Active overflow ventilation for refurbishing of school buildings

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1 The active overflow principle (AOP)

The AOP was developed and tested for the application in residential buildings by "Hochbaudepartement, Amt für Hochbauten, Stadt Zürich" (see [Sprecher 2011]). The occupied spaces take the air from the corridor via a fan installed in the door. 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) back to the corridor, which works as distribution and mixing zone. It is vented by a heat recovery system.

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 flow rate, which is more difficult to distribute without draft risk and low sound emission. Airborne sound transmission from the class room to the corridor and vice versa can be minimized as described in the next section.

2 Active overflow prototype for a listed 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 [Troi 2011]). 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 (about 700 m³/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 (see Fig. 2). The building under investigation is a listed four-story school building (year of construction 1929/30). Fig. 1 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.

Fig. 2: Silencer and fan-box prototype manufactured by ATREA

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.

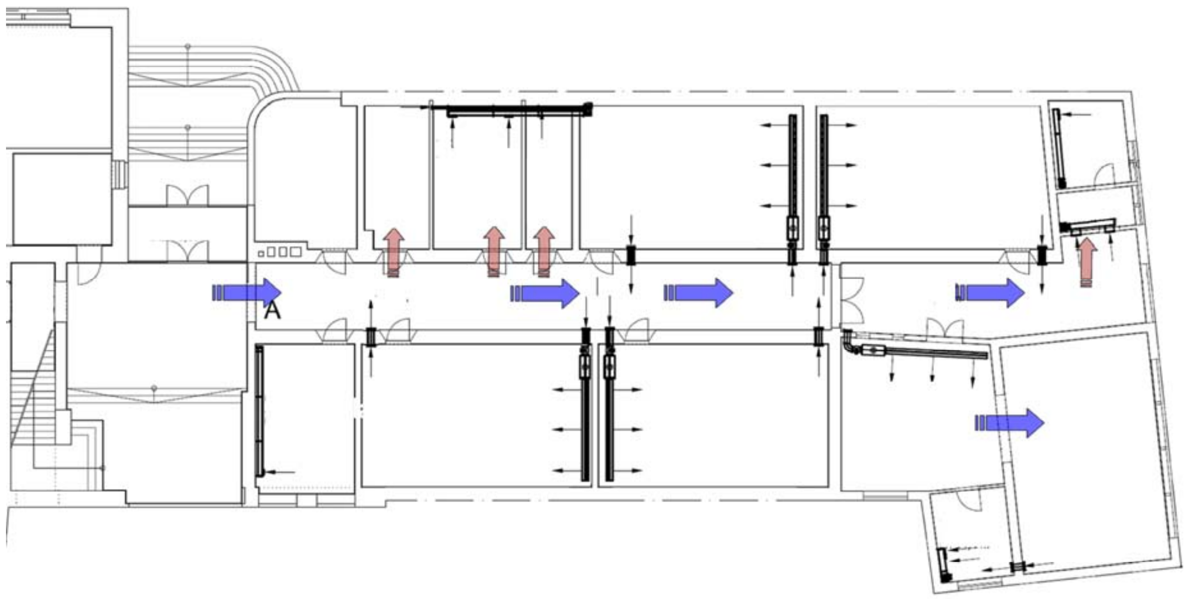

Fig. 3: Ground floor (NMS Hötting, Innsbruck, Austria), ventilation designed by ATREA

3 Control strategies for central and active overflow fans

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.

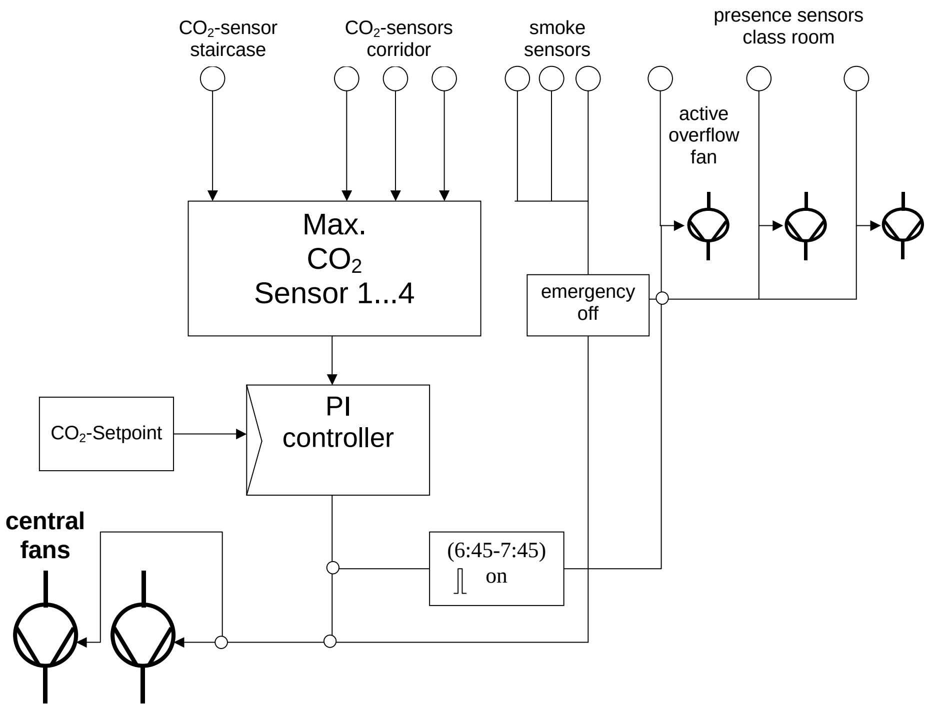

Fig. 4: Control scheme for Central Fans and Active Overflow Fans

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. 4

4 Dynamic simulation of indoor air quality

In order to simulate the CO_2-concentration as well as the indoor air humidity within the classrooms, corridors, staircase, cloakroom and toilets etc., a 52-zone model was set up with the simulation software CONTAM 3.0 (NIST [Walton 2011]). 48 zones are considered as well mixed and four zones (i.e. three corridor zones and the stair case zone) are modelled 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).

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 simulation results for these boundary conditions (CO_2-concentration of ambient air 400 ppm, set point for the CO_2-concentration in the corridor 600 ppm, active overflow flow rate 700 m³/h) show that the CO_2-concentration in the class rooms is limited to peak values of around 1000 ppm. The mean value during occupation time is around 900 ppm.

5 Measurement results

Electricity consumption, pressure drop and flow rate

The electric efficiency of the active overflow fan and the flow rate (by tracer gas) was measured as shown in Fig. 5. The curve shows a minimum at 220 m³/h, the electricity consumption at 600 m³/h is lower than 60 W (electric efficiency 0.1 Wh/m³. As the electric efficiency of the central ventilation system is much better in case of an active overflow systeme due to the short supply air duct system, the total electricity consumption (active overflow fans plus central fans) is lower than an equivalent standard ventilation system, if the control strategies according to section 3 are applied.

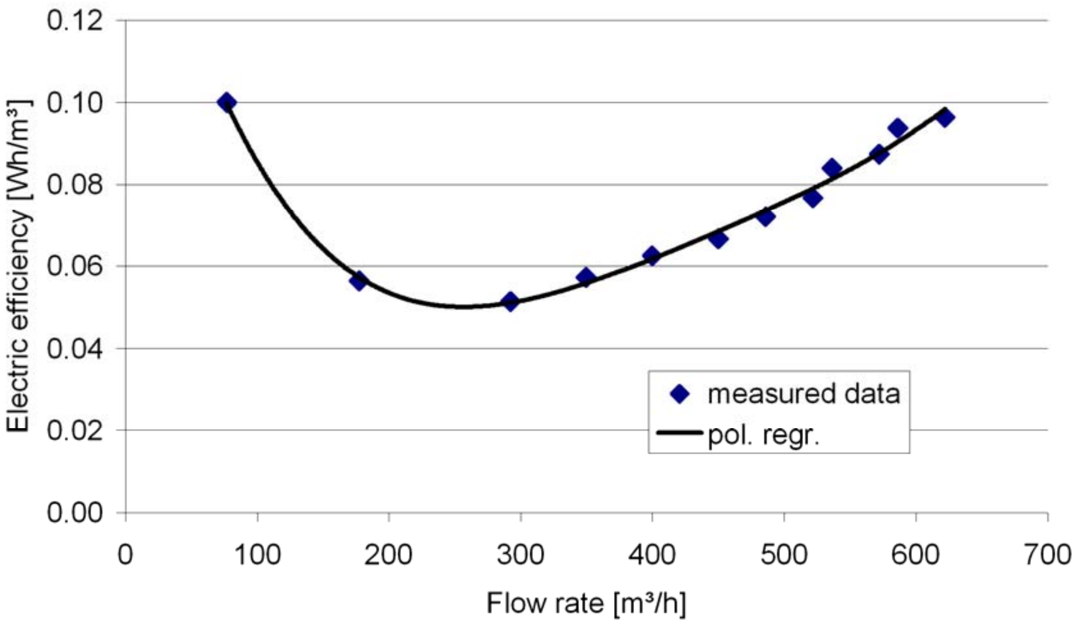

Fig. 5: Electric efficiency of the effective overflow fan prototype (manufactured by ATREA, CZ)

Airborne sound transmission and sound emission

The Austrian legislation concerning the sound protection in school buildings is written in [OISS 2007]. According to [Önorm 2002], table 6, the minimum airborne sound reduction between two classrooms without door in between is 55 dB, whereas with door in between, the limit is 38 dB. This value has to be reached also in case of the active overflow system installed. The measured values are 30 dB for class room 1 and 28 dB for class room 2, which is due to the low sound reduction of the door with large air gaps. With airtight doors the values 42 dB and 41 dB were measured respectively.

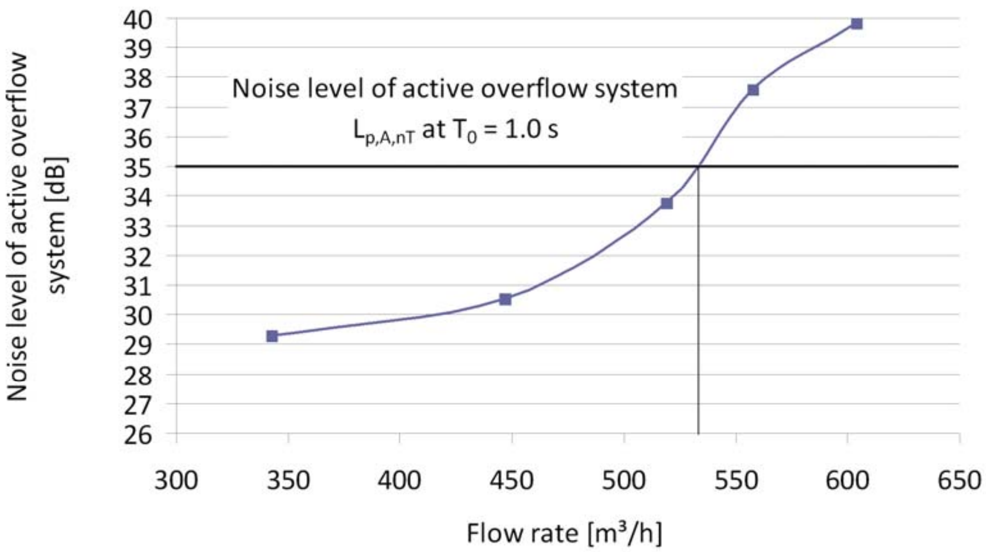

Fig. 6: Measured sound emission of the effective overflow fan prototype as a function of the flow rate

The ventilation system is to be built according to [Önorm 2007]. The max noise level of the ventilation system $L_{p,A,nT}$ for the class rooms is limited to 35 dB, for the corridor and the gymnasium to 40 dB and for the office rooms to 35 dB. The noise level (sound emission of the effective overflow fan) as function of the flow rate is shown in Fig. 6. The maximum sound level is exceeded for flow rates greater than 540 m³/h. If higher flow rates are necessary, the control strategy should restrict the higher flow rate to time-slots without occupation (break-times).

6 Summary and conclusion

A new type of ventilation systems for historic school buildings, based on the active overflow principle is analyzed via measurements on prototypes installed in two class rooms as well as by dynamic simulation. The ventilation efficiency of an active overflow system compared to a cascade ventilation is lower, because of the mixing of supply and extract air in the corridor. The electric efficiency however is higher and the control strategy for the central fans as well as the active overflow fans is rather simple and effective. From the architectural and/or preservation point of view, the active overflow system is preferable, because the ductwork is reduced to a minimum.

7 Acknowledgement

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8 Literature

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