed by generic function simply for the overall system, the resulting configuration has to be parameterised in terms of the characteristics of the individual functions.

The decomposed functions were put into an array. Left column were the functions listed, which were combined with a row of solutions for each function, see figure 5. The matrix of functions and their solutions are called a Morphological chart and were developed by Zwicky (Zwicky, 1969). Each combination of possible solutions for the functions was combined to overall solution for the design task. Selecting the most likely solution could be done with help of the Kesselring-diagram Kroonenberg, 1978). All the solutions were marked based on the criteria of the design brief. The design criteria were divided into criteria concerning functioning and realization. The relative score was presented in de S-diagram, see figure 7. In a next iterative step the most likely variant could again be placed in a Morphological chart to generate new additional variants, see figure 6. By doing so the number of possible variants grew enormous and this increased the chance to generate a good solution. By using Morphological charts communication between design team members becomes easier and there was a clear overview of all the possibilities discussed. The Kesselring method (Kesselring, 1954) made the decision process clear and understandable for the design team and all so for all people outside the team. Kesselring developed a visualization technique, where the different variants can be compared with each other. Within the Kesselring method criterion are separated into a category for realization and a category for functionality. By doing this the strong point can be seen in a so called S-(Stärke)diagram. To visualize the scores the criteria of the program of requirements are separated in groups with relating requirements.

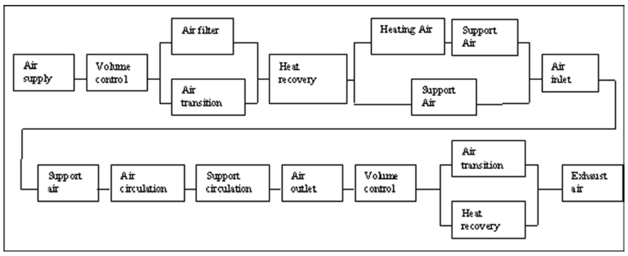

Figure 4. Functional decomposition of main

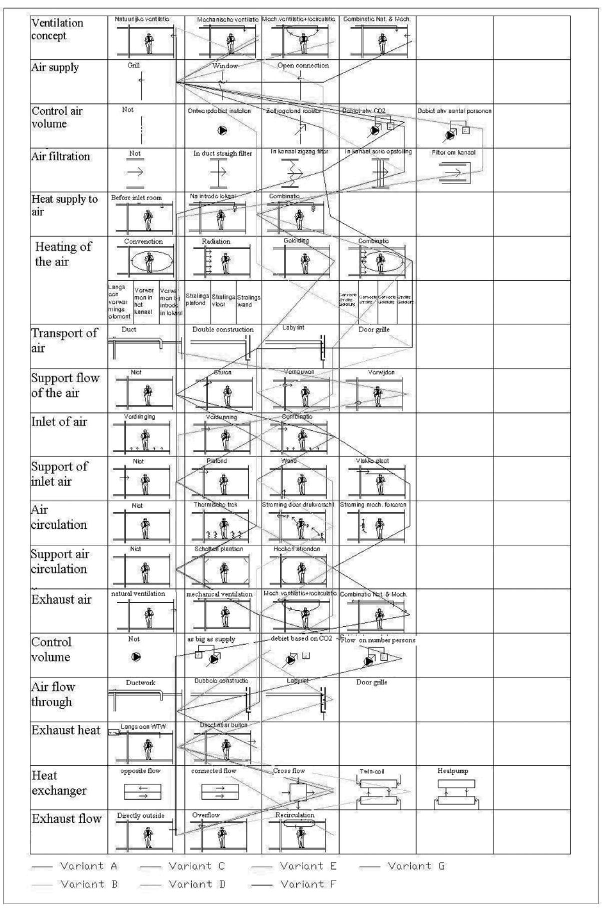

Figure 5. Morphological chart, 18 subfunctions with different solutions

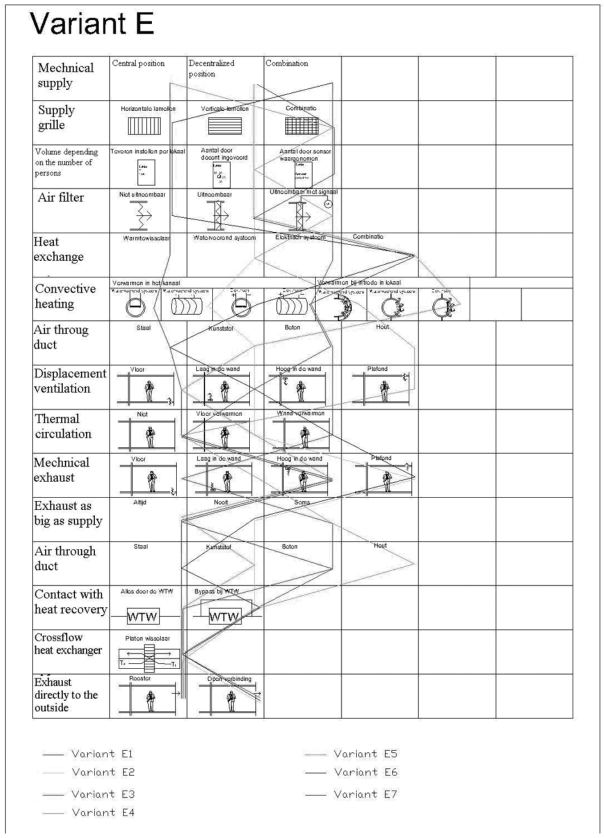

Figure 6. Morphological chart of Variant E, with alternative functions and different solutions

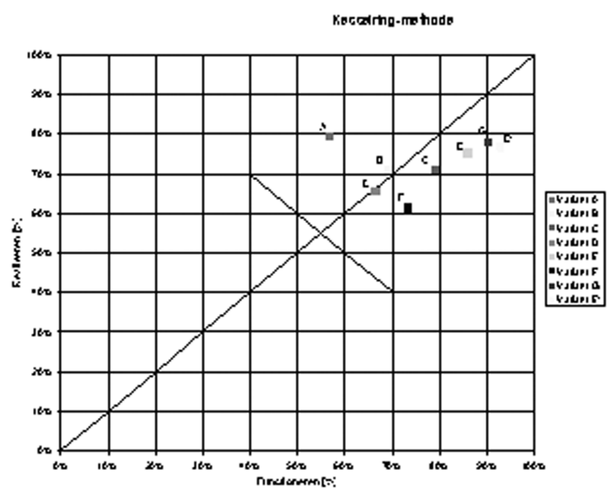

Figure 7. S-diagram Kesselring method

5. RESULT

The proposed method is used to design a ventilation system for a typical classroom. The solution that resulted is a balanced displacement ventilation system with heat recovery, as shown in figure 8.

Instead of normal metal ductwork, textile air ducts are proposed; these can be removed easily and washed in a washing machine.

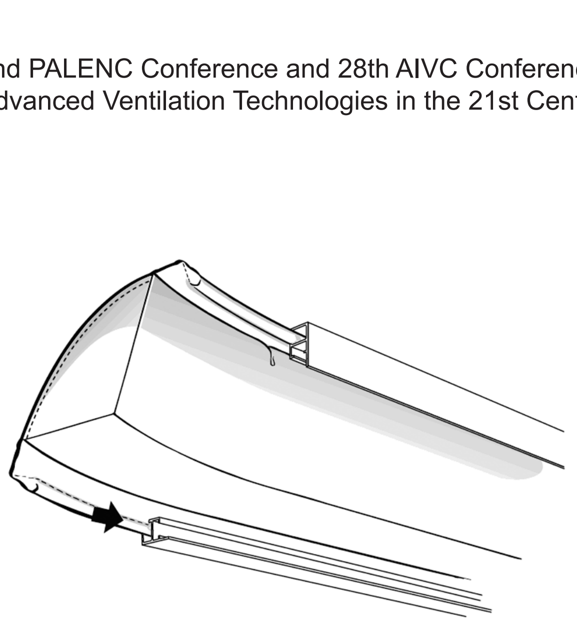

Figure 8. Textile air duct (Euro-Air, 2005)

Normally the flow pattern of heated air is problematic when displacement ventilation is used. In classrooms this is only the situation during start-up, as the pupils generate more than enough heat themselves once they are in the classroom. During the start-up the air distribution is like shown in figure 9. The walls and windows are primarily heated up and there is no good air distribution. But as there are still no pupils this is not a problem. When the room is used there is too much heat and the air through the displacement ventilation system has to be brought in with a slight under temperature. The expected flow pattern will become as shown in figure 9. By putting the textile air ducts nearly all around the floor of the classroom, a good distribution with a low air speed will be generated, see figure 10.In follow-up research, the solution will be simulated and a laboratory test will be done to verify the design.

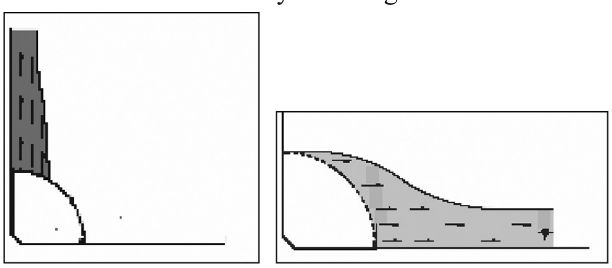

Figure 9. Flow pattern during start-up situation and during normal use

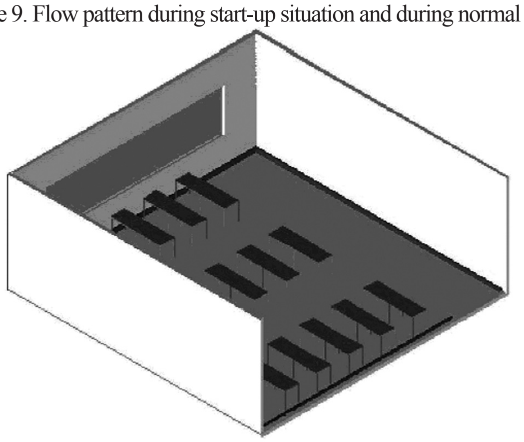

Figure 10. Lay-out displacement air-duct

6. CONCLUSIONS

Many ongoing research efforts aim at introducing the used methodical design process into building design and architecture, and so linking architectural design with HVAC-design. In the Netherlands this has resulted in a stark interest in what is commonly named ‘integral design’. Integral design is meant to overcome the difficulties of design team cooperation, by providing methods that make it possible to communicate the consequences of design moves on areas such as construction, costs, life cycle and indoor climate at early design stages, between the different disciplines (Zeiler, 1997). The integral approach encompasses the built environment from initiative, design and construction as a seamless whole. This is the core of the integral approach. Currently there is a PhD-study by Savanovic in which the Methodical support tools are tested within the Integral design approach(Savanovic, 2005).

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