Minimal Invasive Ventilations Systems with Heat Recovery for Historic Buildings

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Abstract
This paper shows three solutions for integration of ventilation systems with heat recovery in historic buildings with special focus on school buildings. With respect to the cultural heritage, systems with minimal impact (maximum reversibility) for the architecture and structure of the building are needed. In case of decentralized systems, the ductwork can be minimized by wall integrated heat recovery units, whereas for central systems, a horizontal air distribution in the attic combined with vertical ducts was found to be the minimal invasive solution best suited for listed buildings.

A new ventilation system was designed and tested for a listed school building in Innsbruck (Austria), which is one of 8 case study buildings within the EU-project 3ENCULT. In order to minimize the ductwork within the building, an active overflow system takes the air from the corridor to the class room and vents the extract air back to it. A central heat recovery system ventilates the staircase and the corridors with preheated fresh air. The prototype of the active overflow system as well as the control strategy and simulation results are presented.

Keywords – ventilation; wall integration; active overflow; air quality; control strategy; heat recover; efficiency

1. Introduction

Historic buildings require special consideration and thoughtful solutions when considering the implementation of modern ventilation systems in them. Mechanical ventilation with heat recovery can help to protect the building construction from a building physics point of view and it enhances air quality and thermal comfort for the users. On the other hand, the intervention should be as reversible and minimal invasive as possible.

In case of standard ventilation systems for new buildings, ductwork is applied to guide the air to the occupied space. These ducts are installed in vertical shafts or behind the suspended ceiling. The construction of new shafts and suspended ceilings is not possible in most cases for historic buildings. This paper shows several solutions how to avoid ducts, shafts and suspended ceilings as far as possible. This work was performed within the

EU-project 3ENCULT, where a wide range of energy efficient solutions for cultural heritage are investigated and developed. The following strategies for implementation of heat recovery were found to be especially adapted for historic buildings:

- decentralized wall integrated systems
- central system with direct vertical supply air ducts
- central system with active overflow principle

The pros and cons of central and decentralized systems are described hereunder. The active overflow system was implemented and tested in two class rooms in the 3ENCULT case study CS5 (school building in Hötting, Innsbruck, Austria).

2. Centralized Versus Decentralized Systems

The most important decision in terms of the choice of the ventilation system is, whether a central unit or decentralized systems is the most appropriate solution for the individual historic building.

The pros and cons of ***central systems*** can be summarized as follows:

The central heat exchanger needs a plant room (or space in the attic). If the ambient air intake and the exhaust air outlet is placed at the roof or conducted underground, no openings in the façade are necessary. This is very important for architectural reasons. However, the planning and installation costs are relatively high. Especially in historic buildings, individual solutions have to be found in any case – the system is tailor-made for the building, respecting the architectural and historic value of the monument. The horizontal as well as the vertical ducts need space in the building. Sometimes unused chimneys can be used for the vertical ducts, but also horizontal distribution is necessary. In this paper solutions are shown, how to avoid or reduce the ductwork. If any duct passes through a fire zone boundary, additional fire-protection appliances are necessary.

In case of ***decentralized systems*** almost no duct work and no fire protection equipment are necessary; however, the following disadvantages have to be kept in mind:

Ambient air intake and exhaust air outlet has to be conducted through the façade. In case of listed buildings, the aspect of the historic façade may not be changed. Solutions have to be found, which are acceptable respecting the preservation issues. In case of a system placed directly in the occupied zones of the building, the sound protection is difficult. The same holds for the maintenance and the aesthetics of the decentralized units in the occupied zones.

There is no general recommendation for the type of the system, neither in terms of preservation issues nor in terms of costs. The following sections may help to find the optimum solution for the individual building.

3. Wall Integrated Ventilation Systems

For school building various products for decentralized ventilation systems are available on the market. Most of them are constructed for integration at the ceiling. In order to avoid long cold ducts, the unit should be placed close to the window. On the other hand, from a design point of view, this position has a lot of drawbacks. It is not good for an efficient use of daylight and it significantly affects the appearance of the room. These disadvantages can be avoided by placing the ventilation unit at the wall under the window (at the parapet). A design study for this version of a wall integrated ventilation system was performed within the EU-project 3ENCULT.

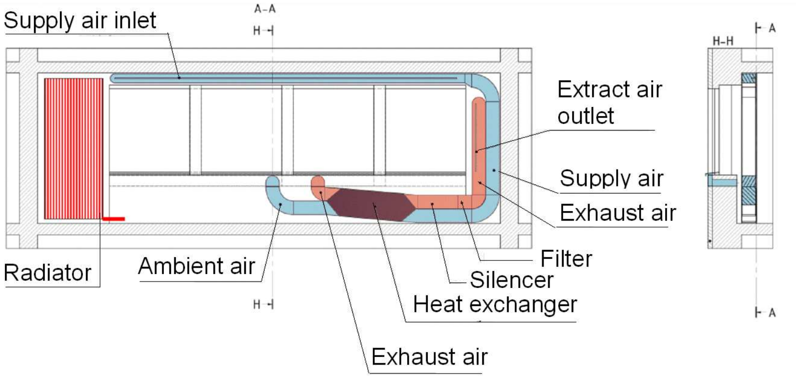

Fig. 1: View from inside: Counter flow heat exchanger mounted at the parapet; supply air inlet above the window; extract air outlet besides the window

As shown in Fig. 1, a flat counter flow heat exchanger can be mounted at the parapet, whereas the supply air inlet and the exhaust air outlet are placed above and besides the window respectively. In order to avoid any grill at the façade for ambient air intake, a slit below the window sill can be applied. For exhaust air outlet, this possibility is not valid, because condensation and freezing problems at the wall surface would occur. Therefore a perforated plate or a cover plate in front of the window post is suggested as exhaust air outlet (see Fig. 2).

The suggested design can be realized for buildings where an external insulation is applicable. In this case, the flat air ducts for ambient and exhaust air can be integrated in the insulation layer. After finishing the plaster (outside) and dry walling (inside), no ductwork is visible from both sides. For most of the listed buildings however, no external insulation is appropriate. In those cases a central heat recovery should be preferred.

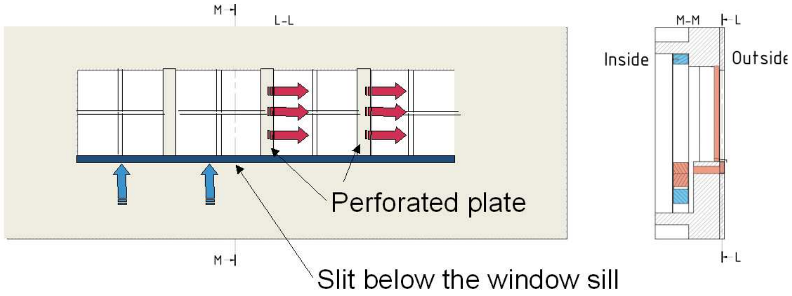

Fig. 2: View from outside: Ambient air intake via slit below the window sill, exhaust air outlet via perforated plate at the window post

4. Central Ventilation with Direct Vertical Ducts

In case of a central system for new buildings or refurbished buildings without special historic or architectural value, the most convenient way to mount the supply air ducts is to fix them at the ceiling in the corridor and to cover it by a suspended ceiling. For architectural reasons or aspects of preserving, this might not be possible in some listed buildings. In that case, a vertical supply air duct can be placed directly in the supply air rooms, whereas the horizontal distribution duct is mounted in the attic or cellar.

The disadvantage of this solution is, that the vertical ducts are crossing the ceilings, which are working as separation between different fire protection areas. For this reason, at each ceiling a fire flap has to be placed, resulting in high costs for investment, operation (pressure drop) and maintenance. The solution described in the next sections works without the supply air distribution duct. The ventilation efficiency however is not as good as in case of the before mentioned systems.

5. Active Overflow Principle (AOP)

The AOP was developed and tested for the application in residential buildings by “Hochbaudepartement, Amt für Hochbauten, Stadt Zürich”. A design competition for active overflow ventilation systems was launched and published in [1]. Within this document the active overflow principle is described as follows:

“Apartments with mostly open doors can be vented with a very simple ventilation system: It must only exhaust washrooms and kitchen, the whole supply air flow may be introduced at any place into the flat, e.g. into the corridor. A structural realization is simple because bathrooms and kitchen are often located close together and are accessible by riser shafts. In reality room doors remain mostly closed at night. To maintain acceptable air quality in these rooms, an active overflow element must ensure that the air from the corridor is vented into the rooms and back into the corridor - in compliance with all comfort criteria. The return flow of the air into the passage can be realized via the crack in the door or via an overflow valve (passive or active)” (trans. by author, [1]).

As the AOP works successfully in refurbishing of residential buildings, the author decided to investigate, if the principle is also applicable for school buildings. The major difference compared to residential buildings is the higher flowrate, which is more difficult to distribute without draft risk and low sound emission. Airborn sound transmission from the class room to the corridor and vice versa can be minimized as described in the next section.

6. Active Overflow Prototype for a School Building

Within the FP7 project “3ENCULT – Efficient Energy for EU Cultural Heritage”, the school building “Höttinger Hauptschule” in Innsbruck (Austria) is one of the 8 case studies for demonstration and verification of energy efficient solutions (see [2]). Besides the reduction of thermal losses, a special focus will be on adaptation and optimization of the ventilation system. The active overflow principle as described above was transferred to school buildings. In this case, the high flow rate (around 700 m^3/h) calls for a dedicated air distribution system to avoid complains due to draft risk and airborne noise. This was realized by textile hoses for supply air distribution as shown in the next figure. The air passes (driven by fan) from the corridor via silencers into that hoses, which are perforated by laser for uniform flow distribution. To minimize the sound transmission between the class rooms and corridor, also the overflow openings are equipped with silencers.

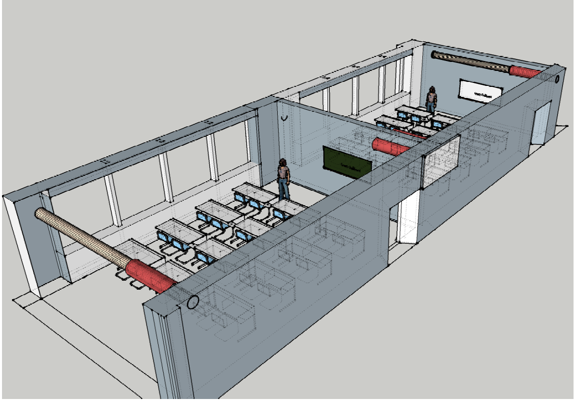

Fig. 3: Active overflow system and air distribution from corridor to class room via textile hoses

Fig. 4: Silencer and fan-box prototype manufactured by ATREA (top-left), mounting of silencer in the wall (top-right), fan box and textile diffuser in operation (bottom)

The building under investigation is a listed four-story school building (year of construction 1929/30). Fig. 5 shows the ground floor plan with four class rooms, a library as well as the toilets and cloakrooms etc. There is a hydraulic heating system with radiators. The cooling in summer is realized by night ventilation via the windows, no mechanical cooling is necessary.

The staircase is directly linked to the open space of the corridors, the fire doors will only be closed in case of emergency. A central heat recovery system ventilates the staircase and the corridors with preheated fresh air. The active overflow system (one for each class room) takes the air from the corridor to the class room and vents the extract air back to it. Finally the air is sucked to the toilets and cloakrooms and from there, via vertical ducts, back to the central heat recovery system located at the attic.

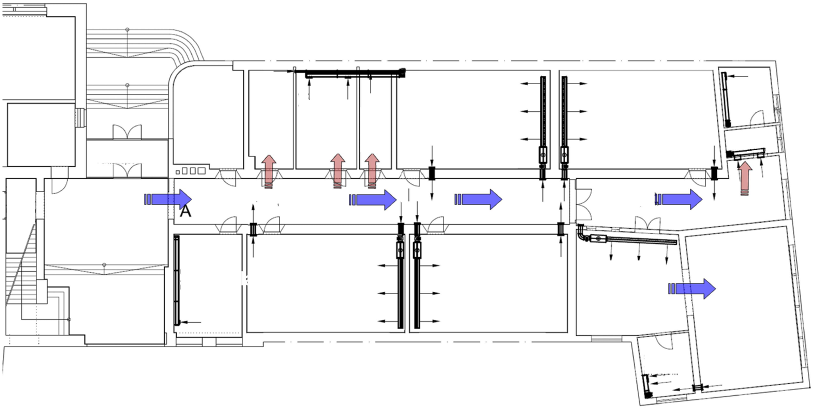

Fig. 6: Ground floor (NMS Hötting, Innsbruck, Austria), ventilation designed by ATREA

7. Control Strategies for Central Fans and Active Overflow Fans

As described above, the active overflow fans are responsible for the air change from the corridor to the classrooms whereas the central fans are venting fresh and preheated (by heat recovery) air to the staircase. The electricity consumption depends on the operation time and flow rate of each of the fans. As the occupation time is only a small fraction of the total time, an occupation dependent control strategy is necessary to save operational costs.

The most simple control strategy is to control the fans (both, the active overflow as well as the central fans) depending on a fix ***time schedule***. The advantage is the low installation costs, because no sensor is necessary. The disadvantage is that this system is not flexible in terms of changes related to the real occupation and the time schedules.

If the ***CO_2-concentration*** is measured in the corridors or in the staircase, the central fans can be controlled via a Proportional-Integral (PI) controller to a set point of e.g. 600 ppm in order to keep high air quality in the staircase and corridor zone for ventilation of the class rooms. The concentration in the corridors will vary according to the occupation of the adjacent class rooms. Hence at least one CO_2-sensor per corridor should be installed; the maximum value measured by all of the sensors compared to the set point (error signal) is used as input signal for the PI-controller.

In general, the ***start time for operation*** of the fans should be at least one hour before pupils enter the school. This guarantees a good indoor air quality already at the beginning of the occupation time. Otherwise the accumulation of contaminants throughout the nighttime would result in low air quality within the first hour of occupation in the morning.

Keeping this in mind, a switch-on signal for all of the fans (both, active overflow and central fans) for one hour (e.g. from 6:45 to 7:45 a.m. at each working day) by time schedule is necessary in any case. As the air quality rating from emissions which are independent of occupation cannot be detected by CO_2-measurements, the flow rate of the central fans should be controlled additionally by TVOC-concentration measurement or simply by time schedule. As the TVOC-measurement is expensive and calls for maintenance, the latter option is preferred.

In order to control more flexible in respect to changing occupation, the on/off signal for the active overflow fans could come from ***presence-control*** sensors in each room, which is considered a rather robust and low cost solution. However, even for this control strategy the pre-ventilation before occupation has to be controlled by time schedule.

To prevent bad odor within the time after the occupation, a **time delay** of one hour after the switch-off signal for the active overflow fan helps to bring down the contamination concentration.

In case of fire, any signal from a sensor for smoke or fire will switch off all fans, the central fan as well as all of the active overflow fans in order to avoid any active smoke distribution.

The control scheme as summarized in this section is displayed in Fig. 7

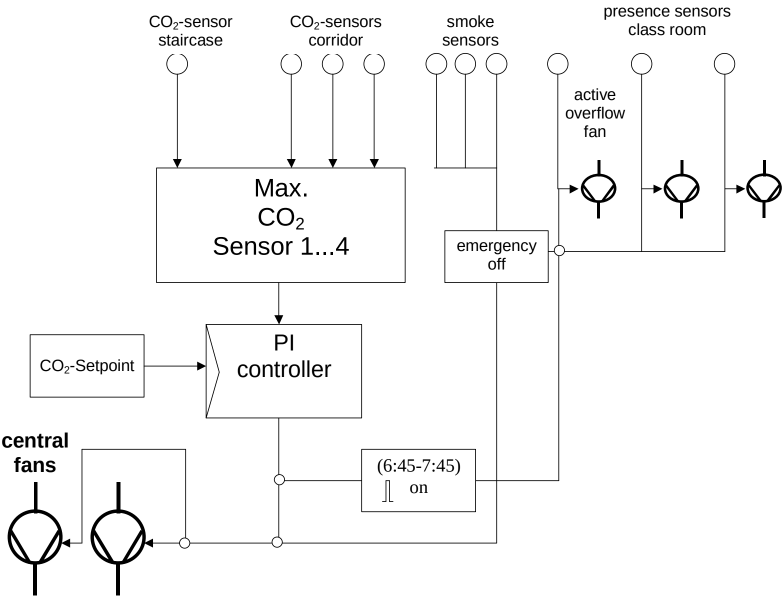

Fig. 7: Control scheme for Central Fans and Active Overflow Fans

8. Dynamic Simulation of Indoor Air Quality

In order to simulate the CO2-concentration as well as the indoor air humidity within the classrooms, corridors, staircase, cloakroom and toilets etc., a multi-zone model was set up with the simulation software CONTAM 3.0 (NIST, [3]). Fig. 8 shows an extract (ground floor only) of the 52-zone model (4 floors). 48 zones are considered as well mixed and four zones (i.e. three corridor zones and the stair case zone) are modeled as 1-D-convection-diffusion zone. The latter was necessary because of the large extent of the corridors in longitudinal direction (length of the corridor 39.5 m in the ground floor, 45.3 m in the first and second floor and height of the staircase 13.1 m). “Contaminant flow in one direction consists of a mixture of convection, the bulk movement of air, and diffusion, the mixing of the contaminant within the air. CONTAM’s primary 1-D convection diffusion model is taken directly from the finite volume method developed by Patankar [4] and described in more detail by Versteeg and Malalasekera [5]. This model divides the zone into a number of equal-length cells and uses an implicit method (with a fast tri-diagonal equation solver) to guarantee stability in computing the contaminant concentrations” [3].

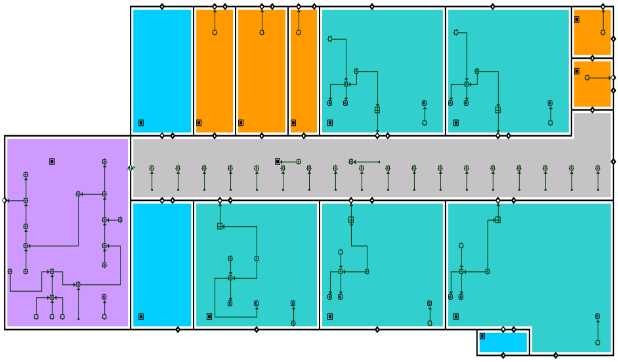

Fig. 8: Extract of the 52-zones CONTAM model (sketch-pad); ground floor with detailed 1D-convection-diffusion corridor zone (grey) and staricase zone (purple); mixed zones for class room (cyan), toilets/wardrobes (orange) and storage rooms (blue)

The time schedules of occupation for all occupied zones are implemented in the model. The occupation of the classrooms is mostly five hours a day, starting from 7:45 a.m.. A number of 20 pupils per class at the age of 10 to 14 years (CO_2-source of 12 L/h and H_2O-source of 90 g/h per pupil) were assumed for the simulations.

The calculated results for these boundary conditions (CO_2-concentration of ambient air was assumed to be a constant value of 400 ppm) are shown in Fig. 9. The CO_2-concentration in the corridor is limited to values of around

600 ppm. With a flow rate of 700 m³/h, the CO_2-concentration in the class rooms is limited to peak values of around 1000 ppm.

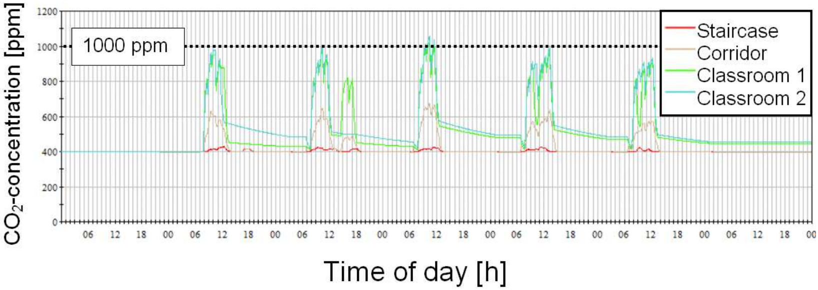

Fig. 9: One week of simulation results of CO_2-concentrations in the staircase, the corridor and the class rooms

9. Summary and Conclusion

In this paper, exemplarily for a school building, different types of ventilation systems for historic buildings were discussed. Depending on the floor plan and the restrictions in terms of preservation, either a central or a decentralized system can be chosen. In case of a central system, either vertical ducts into the supply air rooms or active overflow from the corridor can be applied. The active overflow principle has the lowest ventilation efficiency because of the mixing of supply and extract air in the corridor. From the architectural and/or preservation point of view, the active overflow system is preferable, because the ductwork is reduced to a minimum. The control strategy for the central fan as well as the active overflow fans is rather simple and effective. To reduce installation and maintenance costs, only one CO_2-sensor per corridor and one presence-control sensor per class room are installed.

Acknowledgment

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