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Ventilation of Dutch schools; an integral approach to improve design

Wim Zeiler and Gert Boxem

University of Technology Eindhoven (TU/e), The Netherlands

Corresponding email; w.zeiler@bwk.tue.nl

SUMMARY

Indoor Air Quality and thermal climate in schools is very important as it has a direct relation to the health and performance of the pupils. The status quo in the Netherlands is presented (e.g. average CO₂ levels in schools, quality of ventilation). The goal of a first study was to evaluate the performance of exhaust-only ventilation systems. The performance was rather disappointed there were a lot of problems and insufficient situations found. During the next years different master students [1,2,3,4] together with the staff of Technische Universiteit Eindhoven were researching different aspects of the problem and trying to find solutions. 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 design results are described in the paper.

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).

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·m² at an occupancy rate with 1.3 to 3.3 m² floor area per person. For a standard classroom of 50 m² 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 CO₂-concentration with a maximum of 1200 ppm. So depending on the situation the highest ventilation rate should be used.

The European legislature (CR1752) uses Fanger's model for dissatisfaction and specifies 3 categories of % occupants satisfied with perceived indoor air quality: high quality (at least 85%), medium quality (at least 80%), and moderate quality (at least 70%).

The guidelines for ventilation in North America, provided by ASHRAE (American Society of Heating, Refrigerating and Air-conditioning Engineers), Standard 62-1999, recommends a minimum ventilation rate of 8 l/s-person for classrooms. They pose an acceptable indoor air quality when the air is free of pollution in damaging concentrations and when a majority of satisfaction (80% or more) is found. Indoor air quality here is a combination of air contaminants and the response of occupants exposed to indoor air.

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 CO₂-concentrations. ASHRAE Standard 62-1999 recommends an indoor CO₂-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 CO₂-concentration of 1200 ppm in classrooms (van Dijken, 2004).

Literature on relationships (Shendell et.al 2004) between indoor air and environmental quality (IEQ) in class rooms and students health and academic performance has been reviewed by Heath and Mendell (2005) and Daisey et.al (2003). Relatively not many field studies were conducted on the performance of ventilation systems in schools. For European schools some results are shown in figure 2 (Daisey et.al 2003).

Study	number of schools	CO ₂ , ppm	
		Average	Range
Nielsen,1984	11	1000	500-1500
Norback et.al 1990	6	1290	950-1950
Norback,1995	6	1320	700-2700
Smedje,1997	96	990	425-2800

Figure 2. Average and range of CO₂-concentrations reported in the scientific literature for European schools (Daisey et.al. 2003)

In the Netherlands different investigations on indoor air quality were conducted and CO₂ levels measured. In 1987 the Agriculture University of Wageningen conducted research to indoor air quality. Measurements of CO₂ concentrations were done and in 8 out of 12 schools, CO₂ 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 CO₂ 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, CO₂ 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).

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 (CO₂), 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. CO₂-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	CO ₂ , ppm	
		Average	Range
Joosten, 2004	5	1220	480-2400
van Dijken, 2004	11	1580	450-4700
van Bruchem, 2005	6	1355	550-3000

Figure 3. Average and range of CO₂-concentrations for Dutch schools (Joosten 2004, v.Dijken 2004, van Bruchem 2005)

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.

Integrated design promises major advantages. It draws from all disciplines involved in designing a building and reviews their recommendations as a whole from the early start of a project. Project team collaboration and integration of design choices should begin at the programming phase. Indoor air quality encompasses such factors as maintenance of

acceptable temperature and relative humidity, control of airborne contaminants, and distribution of adequate ventilation air. It requires deliberate care and cooperation on the part of the entire project team. BS-engineers must design ventilation systems that dilute the by-products of occupant activities and, to the greatest extent possible, supply fresh air on demand in the right quantities, in the right locations.

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. During design support, it's important to transfer the essentials of the applied structures and mechanisms without overloading the other party with unwanted details.

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 1978). The methodical design process can be described on the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution.

In order to survey solutions, engineers classify solutions based on various features. This classification provides means for decomposing complex design tasks into manageable size problems. An important decomposition is based on building component functions. The functional decomposition is carried out hierarchically so that the structure 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.

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 6. 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. 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 7.

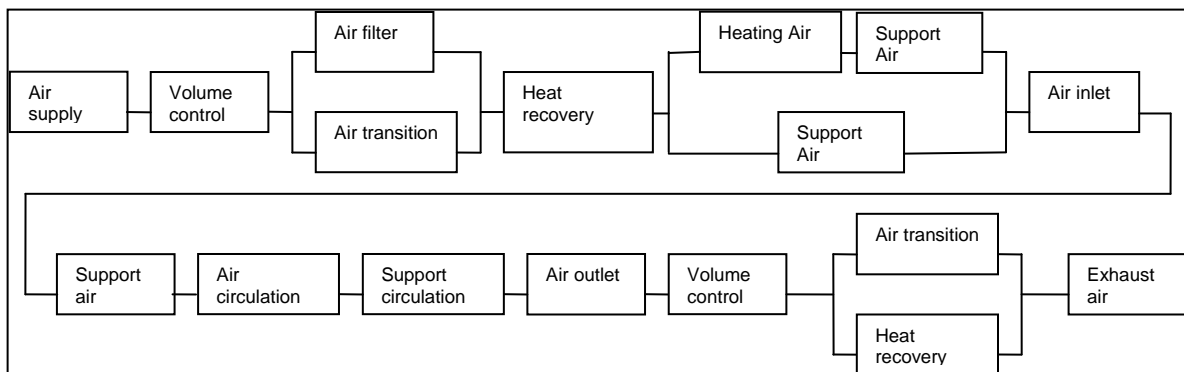


Figure 4. Functional decomposition of main

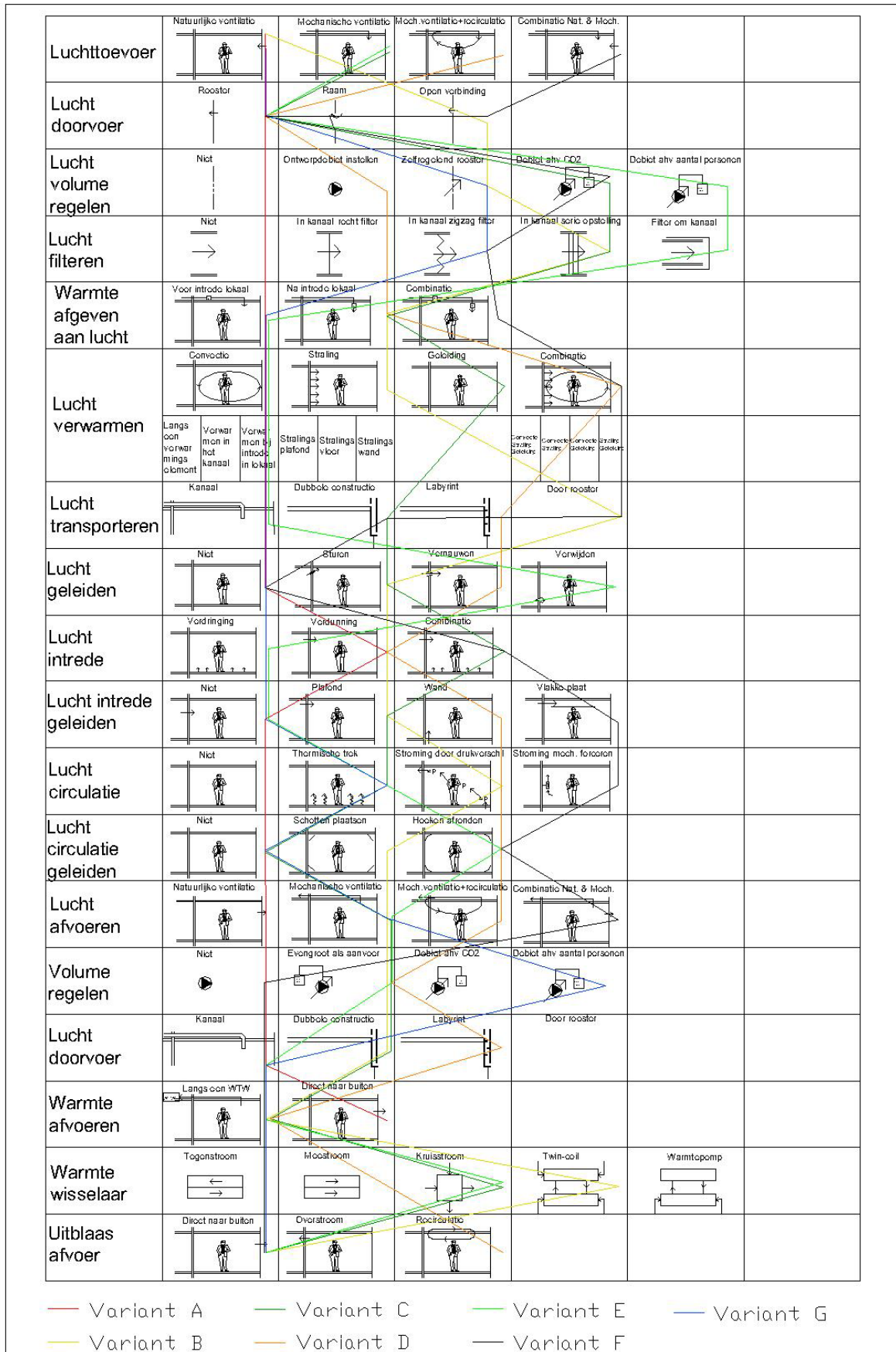


Figure 5. Morphological chart, 18 subfunctions with different solutions.

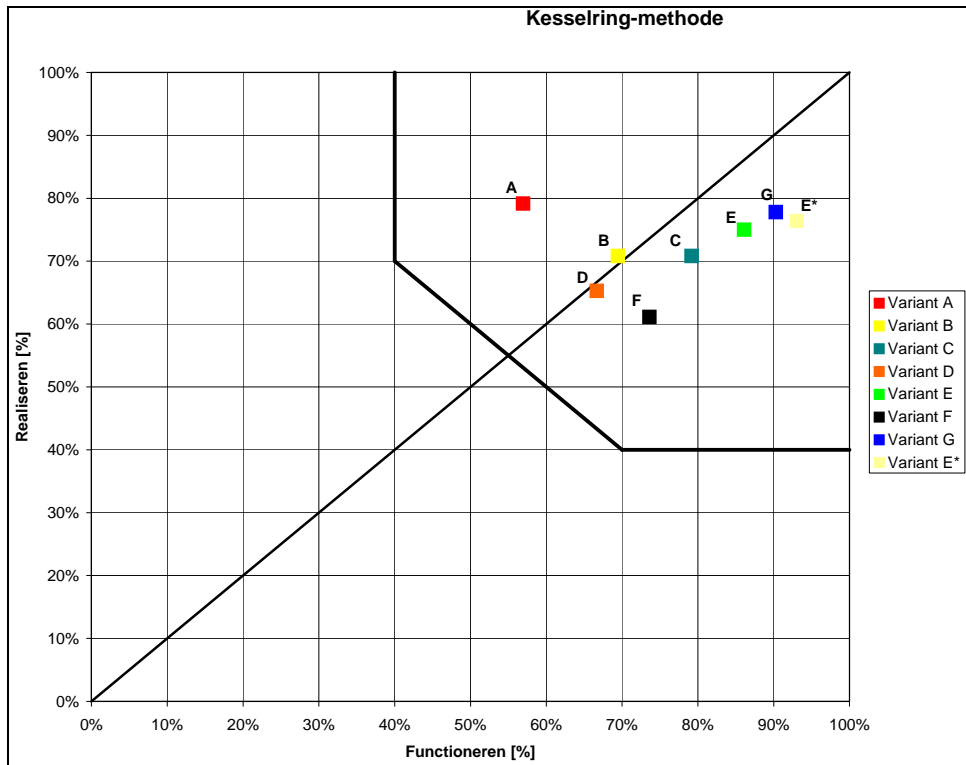


Figure 6. S-diagram Kesselring method

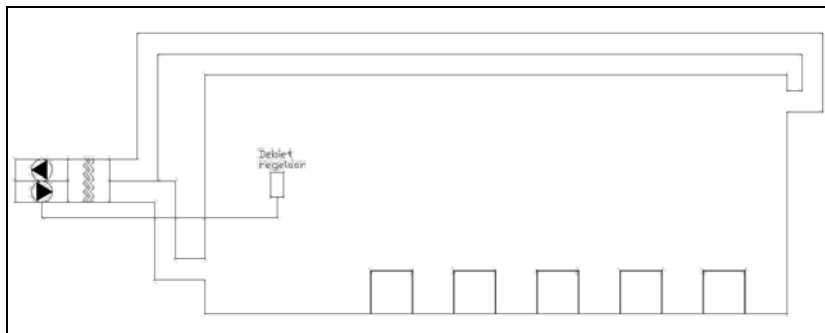


Figure 7. Schematic of displacement classroom ventilation

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

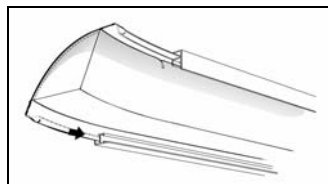


Figure 8. Textile air duct (Euro-Air, 2005)

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. In follow-up research, the solution will be simulated and a laboratory test will be done to verify the design.

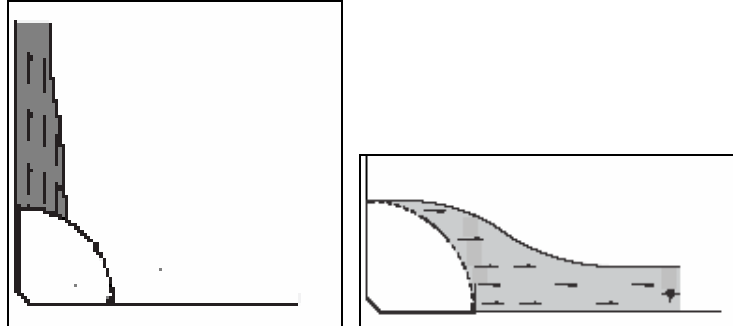


Figure 9. Flow pattern during start-up situation and during normal use

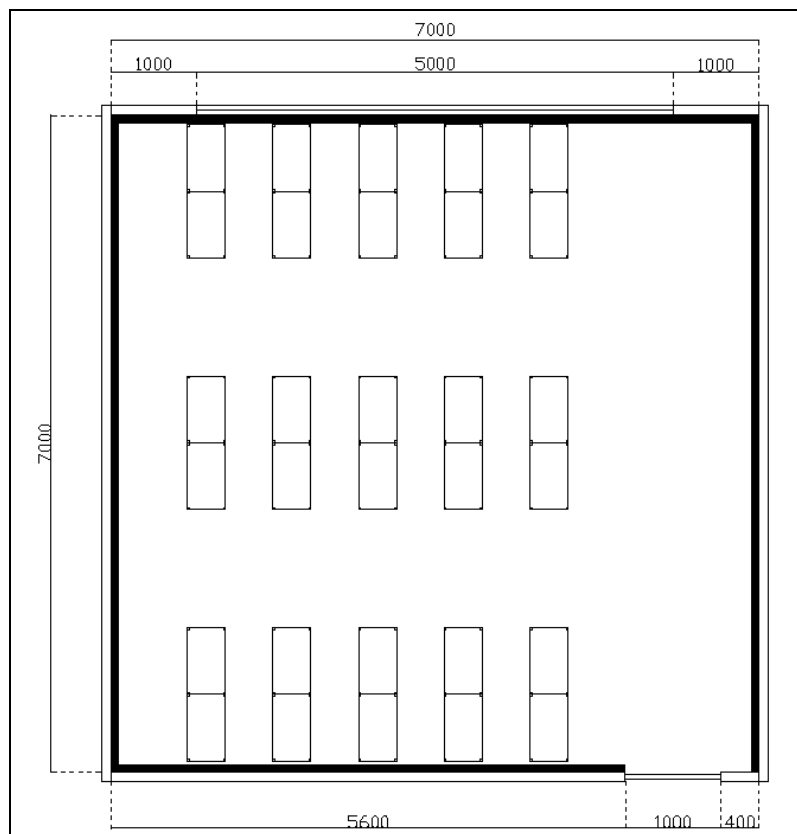


Figure 10. Lay-out displacement air-duct

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.

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