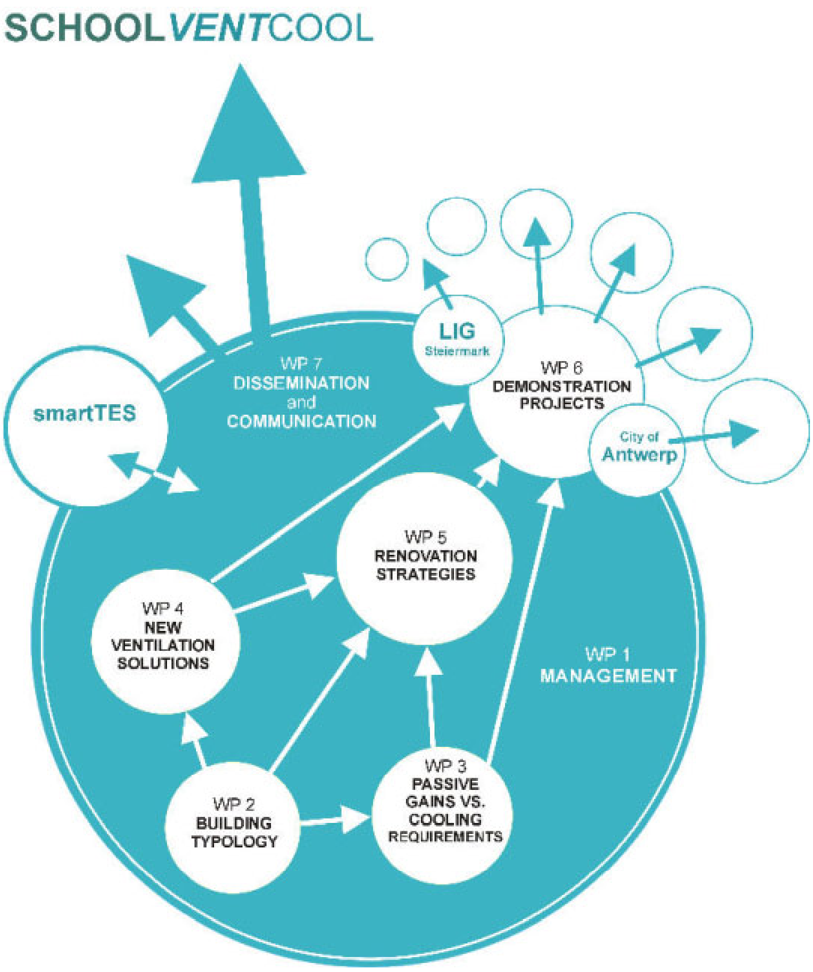
School Vent Cool - “Ventilation, cooling and strategies for high performance school renovations”

SCHOOLVENTCOOL

http://www.schoolventcool.eu

International Report

15th March 2013



Introduction

All over Europe both energy and education related developments require adaptations of our school buildings. Most of them have been built during the 1960s, 1970s and 1980s, they are now expected to be modernised and renovated. Comprehensive school (building) renovation concerns the whole system and meets the technical and educational needs of the future. The central point from the technical point of view is the optimized operation of the building services, a high quality of building construction and a surplus value for the user's indoor comfort. This surplus can only be achieved, when new methods and technologies are developed further.

The project "school*vent*cool" aimed to raise both energy efficiency by high performance retrofit strategies and thermal comfort by proved solutions for ventilation and protection from heat of school buildings in the European partner countries. The project lays the foundation for sustainable educational buildings promoting energy efficiency with high indoor environmental quality and excellent educational conditions.

This report covers activities undertaken and results achieved by the project partners of "school*vent*cool", a European ERACOBUILD-project, during the period of September 2010 to February 2013. All publications and deliverables are made publicly available from the project website: **http://www.schoolventcool.eu**

The Consortium:

Coordinator

AEE - Institute for Sustainable Technologies (AEE INTEC), Austria

Hochschule Luzern Technik & Architektur (HSLU), Competence Centre of Typology and Foresight in Architecture (CCTP), Switzerland

Fachhochschule Nordwestschweiz (FHNW), Hochschule für Architektur, Bau und Geomatik, Institute of Energy in Building, Switzerland

DTU Technical University of Denmark, Civil Engineering - Building Physics and Services (DTU – BPS), Denmark

DTU Technical University of Denmark, Civil Engineering - International Center for Indoor Environment and Energy (DTU – ICIEE), Denmark

Passiefhuis-Platform vzw (PHP), Belgium

City of Antwerp, Cabinet vice mayor for education, work & economy, City of Antwerp - Stedelijk onderwijs, Belgium

Content

1 Project Aim & Objectives

Based on a building typology, the project developed different high performance renovation concepts. Pre-fabrication or modular design components are important parts of these concepts. New solutions for ventilation systems and natural cooling requirements to protect from overheating have been investigated, integrated into the concepts and tested in field trials and demonstration projects.
The European collaboration should prove the adaptation for other countries and ensure that new components and findings improve the system. The project partners exchanged their knowledge on new technologies to set up new solutions particularly for ventilation, thermal comfort and prefabrication.

Detailed Objectives:

- Development of a qualitative school building typology
- High performance renovation strategies that reduce the primary energy use down to 20% or more
- Solution sets for prefabrication and modular design, for ventilation systems and natural cooling requirements
- Impart knowledge to pupils about renovation and related technologies plus launch learning from them
- Improvement of the air quality of classrooms to enhance the performance of pupils and teachers
- Analyses of light supply in classrooms regarding protection from heat and glare

Very special thing on school building renovation is the fact that they need short construction times, especially to be able to retrofit schools without having to close them, even during holidays ("broad" school use). So planning stage and construction time exactly predefined and short on site are the most important parameters for school renovations so far.

Figure 1 The consortium members in Copenhagen, spring 2012

2 School Building Typology

HSLU, Switzerland

2.1 Objective and Research Approach

The aim of the Swiss team, consisting of typology (HSLU - CCTP), construction (FHNW - IEBau) and HVAC (FHNW - IEBau), is to share the existing knowledge of IEA ECBCS Annex 50 [1] on typology and prefabrication for the renewal of multifamily houses and to further develop it for school buildings with an orientation on real case studies in the frame of ERACOBUILD. The intended solutions focus on buildings, where prefabricated façade modules are mounted from the outside and ventilation is an integrated part.

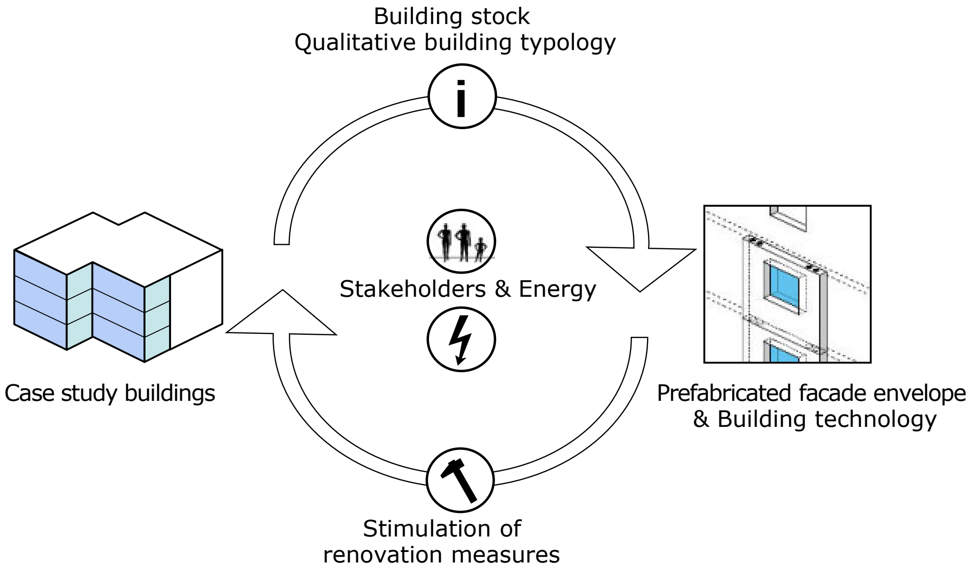


Figure 2 Case study buildings serve as basis for the qualitative building typology

The fundamentals for the adaption of school buildings are based on the boundary conditions derived from typology and on the specific technical requirements of school buildings. A typological analysis serves as a basis to derive guidelines for the technical development of modules and the optimisation of construction processes.

2.2 Results & conclusions

The building features for school buildings are summed up in a feature catalogue, which contains a collection of relevant characteristics of school buildings for renewal [2]. More than 70 building features are included in this catalogue and divided into four focus areas: school complex, school building, classroom and building technology. Focus areas are functional and interrelated parts of the building (e.g. building envelope, building surrounding, provisions of services). Each focus area is characterised by a selection of features that are relevant for the renewal with prefabricated façade modules [3]. The building features are divided into key and focus features.

2.2.1 Key features and general types

In the project the key features type of façade, number of floors and position in construction are analysed for the provided case studies. The type of façade feature characterises the construction of the outside wall that is a relevant feature for the prefabricated module type, the absorption of loads and the ventilation within the modules. The feature number of floors provides information on the size and the type of the school building. The feature position in construction represents the ability for delivery and mounting of the prefabricated modules. The key features are restricted to three simple and easy to determine criteria to secure a quick classification of the school buildings. By combining the characteristics of key features general types can be derived, representing a categorisation of buildings in the sense of the original objective. General types are used to get an overview of the building stock. Furthermore, frequently occurring building types with a high multiplication potential for renewal can be identified and described with the help of characteristic examples. Theoretically, 27 general types could be defined by the combination of three key features each with 9 variants (Figure 3, [4]).

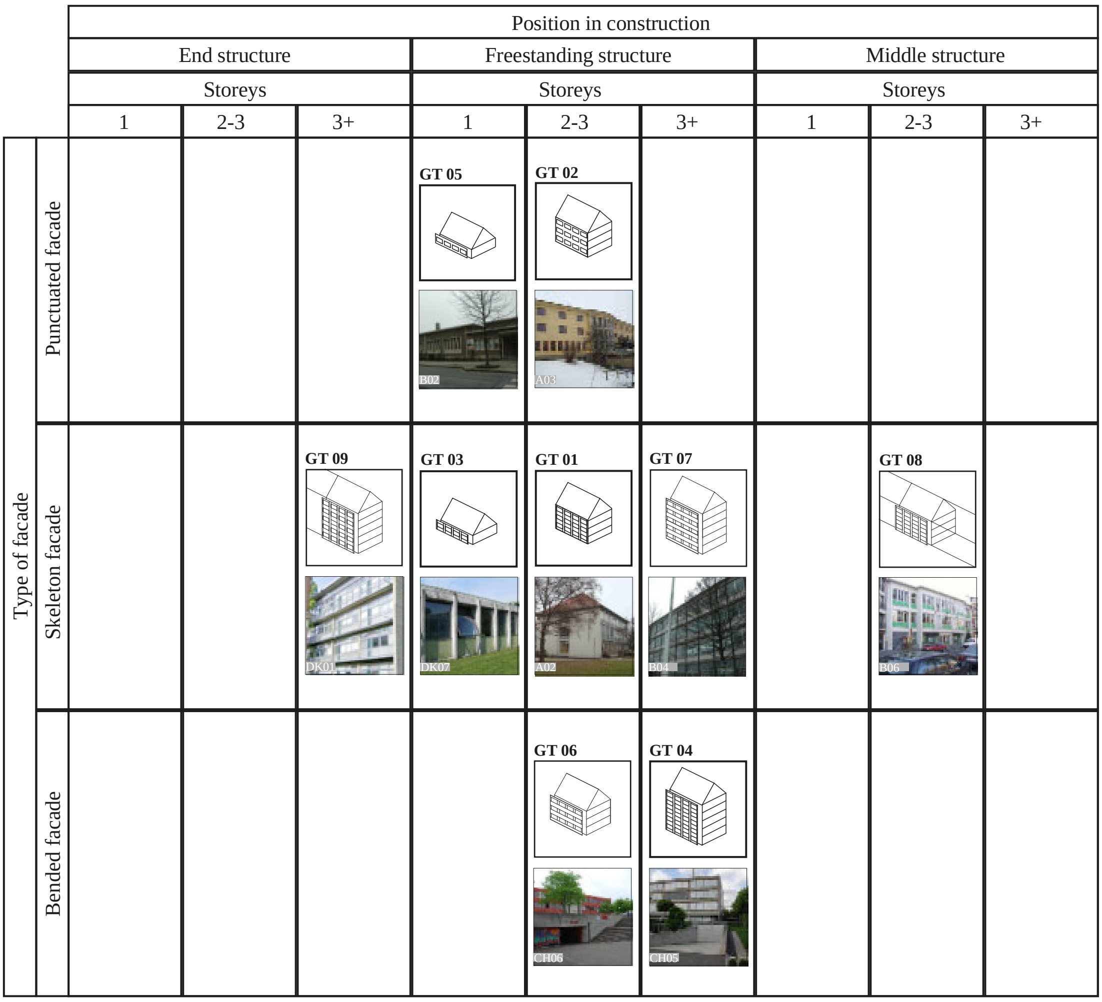


Figure 3 Categorisation of general types regarding the defined key features type of façade, number of floors and position in construction (visualized with case study buildings)

2.2.2 The evaluation of general types leads to the following conclusions:

Façade type: The façades of school buildings can be assigned to skeleton structures in more than 50% of the analysed case study buildings (16 out of 28 case study buildings). This basically means, concerning centralised ventilation, a disadvantage because of small riser zones between the windows. The disadvantage can be neglected if the prefabricated modules can be mounted in front of the vertical skeleton structure (change in appearance of the new façade needs to be accepted). With this measure thermal bridges can be minimised and air tightness can be improved. Considering the façade structure this type of school building has the highest thermal saving potential within the building envelope. Figures 3 - 5 show the identified façade types on the example of the case study school buildings:

- Punctuated façades
- Element based façades (precast)
- Skeleton façades

Figure 4 Punctuated façades on the example of the case study buildings A03 (left - AEE INTEC), A05 (middle - AEE INTEC) and CH04 (right - CCTP)

Figure 5 Element based façades on the example of the case study buildings CH05 (left - CCTP), CH07 (middle - CCTP) und DK02 (right - DTU)

Figure 6 Skeleton façades on the example of the case study buildings A02 (left - AEE INTEC), CH01 (middle - CCTP) und CH08 (right - CCTP)

Position in construction: The access for delivery, mounting and storage of the prefabricated façade modules during the time of construction are important criteria to optimise the building process. School buildings are mostly detached as or planed as a part of a school building complex (26 out of 28 case study buildings). These are good preconditions for the access and the mounting of prefabricated façade modules, as well for the use as storage space. One school building is situated within a block structure and one school building defines the end of a block structure.

Number of storeys: The analysed school buildings have mostly 2-3 storeys over ground level (17 out of 28 case study buildings). In contrast to high-rise buildings this fact favours a ventilation distribution because a little number of classrooms needs to be supported with air through a vertical riser zone. With an increasing number of storeys the centralised air distribution is a challenge because of the increasing cross sections of the air pipes, hence the vertical riser zones (e.g. between windows) offer a limited capacity.

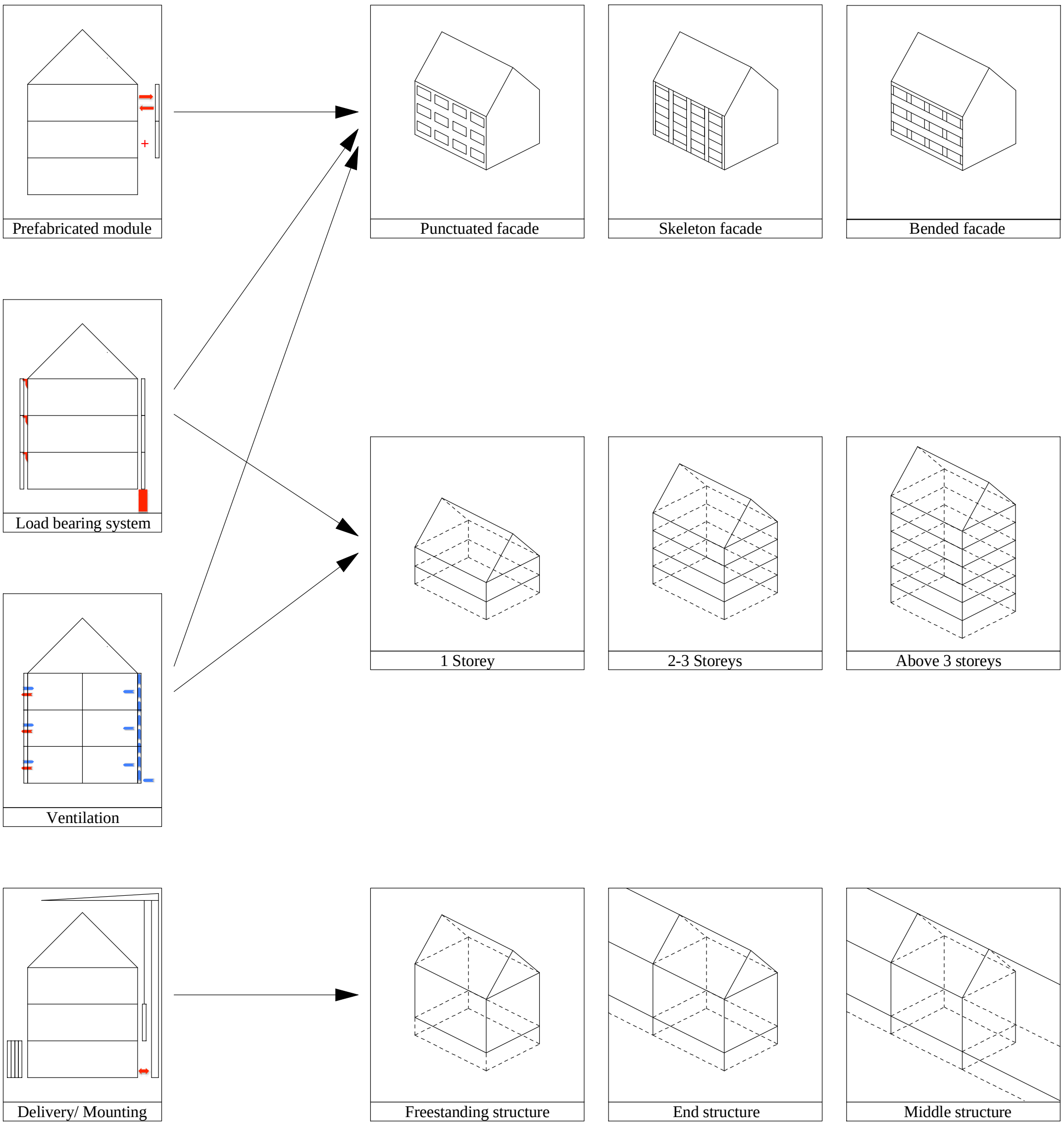


Figure 7 Measures of prefabricated façade modules linked to relevant features (key features)

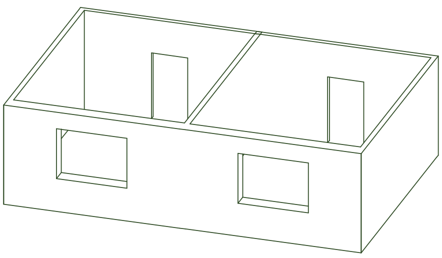
2.2.3 Focus features and focus types

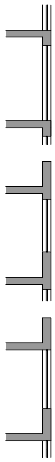
Focus features describe the relevant building elements of the existing building stock for the technological development of prefabricated façade modules. These include the characterisation of the parapet and the lintel situation, façade openings as well as the geometry of typical classrooms.

The parapet and lintel situation describes the available space for ventilation distribution integrated in the outside wall, whereas the construction of the wall defines the possibility of penetration. The evaluation of façade openings collects information on the type of façade and the position of the façade openings to each other and to the outer edges of the building. The analysis of the room geometry evaluates the room length along the façade to determine the available space for decentralised ventilation units. The height of the classroom provides information whether the existing space can be equipped with a suspended ceiling for ventilation distribution (see Chapter 6).

Focus types, which represent specific categories of building parts, can be deduced from combinations of the characteristics of the parapet- and lintel height, as well as the distance between windows. Hence focus types allow first assessments for the substitutability of the building substance, load bearing concepts, as well as ventilation systems- and distribution (for further information see chapter of renovation strategies).

Punctuated facade
(typical student room on the example A03)





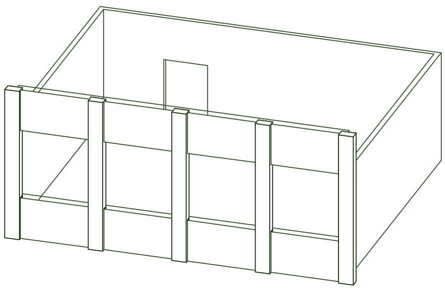
Focustype (FT)
(variants of the balustrade- and lintel situation)

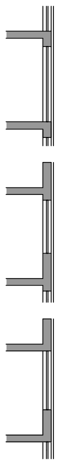
FT L1
Punctuated facade (Window distance > 60 cm)
Hight of lintel > 15 cm
Hight of balustrade -

FT L2
Punctuated facade (Window distance > 60 cm)
Hight of lintel > 15 cm
Hight of balustrade > 60 cm

FT L3
Punctuated facade (Window distance > 60 cm)
Hight of lintel -
Hight of balustrade > 60 cm

Skeleton facade
(typical classroom on the example CH08)





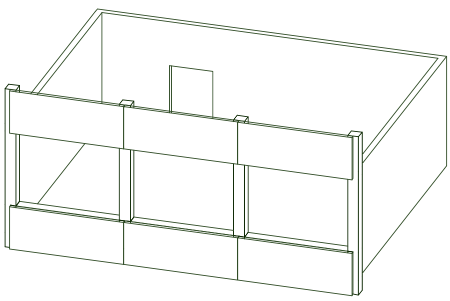
Focustype (FT)
(variants of the balustrade- and lintel situation)

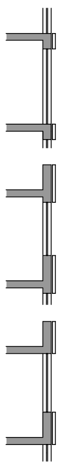
FT S1
Skeleton facade (Window distance < 60 cm)
Hight of lintel > 15 cm
Hight of balustrade -

FT S2
Skeleton facade (Window distance < 60 cm)
Hight of lintel > 15 cm
Hight of balustrade > 60 cm

FT S3
Skeleton facade (Window distance < 60 cm)
Hight of lintel -
Hight of balustrade > 60 cm

Bended facade
(typical classroom on the example CH07)





Focustype (FT)
(variants of the balustrade- and lintel situation)

FT B1
Bended facade (Window distance < 60 cm)
Hight of lintel > 15 cm
Hight of balustrade -

FT B2
Bended facade (Window distance < 60 cm)
Hight of lintel > 15 cm
Hight of balustrade > 60 cm

FT B3
Bended facade (Window distance < 60 cm)
Hight of lintel -
Hight of balustrade > 60 cm

Figure 8: Facade types and derived focus types to assess the substitutability of the building substance, load bearing concepts, as well as ventilation systems- and distribution

2.2.4 Procedure for module selection during planning

Depending on the construction of the external walls the prefabricated façade modules are mounted onto the existing façade, especially for massive construction load-bearing exterior walls (i.e. punctuated masonry façade). For skeleton constructions with non-load-bearing exterior walls (e.g. curtain wall façade elements) the existing elements are replaced with the prefabricated new façade modules. Figure 35 shows schematically a guide for the selection of suitable façade modules during the planning phase of a specific building project.

2.3 Literature

[1] "IEA ECBCS Annex 50 – Retrofit Module Design Guide – Part A"; Kobler R.L., Binz A., Steinke G.; Institute of Energy in Building – FHNW; Muttenz 2011, see also [23]

[2] "ERACOBUILD SchoolVentCool - Energetische und raumlufttechnische Erneuerung von Schulgebäuden"; Dott R., Heim T., Kobler R.L.; Institute of Energy in Building – FHNW and Competence Centre Typology & Planning in Architecture – CCTP, internal report 2013

[3] „Building Typology and Morphology of Swiss Multi-Family Homes 1919-1990"; Fischer R., Schwehr P.; Hochschule Luzern, Kompetenzzentrum Typologie & Planung in Architektur (CCTP); Horw 2010

[4] „Schulhauserneuerung – Typologie und Vorfabrikation, Tagungsband Ökosan 2011"; Heim T., Fischer R., Schwehr P.; AEE-INTEC – Institut für Nachhaltige Technologien; Gleisdorf 2011

2.4 Deliverables

Deliverables and reports are available: www.bfe.admin.ch

3 Passive gains versus cooling requirements

AEE INTEC, Austria

3.1 Objective and Research Approach

As there are very low thermal loads in modernized buildings the importance of the heating demand shifts towards the cooling demand of the buildings. Measures like passive cooling (night ventilation, air ground heat exchanger, etc.) or "intelligent" external and internal blinds including control systems will be analyzed and focused to three practicable solutions.

Therefore it is crucial to investigate the thermal dynamics of (class)rooms concerning the influence and effects of the following two parameters:

1. Passive gains: Thermal performance (g-value, U-value), area and orientation of the windows; number of pupils, duration and activity of schoolwork (amount of internal gains)

2. Cooling requirements: External shadowing like blinds (with or without daylight use, protection from glare), external insulation (U-values), heat storage mass, ventilation rate, etc.

This was done by calculations, measurements and evaluations in Austrian case study schools. Detailed simulations were made in different oriented classrooms of two different school buildings. Qualitative interviews of teachers, pupils and school managers and study investigations completed the results.

3.2 Results & conclusions

When studying the present research in the field of overheating – causes, effects on humans and strategies to overcome - it was very surprising that there is a lot of work around the causes and strategies to overcome, but mainly for residential cases. A very low number of studies refer to the effects of high temperatures in rooms on humans and generally low numbers of studies in the field of school renovation. Research on school renovations is mostly done by technically analysing single demonstration projects. So the focus during the project turned more to the situation and sensation of the users in relation to calculations and measurements, to give planning advice for renovations.

In Austria a lot of big-volume low energy and passive house buildings were monitored by energy and comfort related measurements during the last 10 years. The results have been very similar: The energy consumption for heating fits quite good to the planned values, it is very different for hot water and often too high for electricity. The room temperatures are mostly higher than expected, even in winter. Also during the summer season the temperatures are around 15% too high (Figure 9 [5]). This is especially relevant for school and educational buildings with crowded rooms. Due to the high indoor temperatures it is expected that the ability to concentrate during lessons decreases.[6]

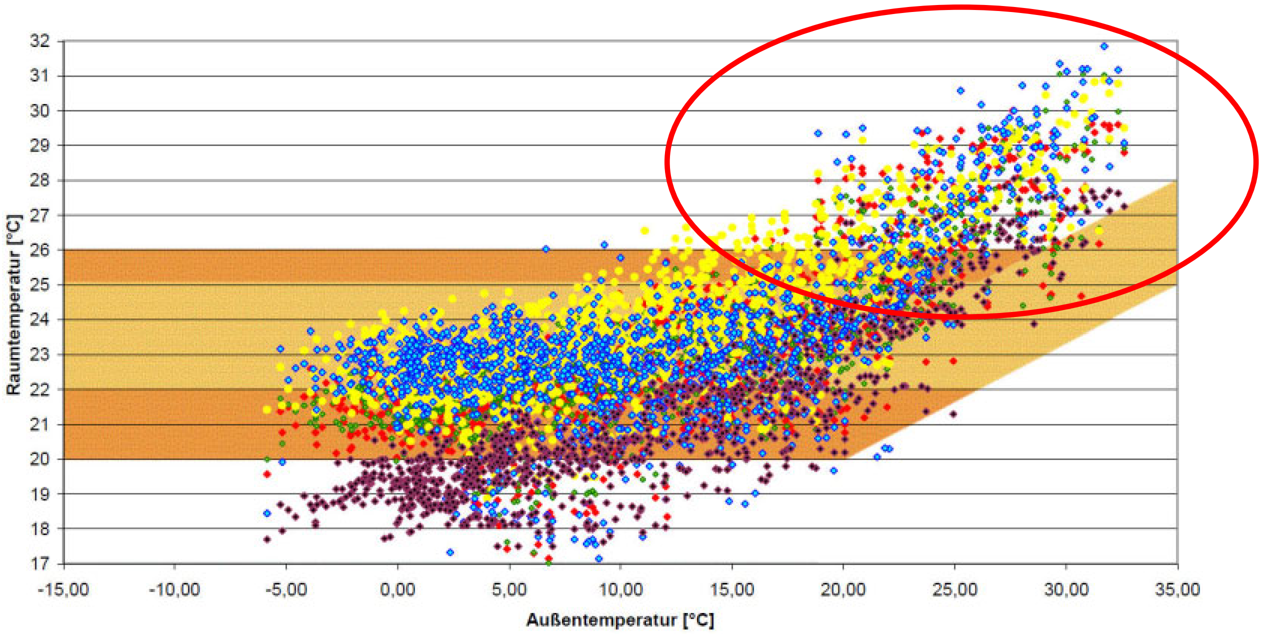


Figure 9 Measured room temperatures during school time, depicted as average hourly values over one year in a high performance renovated Austrian school building [5]

AEE INTEC investigated 15 school buildings during the project. As one interesting result based on energy performance calculations it was found, that classrooms in passive house and nearly zero energy buildings seem to have higher cooling demand and higher risk for overheating than ones in low energy buildings. This is surprising because it has been expected that better insulation leads to both protection from cold and heat. There should be more research and simulation on that point to understand the parameters behind.

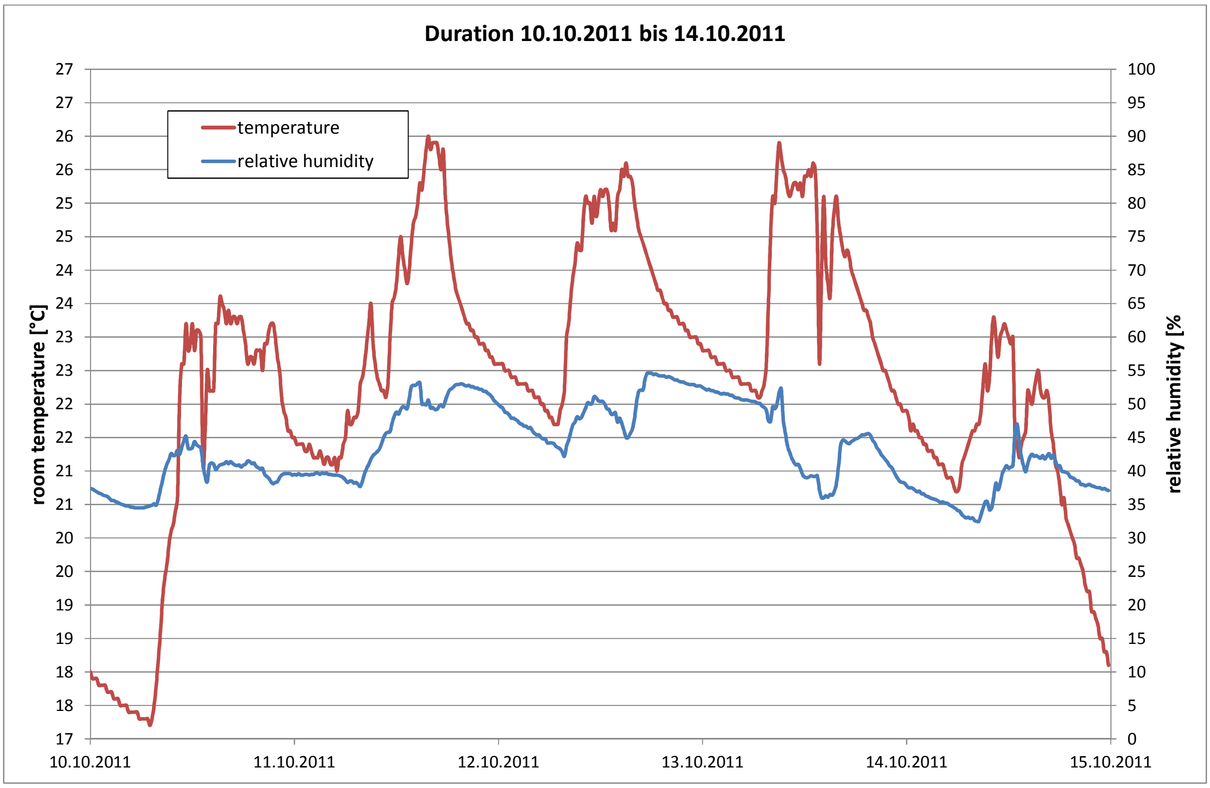


Figure 10 Typical trend of the temperature in one west oriented classroom during one week of transitional season, interesting are the very high temperature differences in a short time

Six classrooms in two different non-renovated schools were analysed in more detail. The sensors for humidity, temperature and CO_2-measurements had been installed there for around one and a half year. It was interesting that in one school in the city of Graz it was very difficult to do measurements because the sensors often disappeared or were damaged. The experience with measurements, communication and cooperation in another school at the countryside has been much better. Continuous monitoring values could be collected there (as in Figure 10).

Interviews with pupils, teachers in all six classrooms based on specially developed questionnaires were made in parallel to verify if calculations, measurements and interviews talk the same language. The work should show where pupils have their highest sensation regarding comfort as one important parameter influencing their ability to concentrate and learn.

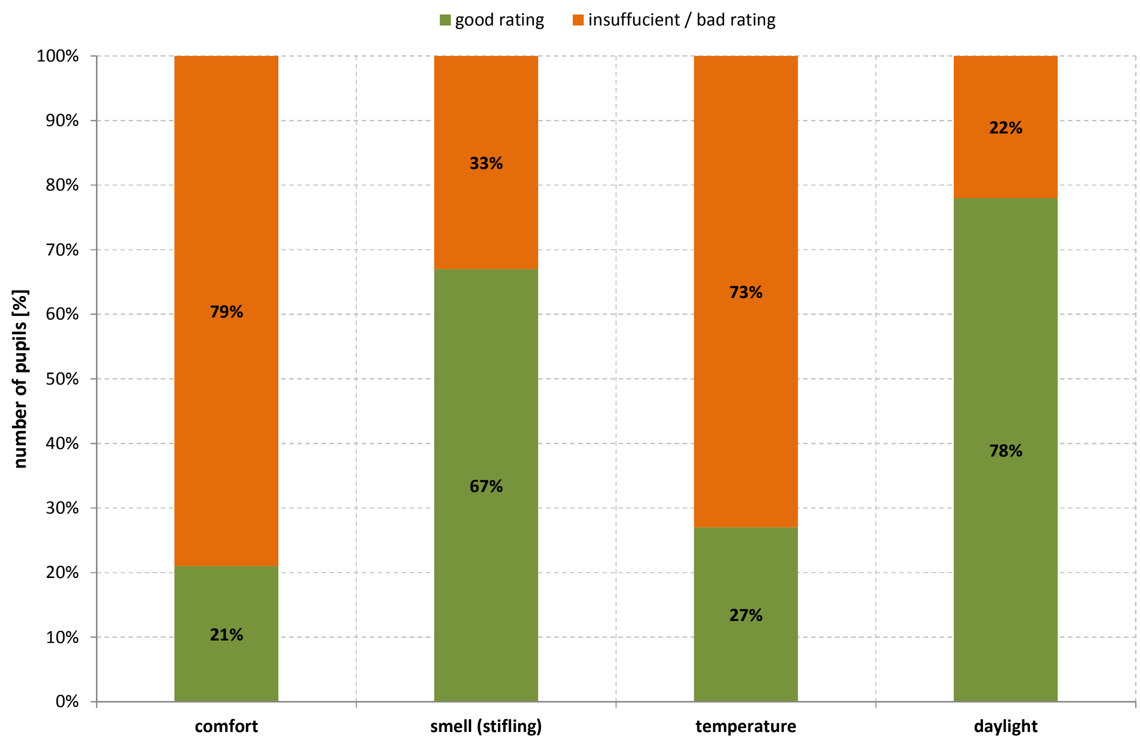


Figure 11 While the comfort of the classrooms is assessed not sufficient in interviews, the same happens only with the room temperature, other objective comfort qualities like smell (fresh air), daylight or humidity got mainly good rating or are unnoticed so far

Calculations and simulations (TRNSYS, iDbuild[1]) were made on different overheating scenarios, by variations of renovation strategies changing shading, ventilation and control systems in different occupied and equipped classrooms. The results verified the thesis that overheating is a serious challenge in future (see Figure 12), first of all in crowded and computerized rooms. After all the key parameters influencing the load of an „average"-classroom[2] could be described like this:

- Internal gains (computers/e.devices, lighting, persons)
- Use of the shading system (mechanically or manually control)
- Ventilation strategy (including night ventilation or not)

[1] "iDbuild" is a hourly-based building simulation tool ideal for generating design advice for use in a goal-oriented design processes, developed by the Technical University of Denmark: http://www.idbuild.dk/

[2] We assumed that also the renovated school buildings are equipped with similar window areas and they have average temperatures around 20°C; quality of windows and insulation is very high.

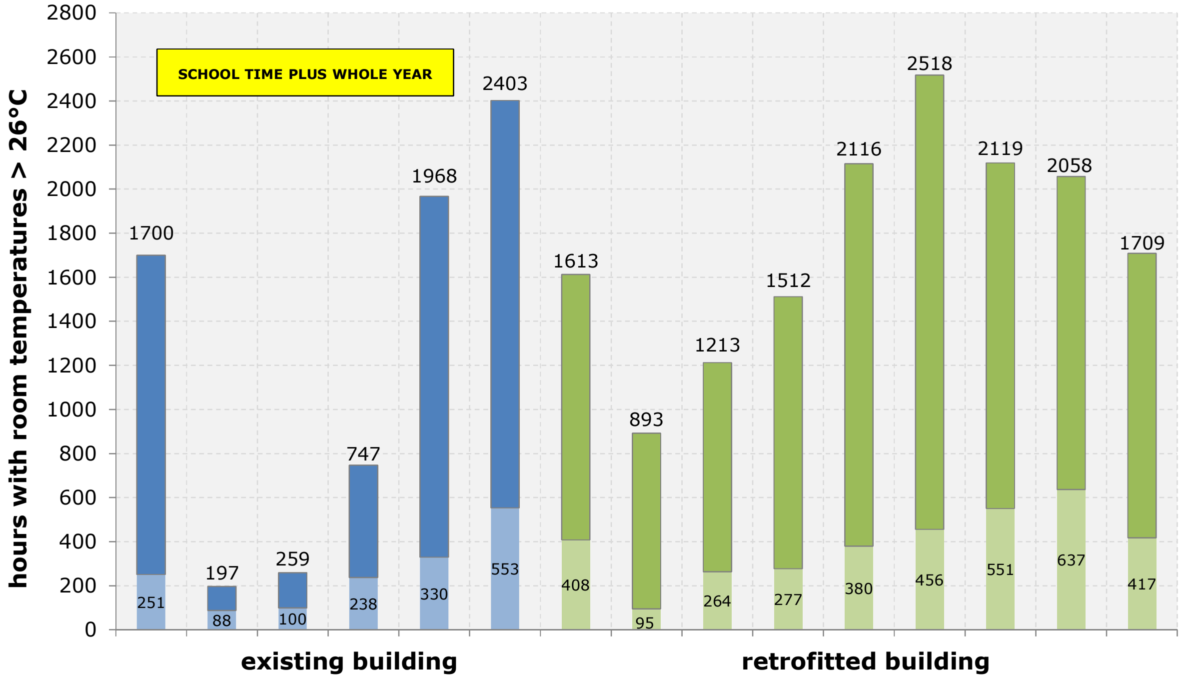


Figure 12 Variations of shading, ventilation, control systems, occupancy and equipment in one typical classroom, performed with iDbuild calculations. The graph shows the hours with room temperatures higher than 26°C for the different variations in an existing compared to a retrofitted school building; the lower numbers in the bars are hours during school time, the higher ones on the top of the bars represent hours of the whole year including summer and holidays

The question in the end is the one about solutions to overcome overheating. As mentioned internal gains should be kept on a very low level (very energy efficient lighting and computers only if necessary in south-, east-, west-rooms), ventilation and most important night-ventilation is crucial for comfortable summer conditions.

A cooperation with the Austrian Solar Shading Organisation (BVST) and the Styrian "Landes-Immobiliengesellschaft mbH" (LIG) made it possible to test three different mechanically and manually controlled shading systems including daylight management and solutions of protection from glare. They should replace the bad shading and daylight conditions in three measured classrooms of the vocational school LBS Gleinstätten in the Styrian countryside. This school was chosen, because of the good cooperation and the typical classroom situations there (Figure 13, Figure 14).

Figure 13: Dark ceiling and shaded disregarded windows lower the incidence of daylight

Figure 14: Bright ceiling but unchecked shading devices inside and outside the window also lower daylight use

The best solution in the sense of managing load and daylight was the one which was not assessed comfortably best by the pupils and teachers (Figure 15, Figure 16): automatically controlled by the direct solar radiation on the facade. Half of the users felt too much disturbance by the blinds automatically going up and down, feeling to have no influence on that. In contrast to that in the interviews before, they assessed the daylight situation as generally not important or properly. After implementing shading pupils and teachers were much more aware of the topic and more critical. The other two shading solutions in other classrooms worked half automatically and full manually – still "unnoticed" (like before their installation). It seemed the shading system should be deliberately disturbing, the only chance to indicate changes.

Figure 15: West-oriented classroom without shading control (Source: Johannes Gerstmann, BVST)

Figure 16: The same classroom after changing outside blinds to bright and mechanically controlled ones (Source: Johannes Gerstmann, BVST)

3.3 Literature

[5] M. Spörk-Dür, W. Wagner, F. Mauthner, K.-P. Felberbauer: Energietechnische und baubiologische Begleituntersuchung der Bauprojekte HdZ, Endbericht für Haus der Zukunft, BMVIT. Gleisdorf, 2010

[6] I. Schwarzl: Überhitzung im Klassenraum und Auswirkungen auf die Leistungsfähigkeit, Ergebnisse von Messungen in verschiedenen Schulen. Presentation at „ökosan'11" conference, 29.09.2011 in Graz

3.4 Deliverables

National deliverables, products and reports (partly to come in spring 2013):
www.aee-intec.at, www.hausderzukunft.at

4 IAQ and school renovation studies - New ventilation solutions

DTU, Denmark

4.1 The costs and economic benefits from ventilation upgrades in classrooms

4.1.1 Justification

Elevated classroom temperatures and poor ventilation can negatively affect the learning process by lowering the performance of typical schoolwork, the academic achievements of children and increasing absenteeism. It is therefore essential that the environmental conditions in classrooms are such that they promote rather than hinder learning and avoid negative consequences for the proper development of young people. Consequently the potentially negative impacts on future generations are avoided as well as increased societal and economic costs.

4.1.2 Objective

The present demonstrations were made to estimate the costs of school renovations comprising also ventilation upgrades and to compare these costs with the potential economic benefits resulting from the improved performance of schoolwork by children.

4.1.3 Research Approach

To examine the costs of school renovations three prototypical schools in Denmark were selected with and w/o mechanical ventilation systems. These schools were selected among the schools used to describe the school typology in Denmark, a part of the school*vent*cool project. The costs of different renovation measures applied singly and/or in combination were estimated; the pay-back times of the investment costs were estimated. The renovations included the installation of the triple-glazed windows with an automatic solar shading system, upgrade of ventilation to meet the requirements of the Danish Building Code, addition of insulation in roof and cellar and installation of a new light facade with better insulation properties. The costs of renovations were compared with the estimated reduction of energy use as well as with the potential economic benefits of improved conditions promoting better learning.

Socio-economic consequences of better air quality in primary schools in Denmark were also estimated. Research results showing that improving classroom air quality can improve the performance of pupils for typical math and language based tasks [11] were used to estimate the effect of improving ventilation rate on learning as measured by PISA, a Programme for International Student Assessment. The estimated improvement of PISA score was associated with the higher productivity and income in the adult life following the reports of [7]. The higher PISA score was also used to estimate the proportion of students taking the 10-year long primary education instead of a 9-year long primary education and the associated costs (in Denmark the elementary education can be 9 or 10 years depending on the level of education and grading; in case of poor grades the pupils are recommended to take the 10th grade). Additionally, using the research results showing that better air quality will result in a lower absence rate [8] the benefits of upgrading the ventilation in schools for the sick-leave of teachers were estimated. In all estimations it was assumed that the ventilation rates in primary schools are improved from the levels currently prescribed by the Danish Building Code to the levels prescribed by the Swedish Building Code; this corresponds to about 40% increase in outdoor air supply rate. It was thus assumed that ventilation in all Danish schools do meet Building Code, which is only partially true as many Danish schools have inadequate ventilation [10]. The estimated benefits are thus conservative. Economic DREAM model (Danish Rational Economic Agent Model) was used to perform the socio-economic estimations of the benefits both for the Danish Gross Domestic Product (GDP) and public expenses. DREAM is a public financed model and used by many different organizations for economic calculations.

4.1.4 Results & conclusions

Figure 17 shows that the different renovation measures undertaken to improve indoor environmental quality in schools and the energy efficiency can be quite costly, particularly when more than one renovation is implemented. The estimated pay-back time of different investments is quite long ranging from 10-20 years up to 50 years and even more. From the economic point of view these renovations may thus not be considered as profitable. However, if the investment costs are compared with the potential benefits from savings due to lower running costs (energy saving) and improved classroom environmental conditions (better control of temperatures and air quality resulting in higher performance of students) the investments are becoming economically attractive. This is illustrated in Figure 18 which shows that assuming that renovations will reduce the expenses needed to cover the teachers' salaries by 5% (due to reduced overtime, extra teaching hours etc. as a result of improved indoor environmental quality in classrooms and consequently higher performance and learning ability of pupils) then there is net benefit of about 10 Eurocents per child per day. The 5% estimate is quite conservative as the results from different research studies suggest that improving classroom conditions can result in up to a 25% higher performance of students [11]; thus if there were proportional relationship the time spend by teachers could be reduced by as much as 25%. In the example presented in Figure 18, the break-even (i.e. equal investment costs and savings) would occur if the renovations had reduced the expenses needed to cover the salaries of teachers by about 3%. Figure 18 shows also that if the cost of investment is expressed per child attending the school the daily cost of investment will be about 20 Eurocents which is far less than the cost of an ordinary lunch box for a child.

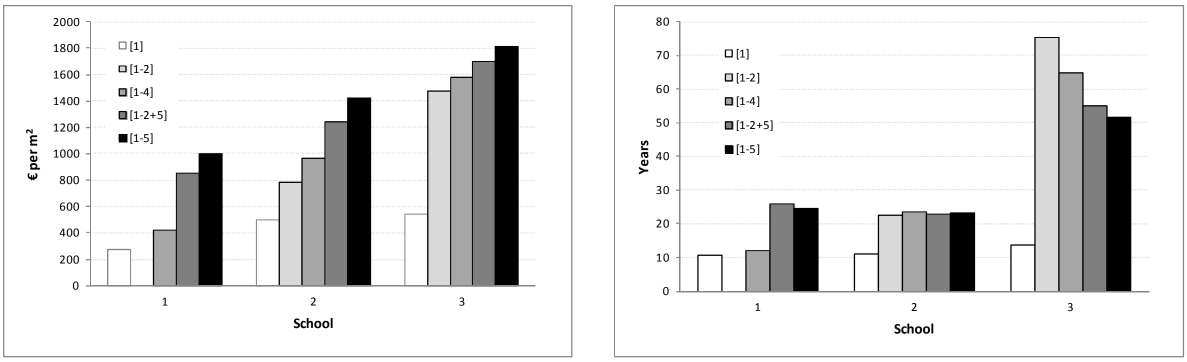


Figure 17: The costs (in €/m² floor) and payback time (in years) of different renovation measures as follows: 1-installation of the 3-glazed windows with an automatic solar shading system, 2-upgrade of ventilation system (or its installation in case of naturally ventilated school), 3-additional insulation of roof, 4-additional insulation of the flooring in the cellar, and 5-installation of the new light façade with extra insulation.

The results of macroeconomic calculations reconfirm the importance of improving the indoor environmental quality, suggesting the long-term benefits of school renovations (Table 1). These results should be treated with caution as they are based on many assumptions which need corroboration by research results. The estimations suggest that the annual macro-economic benefit would be at the level of 1‰ of the Danish GDP which amounted €240 billion in 2011. The benefits are seen both for public expenses and GDP. The benefits for public expenses included lower teaching costs due to more pupils leaving the school after a 9-year long education, and due to reduced absence rate of teachers. They also included increased income from the improved productivity (higher salary of the public officers and thus higher tax incomes following the reports of [7]). The benefits for GDP included again more pupils taking shorter elementary education as well as more productive workforce.

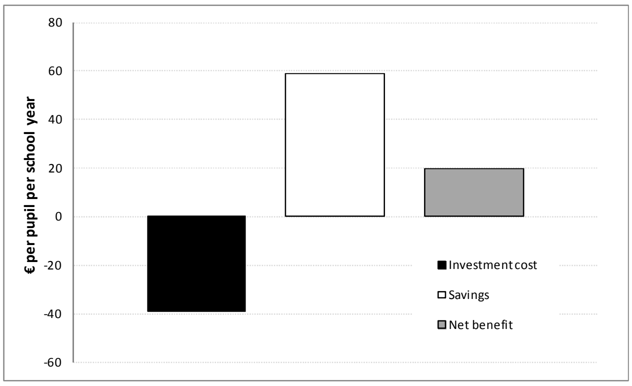


Figure 18: Summary of the annual costs and benefits (in € per pupil attending a school) of the implemented renovation measures; school year in Denmark is 200 school days.

Table 1: Macro-economic effects of improving the indoor environment in Danish schools

	Average annual effect
Public primary balance - total	€37 million
– a) increased productivity	€16 million
– b) fewer pupils in Tenth Class	€15 million
– c) lower teacher sick leave	€6 million
GDP total	€170 million
– a) increased productivity	€104million.
– b) fewer pupils in Tenth Class	€67 million
– c) lower teacher sick leave	None

In conclusion:
School renovations are quite costly but the present estimations demonstrated that the renovations resulting in improved indoor environmental conditions in the classrooms can provide the immediate and long-term revenues not only in form of the benefit for the nation-wide economy as well local-community economy but also because of the general improvement of learning conditions for the young population and thereby the improvement of quality of life and the elevation of the education level.

4.1.5 Literature

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[11] Wargocki, P., and Wyon, D.P. (2013) “Providing better thermal and air quality conditions in school classrooms would be cost-effective”, Building and Environment, 59, 581-589.

4.1.6 Deliverables

Marxen, C., Knorborg, R.B., Hviid, C.A., and Wargocki, P. (2011) "Hvad koster et godt indeklima på folkeskoler?" (What is the cost of good indoor climate in primary schools? in Danish), HVAC Magasinet, 9, pp. 40-49.

Slotsholm (2012) "Socio-economic consequences of better air quality in primary schools", Report prepared by Slotsholm A/S in collaboration with Velux A/S and the Technical University of Denmark.

4.2 The performance of different ventilation strategies on indoor air quality and temperatures

4.2.1 Justification

Many studies have shown that the environmental conditions in elementary schools are often inadequate. The main reasons for this situation are inadequate financial resources for the maintenance and upgrade of school buildings, and an overemphasis on energy conservation. Consequently, classroom temperatures are allowed to drift above the recommended range of 20-22°C in warm weather and outdoor air supply rates are allowed to remain so low that carbon dioxide (CO_2) levels regularly exceed 1.000 ppm during school hours, i.e. that energy conservation is allowed to create conditions that are worse than what is stipulated by the relevant standards and building codes.

4.2.2 Objective

The present study was designed to investigate how different ventilation strategies would affect classroom indoor air quality and temperatures during different seasons of the year.

4.2.3 Research approach

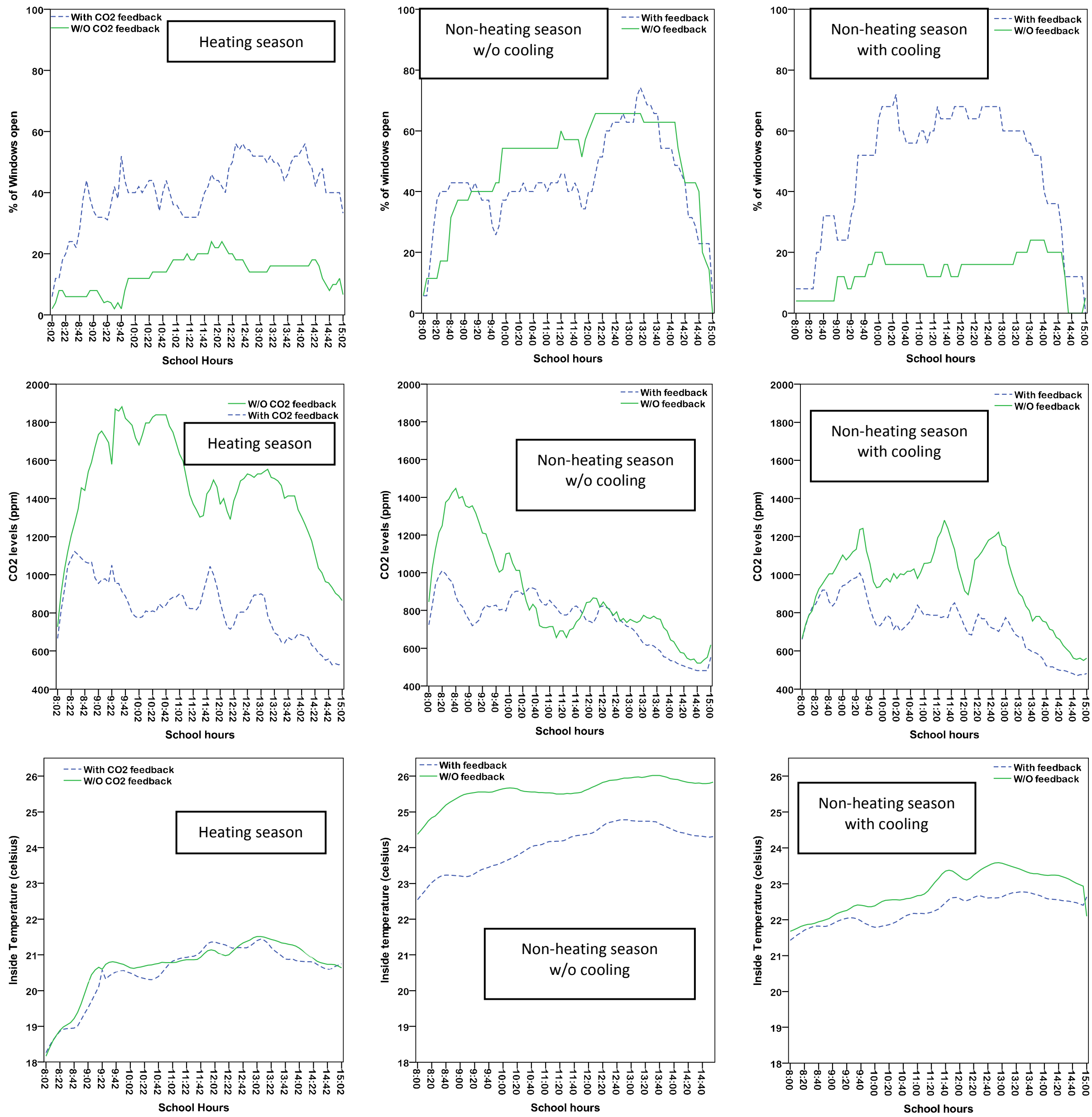
To study different ventilation strategies two series of experiments were carried out in two different schools in Denmark.
In the first series CO_2 sensors that provide a green/yellow/red visual indication were installed in pairs of naturally ventilated classrooms during normal school operation. During a two-week period in the heating and the non-heating season, teachers and students were instructed to open the windows in response to the CO_2 feedback in one week and open them as they would normally do, without feedback, in the other week. In the non-heating season, two pairs of classrooms were monitored, one pair with split cooling in operation and the other pair with no cooling. The resulting indoor environmental conditions in these classrooms and window opening behaviour were monitored. [14]

In the second series of experiments the conditions in the classrooms with different ventilation strategies were monitored for the period of one month in the heating season and for one month in the non-heating season. Four classrooms were selected in one school. One classroom had the mechanical balanced ventilation system and all others had the designed mixed mode ventilation system in which the air was supplied by automatically operable windows and exhausted by the exhaust fan installed in each of the classrooms. In two classrooms selected randomly the systems were modified by idling the exhaust fan to create the conditions corresponding to the naturally ventilated classroom with automatically operable windows, and in another one by idling both the exhaust fan and automatic operation of windows to simulate naturally ventilated classroom with manually operable windows. Similarly as in the first series of experiments described above, the temperature, classroom CO_2, relative humidity and window opening behaviour were continuously measured to compare the performance of the different ventilation systems. [12] [13]

In both series of experiments the pupils were asked to report their perceptions and the acute health symptoms often referred to as the Sick Building Syndrome (SBS) symptoms or Building Related symptoms (BRs).

4.2.4 Results & conclusions

Providing CO_2 feedback in the first series of experiments caused that more windows were opened and this reduced CO_2 levels in the classroom especially in the heating season (Figure 19). Operation of split-cooling in the non-heating season reduced on the other hand the frequency of window opening when no CO_2 feedback was present (Figure 19), suggesting that classroom temperature is the driving factor for this behavioural response. Children generally liked CO_2 feedback; their perceptions and symptoms were somewhat improved with CO_2 feedback, although many of these changes did not reach formal statistical significance.



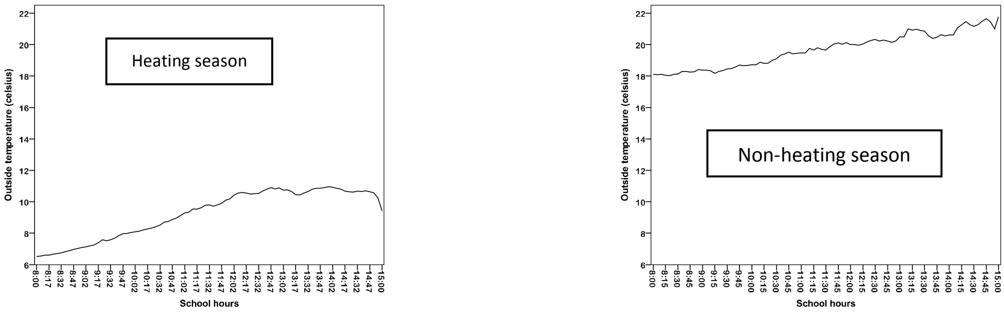


Figure 19: Time-weighted average of % windows opening, CO_2 concentrations and classroom temperature during school hours with and without CO_2 feedback; the last row shows the time-weighted average values of the outdoor temperatures registered during the experiments

The results of the monthly long measuring campaigns performed in the second series of experiments both during the heating season (with average outdoor temperatures of ca. 2°C) and during the non-heating season (with average outdoor temperatures of about 16°C) are shown in Figure 20. They suggest that conditions in the classroom with natural ventilation where windows were opened manually were slightly inferior compared with the conditions in classrooms which had other types of ventilation. Natural ventilation was not able to maintain comfortable indoor temperatures in the non-heating season, leading to elevated classroom temperatures and overheating, and adequate ventilation in the heating season as indicated by high CO_2 levels. The conditions in classroom with mechanical ventilation can be judged as better than in other classrooms except the classroom ventilated by the hybrid system i.e. by automatically operable windows with exhaust fan. In this classroom the conditions can be considered as comparable with the conditions in classroom with mechanical ventilation system.

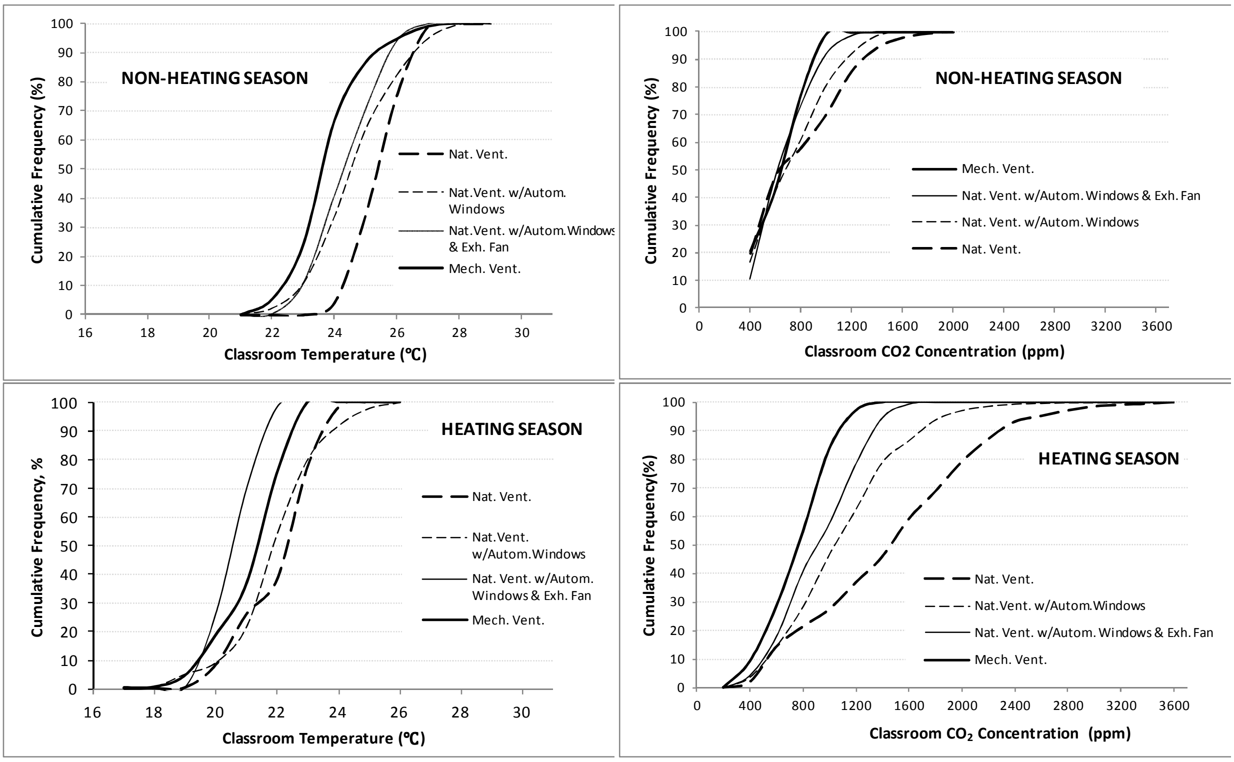


Figure 20: Cumulative frequencies of temperatures and carbon dioxide levels during heating and non-heating seasons in classrooms with different types of ventilation

The measurements performed in the second series of experiments showed additionally that windows were frequently opened in the non-heating season independently of the type of ventilation in the classroom and nearly equally as much in different classrooms (Figure 21). The windows were opened very seldom in the heating season (Figure 21). This suggests that outdoor climate and the season may have the impact on this behavioural response.

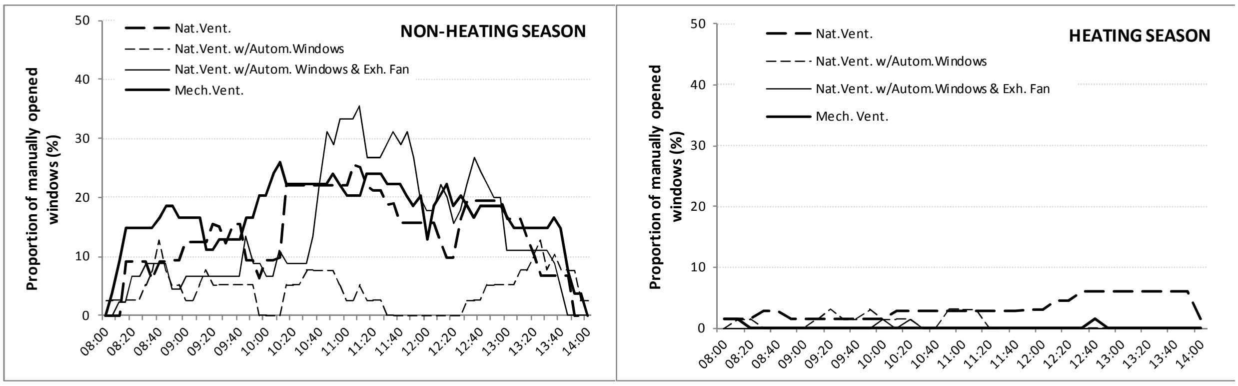


Figure 21: Time-weighted proportion of manually opened windows during heating and non-heating season in classrooms with different types of ventilation

The following can be concluded using the results obtained in the described two series of experiments:

- In temperate climates hybrid ventilation systems seem to provide classroom conditions comparable with the conditions achieved using mechanical ventilation system.
- Airing classrooms by the manual opening of windows is not able to create the adequate conditions in the classrooms as regards indoor temperatures and indoor air quality for the entire school year when building is located in the area with moderate and cold climate. This is true if only no feedback is given to pupils and teachers to indicate when windows should be opened.
- The use of CO_2 feedback may be recommended as a feasible solution for controlling classroom air quality in rural schools with natural ventilation when ambient climate conditions are fairly mild and where ambient air is of a good quality.
- Classroom temperature and the season seem to be the main factors affecting window opening. Cooling of naturally ventilated classrooms may be counter-productive as it will have a negative effect on this behavioural response and may result in poor classroom air quality. During cold winter days windows are opened very seldom probably to avoid cold draughts.

4.2.5 Literature and Deliverables

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4.3 Diffuse ventilation ceilings

4.3.1 Justification

School classrooms are characterized by high occupancy and high thermal load. Consequently high ventilation rates are required which can be difficult to fulfil with conventional inlet diffusers without causing draught.
Development of new concepts to ventilate school classrooms is therefore relevant and one promising solution is diffuse ventilation air inlet. The concept is commonly used in livestock buildings [15] and in the clean room industry [16], yet it is increasingly employed in comfort ventilation. [17] [18] [19] The principle of diffuse air inlet in comfort ventilation is to inject the supply air into a pressure chamber above a standard suspended acoustic ceiling. The air is distributed to the room below through cracks and perforations. The flow velocity is very small and irregular, hence the term diffuse.

4.3.2 Objective

The objective was to validate how diffuse ceiling inlet performs in practise and to document the applicability of diffuse ceiling ventilation in classrooms.

4.3.3 Research Approach

A diffuse ceiling was installed in a classroom at Vallensbæk primary school. The investigation encompassed several elements to document the thermal comfort and to map the air distribution in a class room with diffuse ventilation air inlet, including: local comfort by air temperature and air velocity, air change efficiency, and radiant asymmetry.
The present study was designed to investigate the performance of diffuse ceiling inlet under real conditions in a classroom.

4.3.4 Results and conclusions

Four scenarios of measurements were performed at airflow rates of 500 m^3/h and 1000 m^3/h and inlet temperatures of 10 and 17°C. The airflows correspond approximately to indoor environment category 3 and 1 in the European Standard 15251. The classroom is usually occupied by 24 pupils in 6th grade (age 11-12).
The measurements were performed in 8 points evenly distributed and placed close to tables in the occupied zone of the room.
At each point the air velocity and temperature was measured at heights of 0.1 m and 1.1 m corresponding to ankle and neck level of a sitting person as specified in CR1752 and each measurement was averaged over 3 minutes.

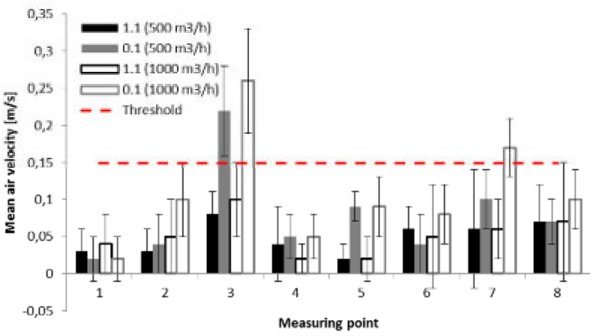

Figure 22: Measured air velocities at flow rates of 500 and 1.000 m³/h with a supply temperature of 17°C

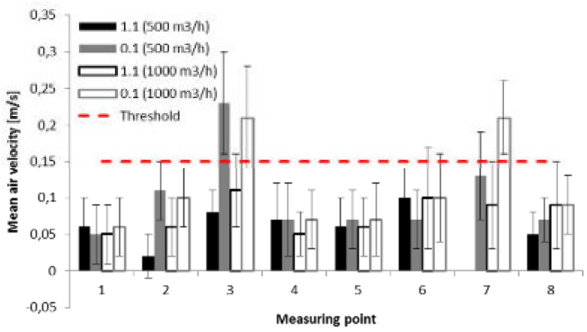

Figure 23: Measured air velocities at flow rates of 500 and 1.000 m³/h with a supply temperature of 10 °C

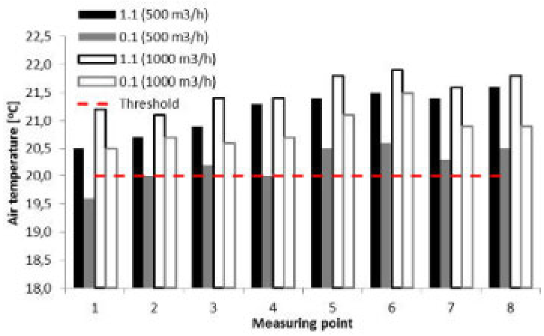

Figure 24: Measured air temperatures at 0.1 and 1.1 m above the floor and flow rates of 500 and 1.000 m3/h with a supply temperature of 17°C

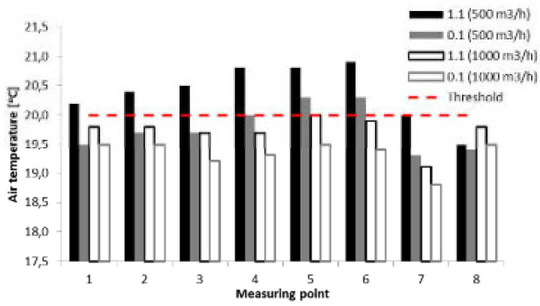

Figure 25: Measured air temperatures at 0.1 and 1.1 m above floor and flow rates of 500 and 1.000 m³/h with a supply temperature of 10°C

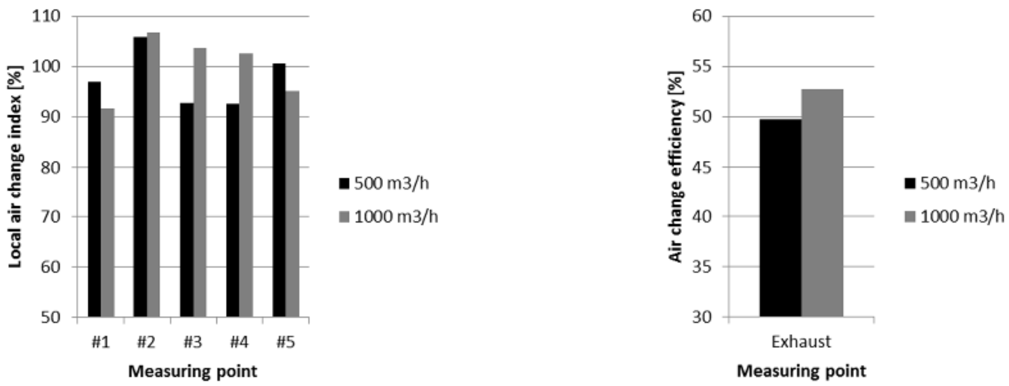

Figure 26: Left: Local air change index at sampling points. Right: Air change efficiency. 50 % corresponds to perfect mixing ventilation

The objective of the work in this paper was to validate the performance of diffuse ceiling ventilation in practise and document its applicability in school classrooms. Based on the investigation the following can be concluded on diffuse ceiling ventilation.

- The experimental results are in good agreement with previous results from test facilities and simulations.
- Virtually no risk of draught at low or high flow rates.
- Uniform airflow field with little difference between ankle and head height.
- Uniform temperature distribution with little difference between ankle and head height at both high and low flow rates.
- Negligible radiant asymmetry
- Perfect air mixing throughout the room independent of airflow rate.

Overall the results are positive and no negative aspects were detected. It is therefore concluded that diffuse ceiling ventilation in the studied form is applicable for use in school classrooms.

4.3.5 Literature

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[16] Chow, T.T. and Yang, X.Y. (2004). "Ventilation performance in operating theatres against airborne infection: Review of research activities and practical guidance". J. Hospital Infection 56, 2, 85-92.

[17] Nielsen, P.V. and Jakubowska, E. (2008). "The performance of diffuse ceiling inlet and other room air distribution systems". Proceedings of Cold Climate HVAC, Sisimiut, Greenland

[18] Hviid, C.A. and Svendsen, S. (2013). Experimental study of perforated suspended ceilings as diffuse ventilation air inlets, Energy and Buildings 56, 160-168

[19] Jacobs, P., van Oeffelen, E.C., Knoll, B. (2008). Diffuse ceiling ventilation, a new concept for healthy and productive classrooms, in: Proceedings of Indoor Air, paperID#3, Copenhagen, Denmark.

4.3.6 Deliverables

Hviid, C.A. and Terkildsen, S. (2012). "Experimental study of diffuse ceiling ventilation in a classroom". Proceedings of AIVC 2012, Copenhagen, October 10-11

4.4 Free cooling potential by diffuse ceiling ventilation

4.4.1 Justification

Distributing the supplied air via the plenum allows for a continuous direct contact between the room air and the thermal mass of the concrete slab in the (internal) ceiling. The effect of more exposed concrete on excessive temperatures and free night cooling has been quantified by a large number of simulations and experiments. [20] [21] [22] However, in practice the thermal mass of the concrete slab in the (internal) ceiling is often encapsulated by a suspended ceiling. This inhibits significantly the free cooling potential of the room which was demonstrated by [22] by removing the suspended ceiling. But removing the suspended ceiling does not address the matter of acoustics – especially in class rooms.

4.4.2 Objective

The study was designed to investigate the effect of supplying air to the room through an upper plenum between the room and the concrete slab.

4.4.3 Research approach

The free cooling potential of diffuse ceiling ventilation has been numerically investigated when the cooling air is supplied above the suspended ceiling. A dynamic building simulation tool is employed to quantify the potential as the consequence on thermal indoor environment quality. In order to model the heat transfer at the internal surfaces in the plenum correctly, a computational fluid dynamics tool is employed.

The potential is illustrated by comparing the simulated thermal indoor environment quality of two ventilation scenarios for a classroom with conventional mixing ventilation and diffuse ceiling ventilation.

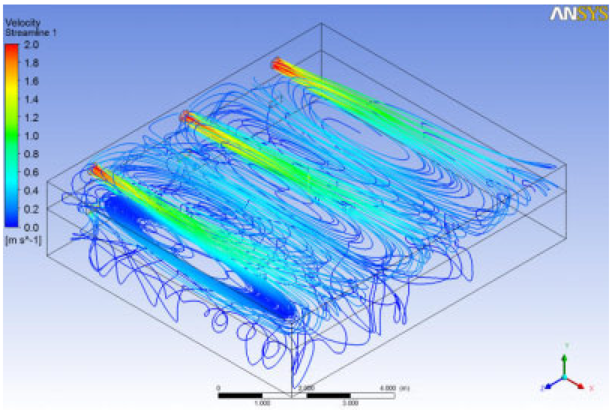


Figure 27: Streamline jets from inlets in plenum

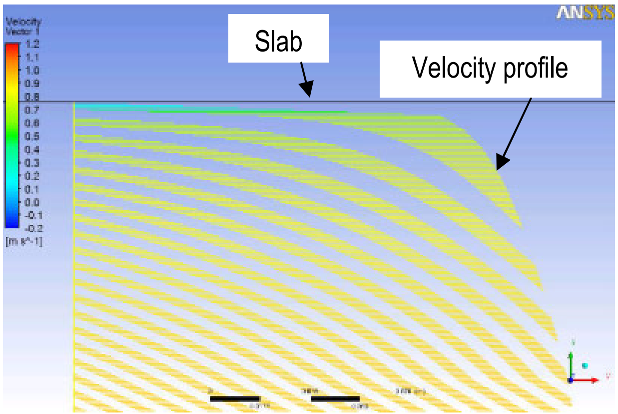


Figure 28: Logarithmic velocity profile of jet near concrete slab surface

4.4.4 Results & conclusions

The free cooling potential is illustrated by comparing the simulated thermal indoor environment of the two ventilation scenarios for a class room, 1) mixing ventilation and 2) diffuse ceiling ventilation. The thermal indoor classes I-IV introduced with EN15251 (EN15251 2007) are designated with the colours white, green, yellow and red and show the amount of time the operative temperature is within a certain comfort range. It is clear from the figure that the percentage of time with overheating (class III and IV) is significantly reduced from 19% to 6% on a yearly basis. However, it is notable that excess overheating occurs even in winter. This is due to the high internal heat gain in the classroom which creates overheating even in winter. This period in particular gains from the extra free cooling potential as overheating is reduced from 22% to 0%.

The number of hours in comfort range I and II shifts from I to II moving from mixing to diffuse ventilation. This is because the overall indoor temperature is lower in the diffuse situation and temperatures below the lower comfort limit in class I are more prevalent.

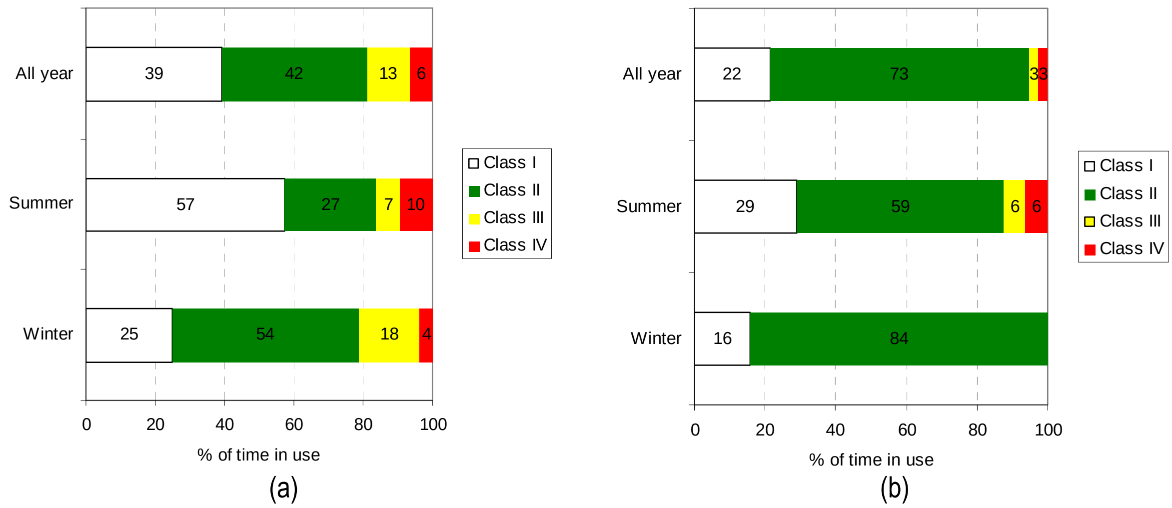


Figure 29: Thermal comfort during occupancy with mixing ventilation (a) and diffuse ceiling ventilation (b). Green and white colours are within normal comfort range.

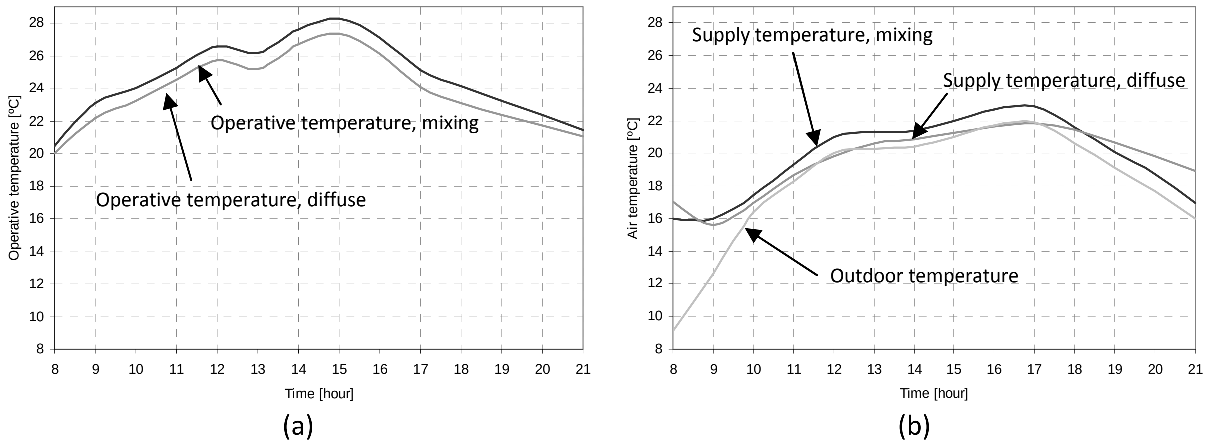


Figure 30: Operative temperatures in classroom (a) and ventilation supply temperatures (b) on example date May 3 with mixing and diffuse ceiling ventilation

The concept sketched here raises some issues regarding the optimal control strategy. Ideally the concrete slab is cooled at night by outside air to a temperature where the cooling capacity is sufficient for the entire next day. However, if the slab is cooled too much, the supply air from the plenum will be too cold the next day thus requiring heating energy. Furthermore, the inlet air should be controlled with respect to outdoor humidity to prevent condensation in air ducts and plenum. An optimal control of temperature as well as humidity might include the use of weather forecasts and other predictions together with building simulations.

It is also important to ensure a sufficient cooling capacity of the concrete slab and room constructions because mechanical cooling, in the event that free cooling is insufficient, can become particularly energy expensive with this concept as the concrete in the plenum must be cooled first. Also the penetration depth of low temperatures within the concrete slab, and consequently the surface temperature on the upper floor, should be given consideration in the control strategy, particularly during winter season.

Extra free cooling potential can be made available by activating the thermal mass of the concrete slab in the plenum of ceiling ventilation. The simulations included investigations of two scenarios with a building simulation tool with CFD-derived surface heat transfer coefficients of the concrete slab. The results showed clearly the effect of the extra exposed thermal mass by overall lower operative temperatures in the classroom in both summer and winter situations. Also peak temperatures were lower.

4.4.5 Literature

[20] Kolokotroni, M. (1998) "Summer cooling with night ventilation for office buildings in moderate climates". Energy and Buildings, Vol. 27, No. 3, 231-237

[21] Kolokotroni, M. and Aronis, A. (1999) "Cooling-energy reduction in air-conditioned offices by using night ventilation". Applied Energy, Vol. 63, No. 4, 241-253

[22] Høseggen, R., Mathisen, H.M. and Hanssen, S.O. (2009) "The effect of suspended ceilings on energy performance and thermal comfort". Energy and Buildings, Vol. 41, No. 2, 234-245.

4.4.6 Deliverables

Hviid, C.A. and Petersen, S. (2011) "Integrated ventilation and night cooling in classrooms with diffuse ceiling ventilation". Proceedings of ökosan'11 conference, Graz

5 Renovation Strategies

FHNW, Switzerland

5.1 Objective and Research Approach

The fundamentals for the adaption of school buildings are based on the boundary conditions derived from typology and on the specific technical requirements of school buildings. With the international cooperation, the school renovation concepts should also be applicable and adaptable to other countries and furthermore incorporate new findings into the own solution.

The Swiss part of the school*vent*cool project regarding renovation strategies consists of four objectives:

1. Knowhow transfer between the IEA ECBCS Annex 50 and the ERACOBUILD research partners to align the level of knowledge
2. Typological analysis, case studies and deriving of guidelines for the technical development of modules and optimisation of construction processes
3. Adaption and further development of facade and roof modules from IEA ECBCS Annex 50 [23] to the specific requirements of school buildings
4. Synthesis report

General delimitation:

The concept of the IEA ECBCS Annex 50 is entirely based on external insulation. In this project, no solutions with internal insulation are investigated. The focus of this project is only non-protected buildings and facilities. This project adapts the typological method and the prefabricated building envelope systems for multifamily houses of IEA ECBCS Annex 50 to school buildings. Further building types are not investigated.

5.2 Results & conclusions

The results were derived by exchange and in cooperation with the participating countries. Cross discipline, institutionalised international exchange with key personnel in Switzerland and abroad led to the findings described in the following.

5.2.1 Fresh air demand

The starting point for the design of prefabricated façade modules with integrated ventilation is based on solutions for multifamily houses as described in [23]. School buildings differ significantly in the amount of required fresh air. This is for classrooms 25 to 30 m^3/h/person [24], where a mixed air flow in the room has to be assumed. Typical sizes of classes with 20 to 26 children plus one to two teachers result in a fresh air demand of 525 – 840 m^3/h. Assuming a classroom of 10 m facade length with 7 m of room depth leads to a specific fresh air demand of 7.5 - 12 $m^3/h/m^2_{floorsurface}$ or of 53 - 84 $m^3/h/m_{façade\text{-}length}$.

5.2.2 Adaption of façade modules from multifamily houses to school buildings

The approach of façade integrated ventilation ductwork leads, for school buildings with big necessary pipe diameters in the range of 0.2 - 0.3 m, to a stronger impact on the architectural appearance of the building. The areas of vertical ductwork dominate the appearance of the façade so strong, that these can hardly be valid solutions.

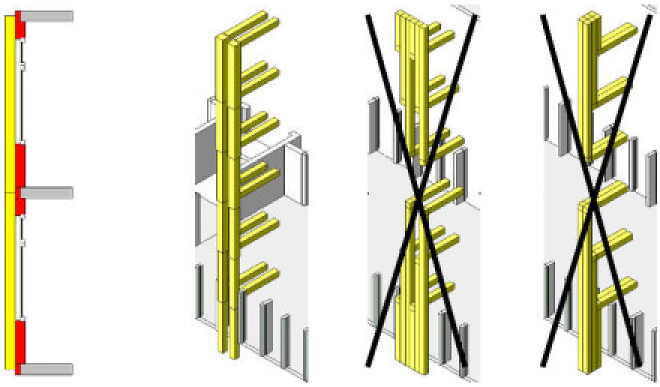


Figure 31 left: façade intersection with additionally mounted modules, right: discussed ventilation ductwork inside the façade elements

One limitation is that these pipe dimensions cover too much window area especially for multiflorous buildings. The ratio between masonry and window is too often unfavourable. Even with greater insulation thicknesses it is only under very limited conditions possible to place the ductwork inside the façade invisible to the outside. Figure 31 depicts discussed piping concepts inside the façade and their effect schematically. In deviation to the individual vertical piping per room like in the multifamily modules, the situation may be somewhat mitigated by common distribution ductwork, taking into account the special fire prevention rules.

Due to the limited transferability, a new approach for the supply of fresh air to classrooms from the façade was addressed. Figure 32 shows a schematic representation of the subsequently selected way-of-thinking. The central issue is how much fresh air demand can be satisfied by a limited façade area considering occupation density or room depth.

With these basic considerations now correlations between typological and constructive criteria were sought.

Figure 32: Ability of a façade area to satisfy a necessary fresh air demand

5.2.3 Ventilation concept and module construction

Centralised ventilation with vertical ductwork

The limiting criterion for the use of a central ventilation unit with vertical distribution ductwork in the façade modules, as shown in Figure 32, is the required space in vertical direction in the façade as well as the parapet and lintel situation. Hence, rooms located behind a banded façade cannot be served directly from the outside wall with the vertical distribution concept. This ventilation type is therefore suitable for buildings of solid construction with punctuated façades under the condition that the distance between the windows allows a vertical ventilation distribution.

Centralised ventilation with vertical and horizontal ductwork

The relevant features of a combined vertical and horizontal ventilation supply correspond to the central ventilation system with only vertical distribution system. Closely spaced or contiguous façade openings that block vertical distribution can be solved in combination with horizontal distribution (e.g. buildings with skeleton structure and banded façade). For the horizontal distribution especially parapet and lintel heights are relevant, and because of the duct dimension an installation of the ductwork without crossing. Figure 33 shows two schematic solutions for horizontal air distribution and access to the room.

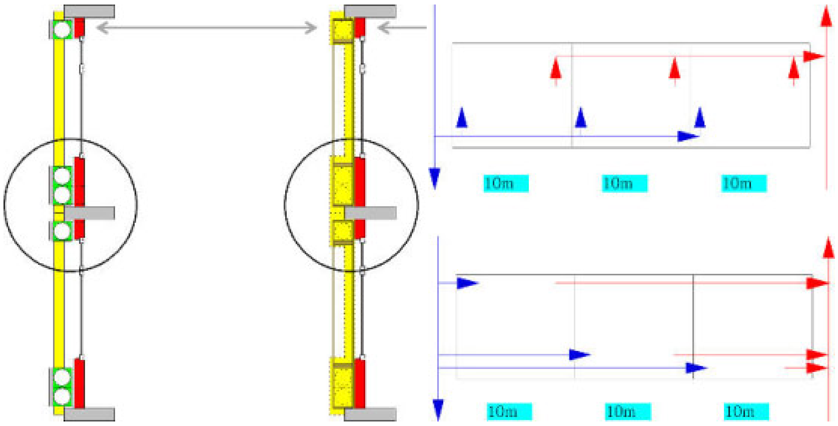


Figure 33 Central ventilation with horizontal air distribution and smaller effect on architecture; Left: Cross section of two façade-Storeys; Right: Elevation of two façade-storeys with horizontal ductwork

Decentralised ventilation per room

Decentralised ventilation units serving single rooms can be placed in the lintel or parapet area. Therein the height of the units and the construction of outside wall are the limiting criteria (c.f. Figure 34). Decentralised ventilation units are more suitable for non-load-bearing exterior than for massive wall constructions since they are located in the field of load-bearing building parts for supporting exterior walls [25]. Especially with decentralised ventilation units one has to pay attention to avoidance of shortcuts between supply and return and to sound emissions.

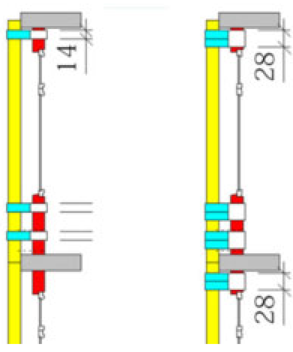


Figure 34: Decentralised ventilation with façade integrated ventilation units

5.2.4 Procedure of module selection during planning

Depending on the construction of the external walls the prefabricated façade modules are mounted onto the existing façade, especially for massive construction load-bearing exterior walls (i.e. punctuated masonry façade).

For skeleton constructions with non-load-bearing exterior walls (e.g. curtain wall façade elements) the existing elements are replaced with the prefabricated new façade modules. Figure 35 shows schematically a guide for the selection of suitable façade modules during the planning phase of a specific building project.

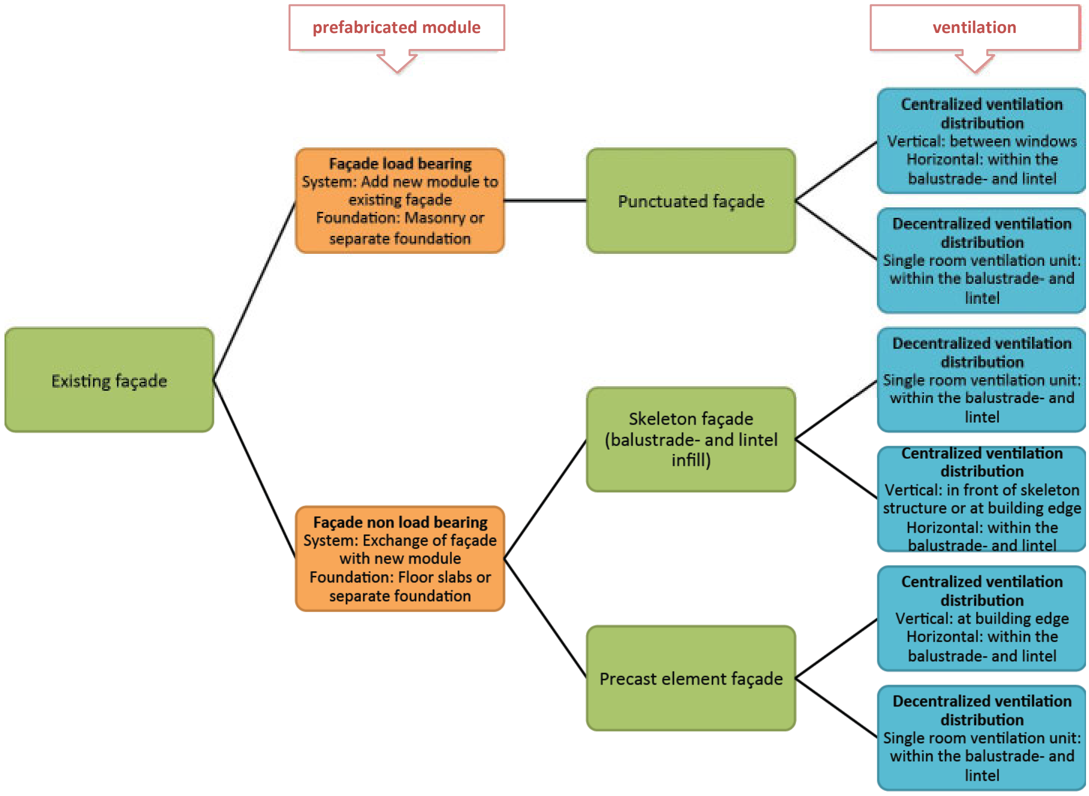


Figure 35 Link between typology and construction/ventilation in the planning phase

5.2.5 Krummbach dwelling and school building

The project is located in the open countryside between the two municipalities Krummbach and Geuensee (CH) on 700 m above sea level. The two-storey building (c.f. Figure 36) with a total of 572 m^2 energy reference area consists of two connected wings, a residential and a school wing. The Krummbach School was taken out of service in 2003. The building was no longer used and stood empty for several years. 2009, the new owner acquired the building with the intent to occupy the residential part and to use the school wing for adult education in the communicative, creative field. In 2010, the architectural design was started. In February 2011, the construction company was defined by the client. In the beginning, the owner only wanted to achieve the legal requirements of energetic quality and it was provided no mechanical ventilation with heat recovery. The connection to the research project “CCEM advanced retrofit” [26] was made in spring 2011 and led to enhancements like façade-integrated ventilation, a slight enhancement of the thermal insulation and the use of renewable energy in the form of photovoltaic on the roof. The intended energy labels were Minergie-P, Minergie-ECO and Minergie-A and are likely to be achieved. The prefabricated façade modules were mounted on September 12th/13th and have been produced the week before. The entire building was completed in late 2011. The project is suitable for the observation of the building process in practice in terms of planning and construction of prefabricated façade modules with integrated ventilation ducts. Furthermore, first insights into the transformation of the modules for the renovation of school buildings could be gained.

Figure 36 View of the Krummbach building at the begin of renewal (left) and before finishing (right)

The analysis of ventilation ducts in prefabricated façade elements is so demanding and decisive that they got the status of “the critical path” (see detailed explanation in chapter 2.2.4 of [23]). The architectural preparations were already completed before the decision for modules with integrated ventilation ducts was taken. Thus, the additional finding of changing to a system with integrated ventilation shortly before production without big additional effort in this case could have been made along the way. However, it should be noted that the design of the ventilation ducts was rather easy in this case. Lower air change rates than in typical schools could be assumed since the owner expects a maximum occupancy of 10 persons per classroom. Thus, supply and return air duct can provide a sufficient amount of fresh air with two tubes of 80 mm diameter for each direction. The positioning of the ventilation units and the installation of the ductwork are depicted in Figure 37.

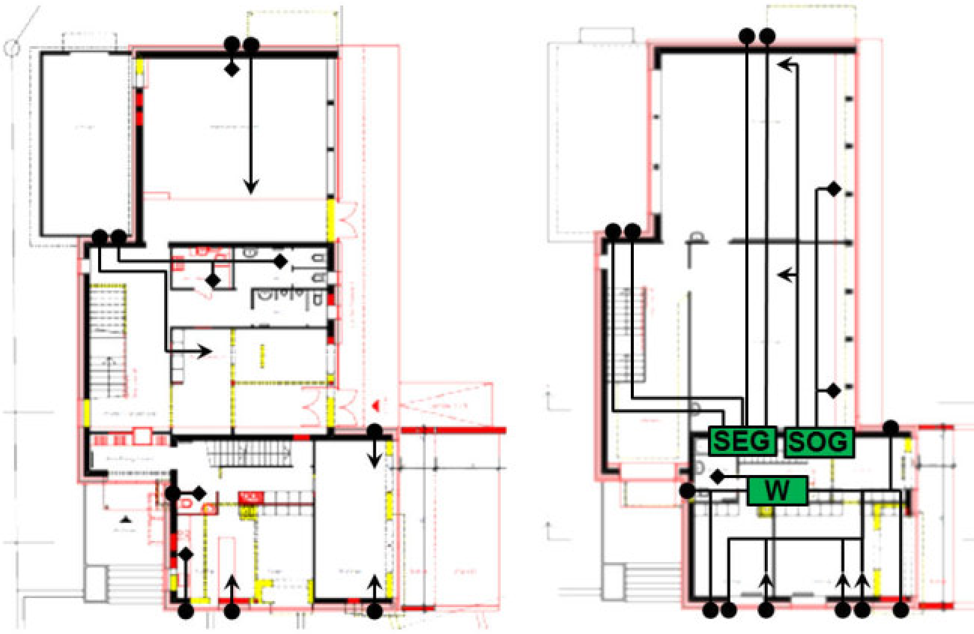


Figure 37 Floor plans of the Krummbach-building – left: ground floor / right: first floor
Legend: SEG: Ventilation unit for groundfloor of school wing / SOG: Ventilation unit for upper floor of school wing / W: ventilation unit dwelling / →: supply air / ⟶•: return air / ─●: vertical ventilation duct inside the facade

During the planning of the façade modules, the ventilation ductwork with insulating and fixing half-shells (called “Flumroc”-half-shells) of 140x140mm give clear measures for intersections in the façade modules. For smaller school buildings also slightly bigger half-shells with bigger ducts are still conceivable. The half-shells have slots for the exact positioning and fixation of the ventilation tubes. In the factory-made cut-outs at defined positions with accurate measure the half-shells are introduced. With exact measure compliance sufficient pressure arises from the half-shell on the metal ventilation tube, so that a falling out is prevented during assembly.

Figure 38 left: Detail of a ventilation duct during production of the facade modules in the factory right: Joining of two modules during assembly with ventilation ducts at the building site

In Figure 38 left, the upper half-shell still has to be inserted. The geometric requirements force the planner and the craftsman to a common planning before the module production begins. Figure 38 right shows the joining of two façade modules during assembly at the building site. The lower module is already fixed and duct connectors are inserted. The upper façade module is now lowered just above the lower one, so that the connectors can be plugged into the upper module, and then completely settled on the lower one.

5.3 Conclusion

The principle of planning for prefabricated modules with integrated ventilation for school buildings is based on the "critical path of ventilation". The significantly thicker ventilation ducts for school buildings (with centralised ventilation) result in the fact that a one-to-one transfer of multifamily building modules cannot always be applied. A solution "in between" like in Krummbach should however not be underestimated since there are many smaller school buildings where the solution could still be suitable. The prefabrication of façade modules requires an appropriate knowledge in the local timber construction industry and a sufficient level of necessary experience which both has to be set-up soon in the most European countries.

5.4 Literature

[23] "IEA ECBCS Annex 50 – Retrofit Module Design Guide – Part A"; Kobler R.L., Binz A., Steinke G.; Institute of Energy in Building – FHNW; Muttenz 2011 (available at http://www.empa-ren.ch/A50.htm)

[24] „Classroom ventilation must be improved for better health and learning"; Wyon D.P., Wargocki P.A., Toftum J., Clausen G.; REHVA-Journal 47-4 S.35-39; ICIEE-DTU; Copenhagen 2010

[25] „Schulhauserneuerung – Typologie und Vorfabrikation, Tagungsband Ökosan 2011"; Heim T., Fischer R., Schwehr P.; AEE-INTEC – Institut für Nachhaltige Technologien; Gleisdorf 2011

[26] „CCEM Retrofit - Advanced Low Energy Renovation of Buildings"; http://www.empa-ren.ch/ccem-retrofit.htm, accessed on 14th March 2013

5.5 Deliverables

Deliverables and reports are available (partly to come in spring 2013) from:
National Weblink: http://www.fhnw.ch/habg/iebau/afue/gruppe-bau/schoolventcool-eracobuild
Swiss Government: www.bfe.admin.ch
School*vent*cool brochure: see Chapter 7.6!

6 Design criteria for implementing ventilation in existing schools

DTU, Denmark

6.1 Justification

The appropriate ventilation solution for an existing school is primarily constrained by the existing conditions (service space, load-bearing elements, room height, location etc.) and secondarily by trade-offs between initial costs, running costs, desired indoor climate quality, expected energy use and aesthetics. The task of determining a ventilation solution for classrooms is therefore a complex task where various interrelated performance variables need to come together as a whole.

6.2 Objective

In this study, a criteria list in the form of design charts for natural, mechanical and mixed solutions is generated. The aim is to enable designers to determine the most appropriate type of ventilation for any existing school, which currently has no ventilation, in an easy and quick way.

6.3 Research approach

In this study we seek to facilitate this complex task by decomposing the problem complex into manageable variables and assign best-practice values to them. The Figure 39 shows the aspects of ventilation that is linked to the design of ventilation in classrooms. Each category can be divided into many more subcategories, e.g.:

- energy consumption is a function of heat exchange efficiency and air transport efficiency
- building characteristics are a function of internal and external structural elements
- initial costs are dependent on the challenges/compromises that proper ventilation implementation causes to the structural integrity of the building
- running costs are a function of maintenance, salary, and energy costs
- comfort is dependent on many factors, e.g. the air quality (ventilation rate), the temperatures, filtration, noise, the ability to use energy-efficient night cooling

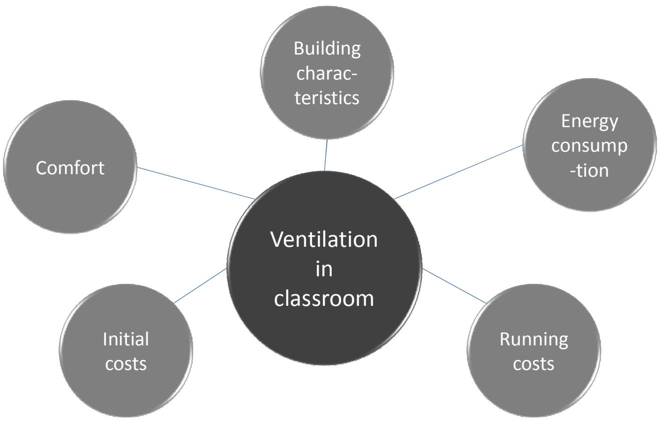


Figure 39: The aspects of ventilation that the designer of classroom ventilation must relate to during the design process.

6.3.1 Building typology

The structure in some schools comprises load-bearing outer and inner walls while others are built from columns and beams with light façade elements and partitions. Ventilation requires space and penetration of structural elements is, if possible, financially expensive. Consequently, building characteristics that restrain certain ventilation solutions are important to register.
In order to identify the appropriate ventilation type for a certain school building, we need to know the building characteristics. In a European perspective schools can be categorized by the external and/or internal structures:

- The outer façade construction mostly restrains how local room-size ventilation solutions can be implemented, e.g. natural ventilation or decentral compact units.
- The internal structures affect mostly vertical and horizontal routing of ducted ventilation solutions. In practice, in order to design ducted ventilation systems with high performance, room height requirements, height to slab, and height below beams are of greatest interest to the ductwork designer.

The Figure 40 states the parameters of different school building typologies that have significant influence on ventilation solution located in the façade.

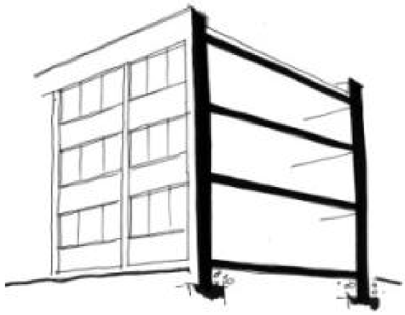
Façade structures	**Punctuated façade**	**Façade elements**
Façade type		
Characteristics	Massive structures perforated with windows	Skeleton structures with light facade elements
Structural elements	**Monolithic load-bearing external walls**	**Load-bearing columns in façade or behind façade.** Sometimes horizontal beam in façade restricts window size
Glazed façade	Small area	Large area

Figure 40: Structural elements in the façades which influences on the ventilation solution.
Drawings courtesy of: Sonja Geier, AEE INTEC

The Figure 41 below analyses the structural system - different building typologies and consequently the effective height of classroom and corridor. The corridor height is crucial to the space requirements of ducted ventilation and is determined by height to either slab or crossing beam, which is lowest. The room height is crucial to the room supply principle which in classrooms can be either mixing from central ceiling diffuser or mixing from side wall supply grille. Low room height effectively eliminates the side wall supply because of draught risk.

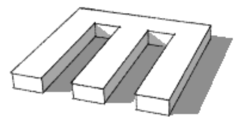
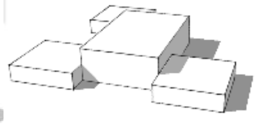
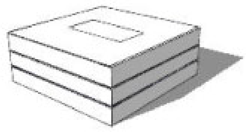
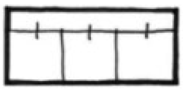
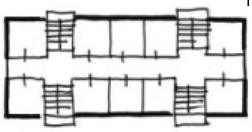
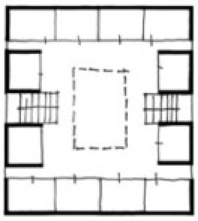
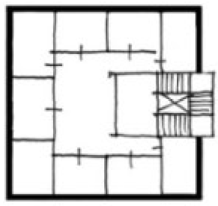
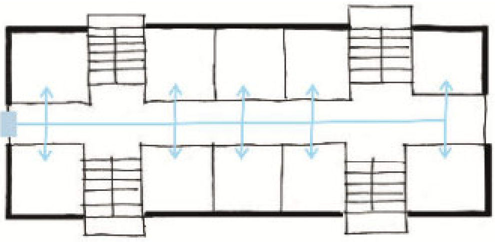
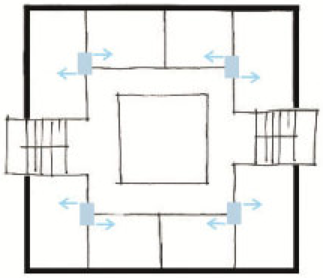
Internal structures	Horizontal low	Horizontal high	Centered	Vertical
Building shape				
Floor plans				
Structural elements	**Internal load-bearing walls**	**Internal load-bearing walls**	**Columns and beams with light partitions,** some stabilizing walls	**Internal *or* external load-bearing walls**
Main duct routing	 Horizontal supply duct		 Vertical supply ducts	
Room height	**Determined by slabs,** low height	**Determined by slabs,** high height	**Determined by beams**	**Determined by slabs,** low height
Corridor height	**Same as room height**	**Same as room height**	**Determined by beams**	**Determined by beams**

Figure 41: Different school geometries and typical constructions
Drawings courtesy of Sonja Geier, AEE INTEC and Michela Pentericci, DTU Byg.

6.3.2 Solutions

The investigation ventilation solutions included principles based on natural ventilation as shown in Figure 42 and on different kinds of mechanical systems as shown in Figure 43 to Figure 45.

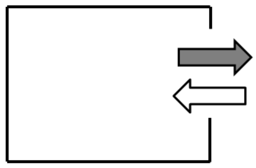
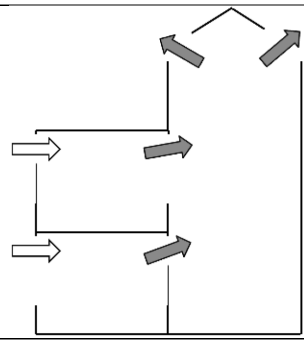
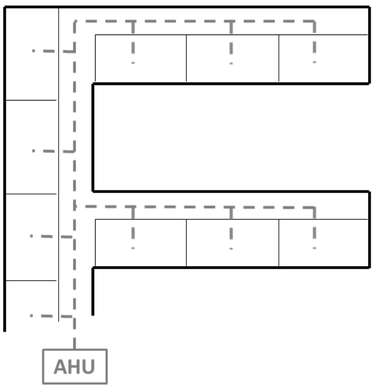
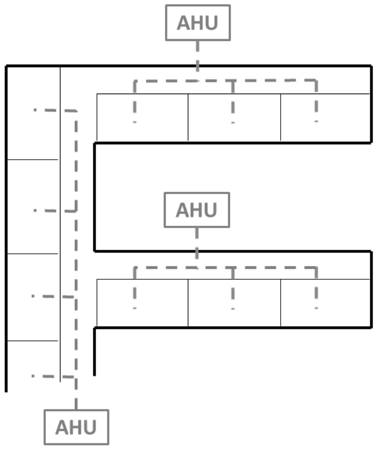
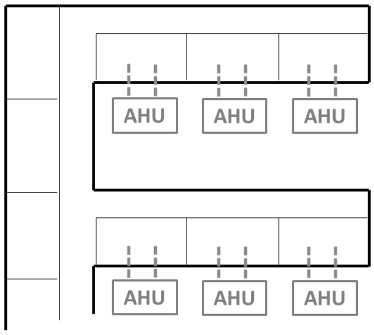
Single-sided	Cross	Stack
		

Figure 42: The three main principles of natural ventilation. Other variants of especially stack ventilation are possible.

Central	Decentralised	Decentral compact room unit
 *Figure 43: One air handling unit and large ducts ventilate large areas*	 *Figure 44: Multiple air handling units and smaller ducts for smaller areas*	 *Figure 45: Compact air handling unit in each room eliminates ducts*

6.3.3 Design charts

Implementation of ventilation in existing schools entails changes to the constructions of the building. Changes that compromise structural stability are, of course, financially expensive to implement. The installation cost of different ventilation solutions in different building categories in different European countries is beyond the scope of school*vent*cool. However, we assume that structural building changes and installation costs are proportional.

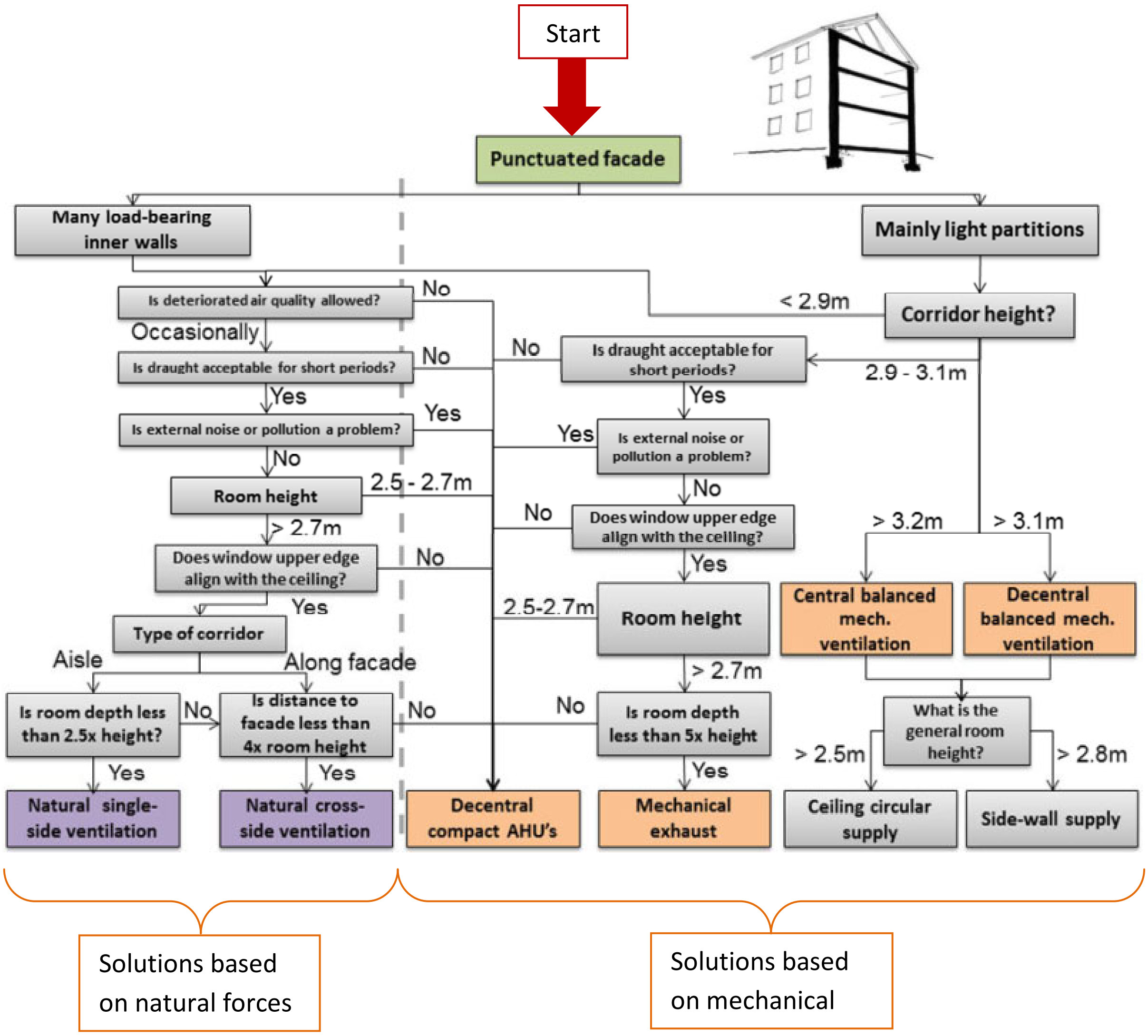
The design charts illustrate prioritized and best-practice ventilation solutions in terms of comfort, energy, building implementation and running costs.

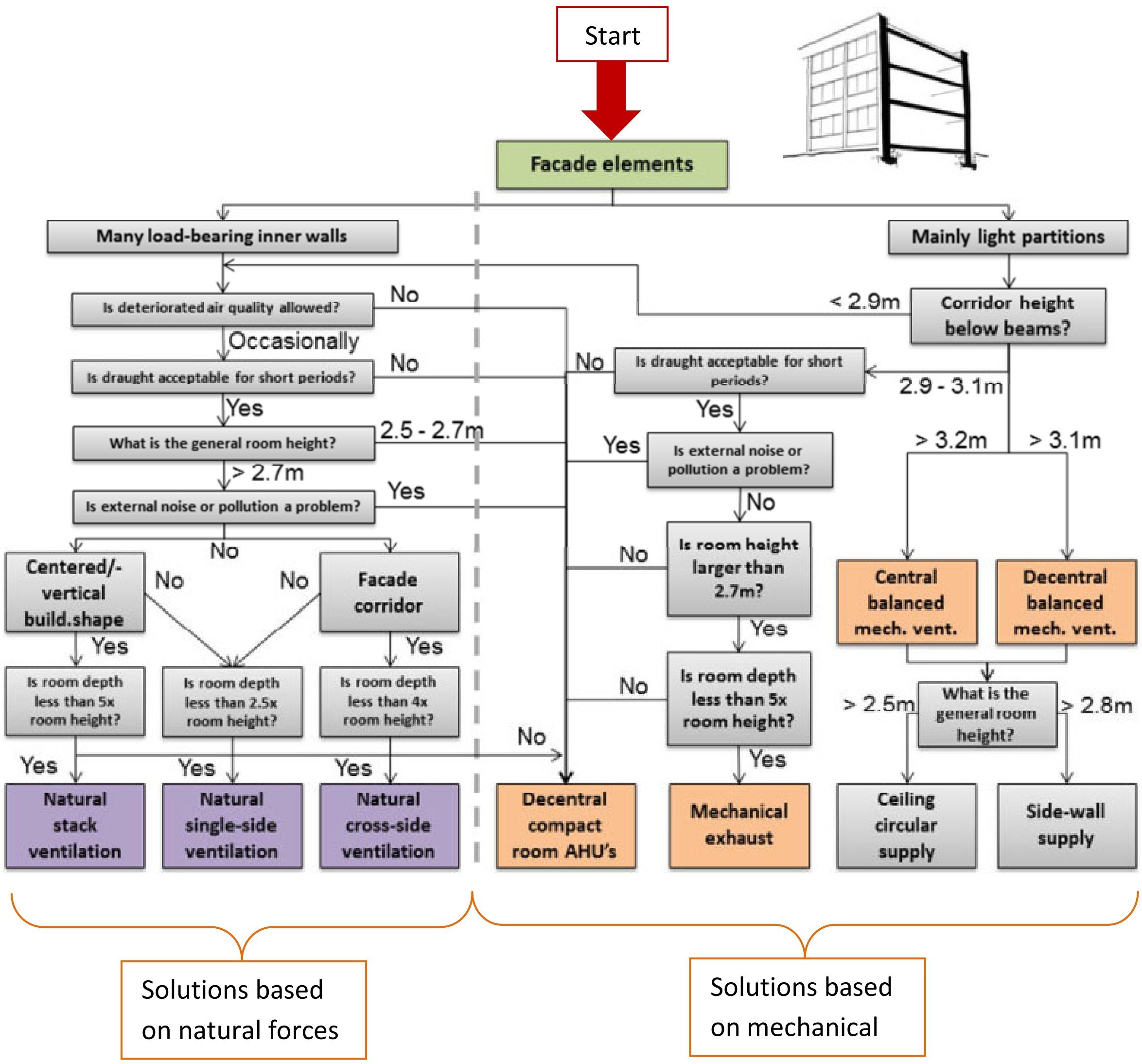
The charts are generated with the priority that the ventilation solution 1) fits the internal and external structure to minimize construction costs and 2) is able to perform adequately on air quality and heat recovery.

Once the façade typology of a building has been determined, either punctuated façade or element façade, the ventilation solutions are prioritized according to this list:

- Central or decentral balanced mechanical with either side wall or central ceiling room supply
- Decentral compact units
- Mechanical exhaust with intake through façade openings
- Stack ventilation (natural)
- Cross ventilation (natural)
- Single-side ventilation (natural)

The design chart is a visualization of the criteria that each solution must fulfil in order to be the recommended solution for a given building typology.
It is also possible to go backwards in the charts, i.e. to start with a ventilation system and move backwards taking the shortest path following the arrows.


Start
Punctuated facade
Many load-bearing inner walls
Mainly light partitions
Is deteriorated air quality allowed?
No
Occasionally
Corridor height?
< 2.9m
Is draught acceptable for short periods?
No
Is draught acceptable for short periods?
No
2.9 - 3.1m
Yes
Yes
Is external noise or pollution a problem?
Yes
Yes
Is external noise or pollution a problem?
No
No
Room height
2.5 - 2.7m
> 2.7m
No
Does window upper edge align with the ceiling?
> 3.2m
> 3.1m
Does window upper edge align with the ceiling?
No
Yes
Yes
Type of corridor
2.5-2.7m
Room height
Central balanced mech. ventilation
Decentral balanced mech. ventilation
Aisle
Along facade
> 2.7m
Is room depth less than 2.5x height?
No
Is distance to facade less than 4x room height
No
No
Is room depth less than 5x height
What is the general room height?
> 2.5m
> 2.8m
Yes
Yes
Yes
Natural single-side ventilation
Natural cross-side ventilation
Decentral compact AHU's
Mechanical exhaust
Ceiling circular supply
Side-wall supply
Solutions based on natural forces
Solutions based on mechanical



6.4 Deliverables

Hviid, C.A., Petersen, S. (2012). "Implementation of ventilation in existing schools – a design criteria list towards passive schools". Passive House Symposium, Bruxelles, Oct. 5th

7 How to disseminate and communicate school renovation?

PHP, Belgium

7.1 Objective

The main objective is to coordinate and manage all project dissemination and knowledge transfer, and to promote and communicate activities and results of the project to the stakeholders of the target groups of school*vent*cool. The two target groups are:

1. Architects, building contractors, installers, energy advisors and school building owners, public authorities.
2. School building users: pupils, teachers, school managers.

7.2 The three international workshops – highlights

During the course of the project three international workshops tool place:

1st international experts workshop: 14th October 2010 in Antwerp, Belgium. The experts group of School Vent Cool gave its opinion on potential of building on "Disguinlei 33, Antwerp" for renovation with modular prefabrication. Statement of the expert group paper was produced.

Figure 46 Experts at the workshop, October 14th 2010, Antwerp, Belgium.

2nd international experts workshop: 25th March, 2011 Liestal, Switzerland with focus on developing renovation strategies for school buildings renovation. The participants were split into four groups; each consisted of an expert within the fields of building/architecture, ventilation/HVAC and one generalist. Key focus areas of each group were:

- Group A: envelope; indoor space;
- Group B: Requirements; Software tool school*vent*cool: process-driven strategy
- Group C: Important determinants for every renovation strategy
- Group D: Requirements, flexibility within usage; flexibility within public service systems; user comfort; zoning.

These results were summarized in a Blue Sheet that was disseminated to the key stakeholders of the target groups in the partner countries and via the SVC website.

Figure 47 Workshop sessions, 25th March 2011, Liestal Switzerland

3rd international experts workshop: 27th September 2011, Franciscan monastery of Graz, Austria:

Focus on development of renovation strategies for selected demonstration buildings in the Denmark, Switzerland and Austria, and strategies for renovation of school typologies in City of Antwerp, Belgium. Participants: 30 experts (multi-disciplinary) from Denmark, Belgium, Switzerland, Germany and Austria. Blue Sheet was produced resulting from this workshop that was disseminated to the key stakeholders of the target groups in the partner countries and via the SVC website.

Figure 48 Workshop discussion, September 27th 2011, Franciscan Monastery, Graz, Austria

7.3 The three most important presentations

Info session sustainable buildings: school*vent*cool, organized by Voka (Chamber of Commerce) - Kamer van Koophandel Antwerpen-Waasland, Stad Antwerpen and the Vlaamse Confederatie Bouw23rd January 2012.

Presentation at “Themenworkshop: Zukunftsfähige Gebäudesanierung – Konzepte und praktische Erfahrungen” of the programme “Building of Tomorrow“ with the title “school*vent*cool – Sanierungskonzepte für Schulen”, Armin Knotzer, AEE INTEC, held on 13th June 2012, Vienna.

Nine minutes-contribution to the radio programme “Dimensionen – die Welt der Wissenschaft” (http://oe1.orf.at/dimensionen) of the famous Austrian quality radio station “Ö1” on 30th September 2011.

7.4 The best three videos

Video “SchülerInnenprojekt school*vent*cool”
The Austrian partner of school*vent*cool AEE INTEC asked pupils from the trade school “LBS Gleinstätten” in Styria, Austria to make a film about their own ideas to school renovation topics in the frame of the SVC project. Aim was to raise awareness (bottom up) with pupils and teachers.
The video is available from: http://www.schoolventcool.eu/node/84

Video “Smoke tests of ventilation system in a school”
The Danish partner of school*vent*cool the dept. of Civil Engineering, Technical University of Denmark (DTU), made a video of diffuse-ventilation smoke-tests in two different demonstration classrooms.
The video is available from: http://www.schoolventcool.eu/node/83

Video “Demonstration project Krummbach”
The Swiss partners of school*vent*cool FHNW made a video showing an on-site installation of modular prefabricated façade elements including ventilation.
The video is available from: http://www.schoolventcool.eu/node/90

7.5 The three most important papers

Paper “School renovation with modular prefabricated facade elements including ventilation solutions”.
Presented and in the proceedings of the Passive House Symposium 2012, 5th October 2012 Brussels.
Authors: René L. Kobler[1], Ralf Dott[1], Thomas Heim[2]
[1] University of Applied Sciences and Arts Northwestern Switzerland, Institute of Energy in Building
[2] Lucerne University of Applied Sciences and Arts, Competence Centre of Typology and Foresight in Architecture.
This paper can be downloaded from:
http://www.schoolventcool.eu/node/87

Paper “School renovation to passive house standard – a methodical approach and a realized success story”.
Presented and in the proceedings of the Passive House Symposium 2012, 5th October 2012 Brussels.
Authors: Sonja Geier (architect Austria) & Gerhard Kopeinig (ARCH+More ZT GmbH, Austria)
This paper can be downloaded from:
http://www.schoolventcool.eu/node/80

Paper “Implementation of ventilation in existing schools - a design criteria list towards passive schools”.
Presented and in the proceedings of the Passive House Symposium 2012, 5th October 2012 Brussels.
Authors: Christian Anker Hviid Dept. of Civil Engineering, Technical University of Denmark & Steffen Petersen, Aarhus School of Engineering, Aarhus University,
This paper can be downloaded from:

http://www.schoolventcool.eu/node/82

7.6 The school*vent*cool Brochure

A School Vent Cool Brochure “The Way towards Your Cool School” A guideline to high performance school renovation in Europe was produced (available to download at: http://www.schoolventcool.eu/node/48).

Figure 49 Cover page of the Brochure

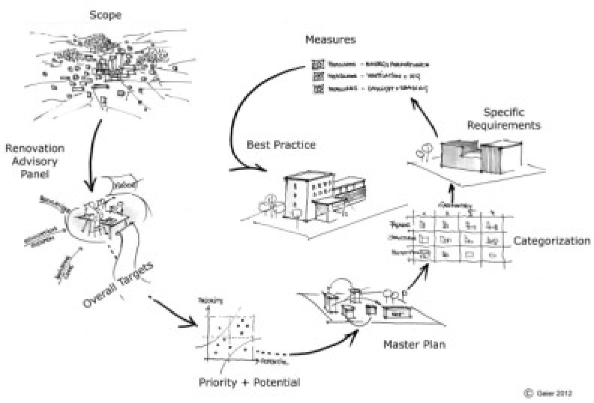


Figure 50 schoolventcool methodology diagram (Sonja Geier, AEE INTEC)

7.7 Last but not least:

The continuously updated SVC website: http://www.schoolventcool.eu