SCHOOL RENOVATION WITH MODULAR PREFABRICATED FACADE ELEMENTS INCLUDING VENTILATION

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ABSTRACT

In the international project SchoolVentCool in the frame of the Eracobuild program, the aim is to find and support solutions to improve indoor environment quality, secure sufficient and efficient ventilation as well as to reach a low-energy building standard for existing school buildings by renovation with modular prefabricated façade elements including ventilation.
Hence, the experience with prefabricated façade elements with integrated ventilation ductwork for the renewal of dwellings (CCEM-Advanced Retrofit) has been transferred to school buildings. The increased specific fresh air demand in school buildings leads to a stronger impact on architectural appearance and herewith to a required second solution with decentralised fresh air supply. A typological analysis helps to decide between two solution pathways, that base predominantly on the criteria of the "critical path of fresh air supply". One realised demonstration object, a single family house with attached school rooms, shows the feasibility of the façade integrated centralised ventilation solution.

1. SCHOOLVENTCOOL

Energetic, social and educational developments require adaption of schools. Holistic renewal strategies affect also the whole system "school buildings complex" including energy supply, ventilation and cooling, as well as thermal comfort. They aim at adapting the building to current and future needs and to make them fit for future. In the frame of the ERACOBUILD program, teams from Belgium, Denmark, Austria and Switzerland share their knowledge in the "SchoolVentCool" project [1]. The aim of the Swiss team, consisting of typology (CCTP), construction (IEBau) and HVAC (IEBau), is to share the existing knowledge of IEA ECBCS Annex 50 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. School buildings play a particular role in the public building portfolio because of their central and integrative usage. An energetic renovation of these buildings to level between Minergie and Minergie-P also serves as leading example and hence trigger further stimulus. Future teaching environments supply optimised indoor climate and have an atmosphere, where teachers and students are able to unfold their full performance. The intended solutions focus on buildings, where prefabricated façade modules are mounted from the outside and ventilation is an integrated part. The project started in October 2011 and will be finished by February 2013. The Swiss part is financed by the Swiss Federal Office of Energy.

2. APPROACH

The fundamentals for the adaption to 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 concept should also be applicable and adaptable to other countries and furthermore incorporate new findings into the own solution.

The project consists of four work packages:

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 [2] to the specific requirements of school buildings
4. Synthesis report (February 2013)

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.

3. RESULTS

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

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 [2]. School buildings differ significantly in the amount of required fresh air. This is for classrooms 25 to 30 $m^3/h/person$ [3], where a mixed air flow in the room has to be assumed. Typical sizes of classes between 20 and 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 $m^3/h/m_{façade\ length}$.

Adaption of façade modules for multifamily houses

The approach of façade integrated ventilation ductwork leads, for school buildings with bigger 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.

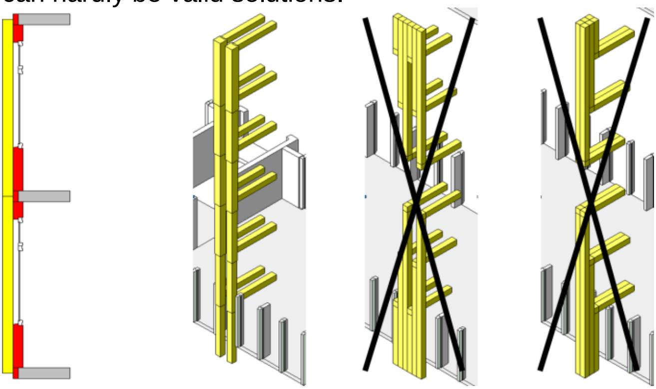

FIGURE 1: LEFT: FAÇADE INTERSECTION WITH ADDITIONALLY MOUNTED MODULES, RIGHT: DISCUSSED VENTILATION DUCTWORK INSIDE THE FAÇADE ELEMENTS

One problem 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 possible only under very limited conditions to place the ductwork inside the façade invisible to the outside. Figure 1 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 2 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.

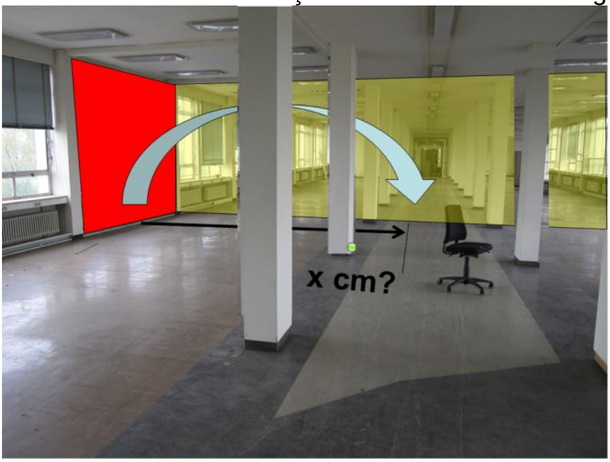

FIGURE 2: ABILITY OF A FAÇADE AREA TO SATISFY A NECCESSARY FRESH AIR DEMAND

Typology

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. 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, provision of services). Each focus area is characterised by a selection of features that are relevant for the renewal with prefabricated façade modules [4]. The building features are divided into key and focus features.
In the project the key features type of façade, number of floors and construction period 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 development of prefabricated façade modules. The construction period gives advice to the possible constructions and state of the

art at the time of construction. The number of floors provides information on the size and the type of the school building. The key features are restricted to three simple and easy to determine criteria to secure a quick classification 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.

Link between typology and construction/ventilation

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, where 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.

Focus types, which represent specific categories of building parts, can be deduced from combinations of the characteristics of the above described focus features. From these basic types of prefabricated façade modules are derived. These allow a first assessment of possible air distribution concepts.

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 1, 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 3 shows two schematic solutions for horizontal air distribution and access to the room.

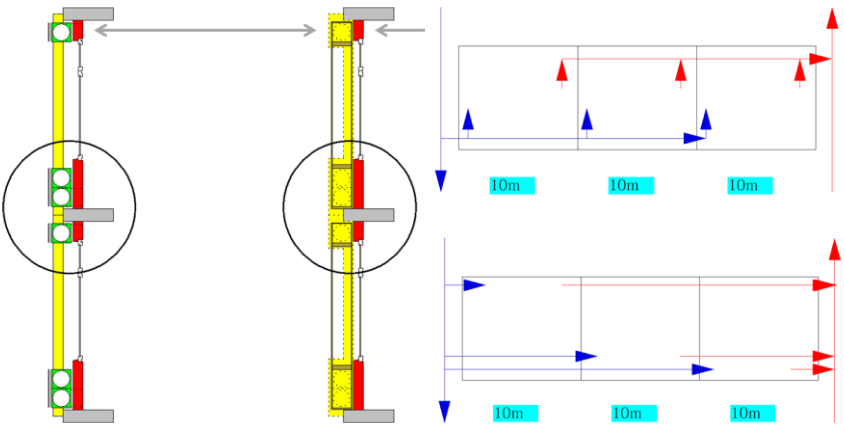

FIGURE 3: CENTRAL VENTILATION WITH HORIZONTAL AIR DISTRIBUTION AND SMALLER EFFECT ON ARCHITECTURE

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 4). Decentralised ventilation units are less suitable for massive than for non-load-bearing exterior wall constructions since they are located in the field of load-bearing building parts for supporting exterior walls [5]. Especially with decentralised ventilation units one has to pay attention to avoid shortcuts between supply and return and to sound emissions.

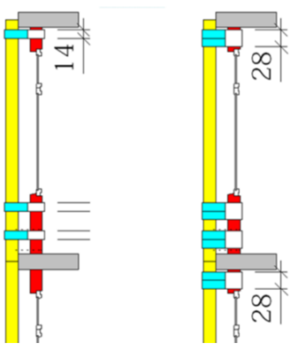

FIGURE 4: DECENTRALISED VENTILATION WITH FACADE INTEGRATED VENTILATION UNITS

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 5 shows schematically a guide for the selection of suitable façade modules during the planning phase of a specific building project.

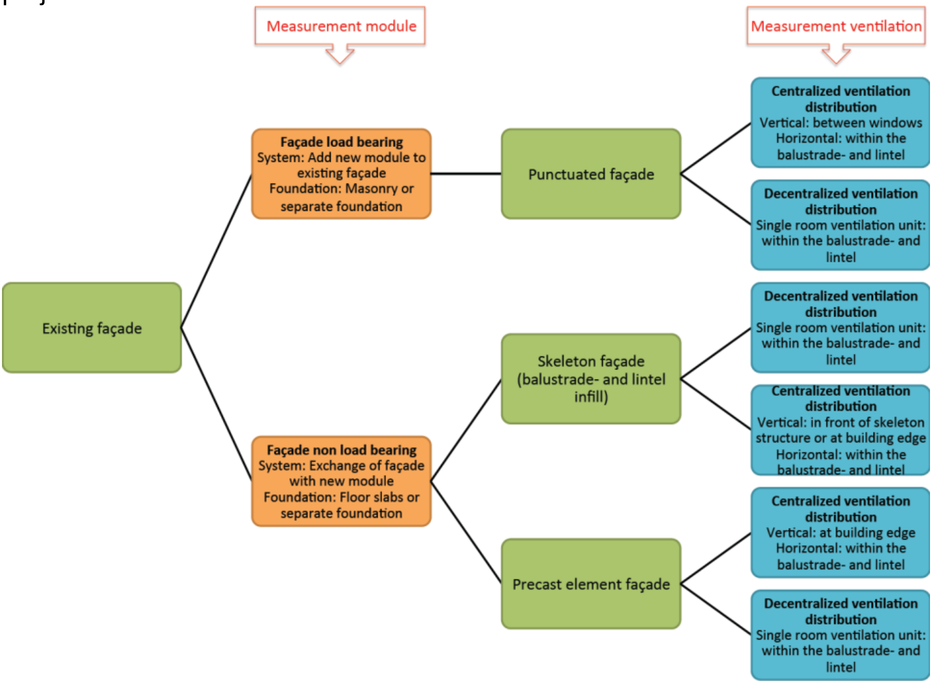

FIGURE 5: LINK BETWEEN TYPOLOGY AND CONSTRUCTION/VENTILATION

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 6) 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” [2] 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 6: 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 get the status of “critical path” (see detailed explanation in chapter 2.2.4 of [2]). 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 7.

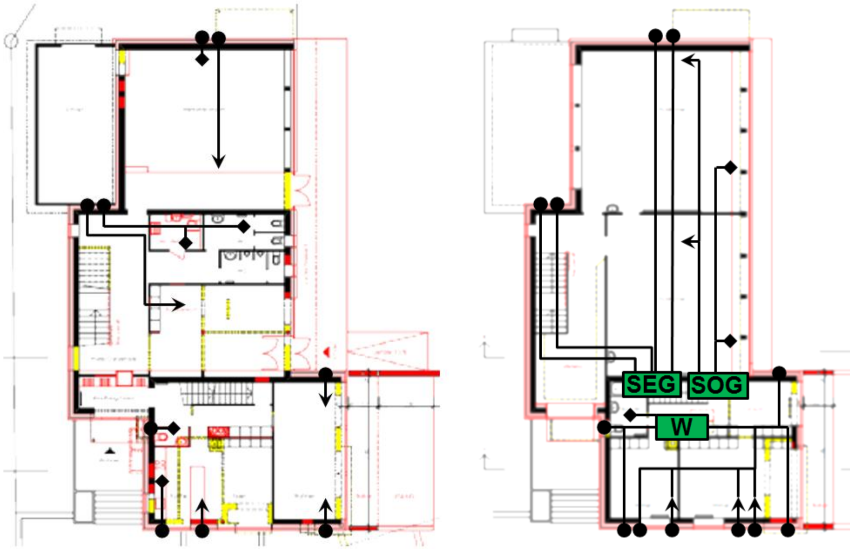

FIGURE 7: FLOOR PLANS OF THE KRUMMBACH BUILDING – LEFT: GROUND FLOOR / RIGHT: FIRST FLOOR LEGEND: SEG: VENTILATION UNIT FOR GROUNDFLOOR OF SCHOOL WING / SOG: VENTILATION UNIT FOR UPPER FLOOR OF SCHOOL WING / W: VENTILATION UNIT DWELLING / →: SUPPLY AIR / ─◆: RETURN AIR / ─●: VERTICAL VENTILATION DUCT INSIDE THE FACADE

During the planning of the façade modules, the specification of 140x140mm outside measures for the Flumroc-half-shells give clear measures for intersections. 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.

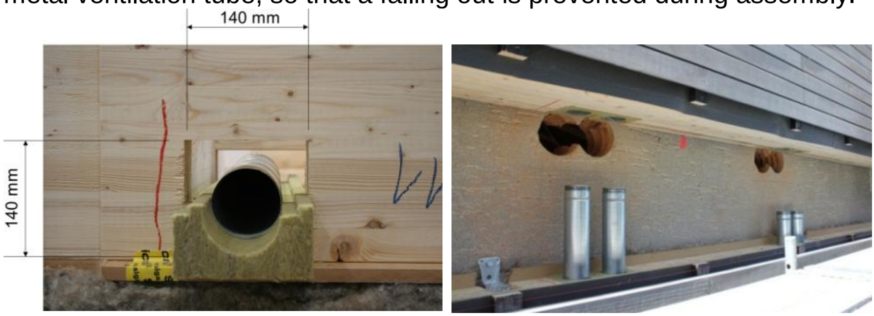

FIGURE 8: LEFT: DETAIL OF A VENTILATION DUCT DURING PRODUCTION OF THE FACADE MODULES IN THE FACTORY RIGHT: JOINING OF TWO MODULES DURING ASSEMBLY WITH VENTILATION DUCTS AT THE BUILDING SITE

In Figure 8 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 8 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.

4. OUTLOOK

The principle of planning for prefabricated modules with integrated ventilation is based also for school buildings 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 the façade construction for 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 industry. Not in all countries a sufficient level of necessary experience and knowledge is available.

REFERENCES

[1] SchoolVentCool Projekt-Webseite: http://www.schoolventcool.eu

[2] „CCEM Nachhaltige Wohnbauerneuerung, Schlussbericht der Module A3, A4, Vorfabrizierte Fassaden- und Dachmodule", Kobler R.L., Binz A., Steinke G.; IEBau-FHNW; Muttenz 2010. http://www.fhnw.ch/habg/iebau/afue/gruppe-bau/advanced-retrofit-nachhaltige-wohnbauerneuerungen

[3] „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

[4] „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

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