Planning Guidelines and Product Development for Air Supply Distribution using Active Overflow Elements in Apartment Buildings

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Abstract

In this paper, an innovative "duct-less" supply air distribution concept using active overflow elements is surveyed. Its minimal space requirement allows for easier installation of high efficient ventilation units with heat recovery in residential buildings, especially in renovations. By means of simulations, the ability of this concept as a standard solution that ensure occupants comfort is investigated. A functional model of an active overflow element was also developed with particular attention on the sound emissions and measured. The results confirm that with this concept the same comfort is reached for much less installation effort than for the usual concept.

Introduction

Whether in new residential buildings or in retrofits, the acceptance of high efficient ventilation system with heat recovery in high efficient buildings such as passive houses highly depends on disturbances caused by its installation and on place requirement of the ducting system. Hence, this article investigates a distribution concept that reduces supply air ductwork to only one outlet.

The whole supply air flows through one main valve installed in a so-called "mixed air zone". This mixed air zone can be either a corridor, a living room but also a stair case in case of a multi-storey apartment or house. Fresh air from supply main valve is brought into the bedrooms by mean of active overflow elements (AOE) installed between the mixed air room and the bedrooms, as illustrated below.

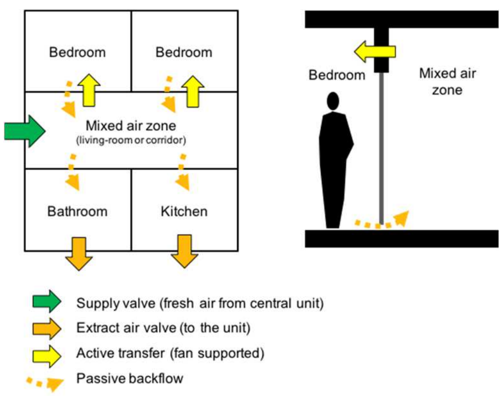

Figure 1: Illustration of the ventilation concept with active transfers in an apartment.

The extract air rooms (bathroom, kitchen, WC) are as usual connected to an extract air ductwork, using the principle of cascade ventilation. The idea of AOE come from Switzerland (Barp et al., 2009), though its implementation as a standard solution for ventilation in residential areas has not been surveyed yet. This requires products that delivers the necessary volume flow to ensure air quality to the occupant while minimizing noise emissions. The first part of this article thus aims at defining the necessary air flow rate that is required through the AOE in order to ensure appropriated air quality and humidity in the rooms in order to provide clear planning rules using this principle. In the second part focuses a functional model of an AOE was constructed and measured.

The principle of supply air distribution using AOE as illustrated in figure 1 allows for several planning strategies. The goal of this study was to define the airflows to be set with each of them to ensure indoor air quality (IAQ) and thermal comfort to thus occupants.

Strategy 0: No AOE is installed between mixed air zone and bedrooms. Only natural convection drives the fresh air from mixed air zone into the bedrooms. Air exchange between the two zones thus highly depends on the opening of the separating door.

Strategy A: AOE combined with supply air valve in the mixed air zone, all with fixed airflows. In this case the airflow through the main valve and through the AOE must be designed such that IAQ and thermal comfort to the occupants are provided.

Strategy B: Same as strategy A but supply air flow at the main valve is controlled through CO_2 level in the mixed air room. In this case, CO_2 concentration in the mixed air room as well as the airflow through the AOE must be designed such that IAQ and thermal comfort to the occupants are provided.

Simulation of air quality and humidity

Simulations were performed to define the optimal global airflow through main supply valve depending on the airflow rate through the AOEs, for the different strategies described above. Two typical floor-plan configurations, were simulated. Basically, these floor plans include two bedrooms, a small corridor, a bathroom, a kitchen and a living room, which is or is not, depending on the configuration, separated from the corridor.

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For the simulation, the multi-zone software CONTAM (NIST) was used. Every room of the two floor-plans were modelled with one zone in which the air is assumed to be perfectly mixed. The AOE have been modelled as a fixed flow opening. For all the rooms, an ideal heating has been assumed and the temperatures have been taken according to Rojas et al. (2012).

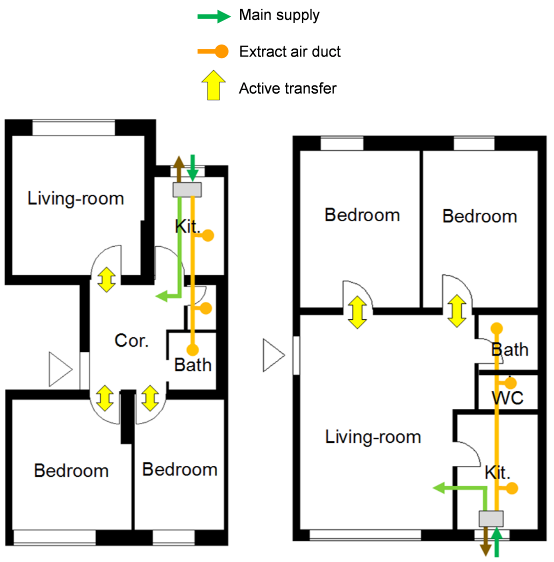


Figure 2: Floor-plans retained for the simulations. Left: with insulated living-room and corridor as mixed air zone. Right: “open” floor-plan with living-room as mixed air zone.

Boundary conditions for the simulations:

Simulation were performed with the climate of Innsbruck, Austria in the winter season, which is typical from Central Europe. Results of this study can thus be applied to any region of the world with dry and cold winter like for example Canada or the North of China (Schnieders et al., 2012).

Table 1, below, summarizes the model assumptions and boundary conditions:

Table 1: Assumptions and boundary conditions, based on Rojas et al. (2012)

Building	
windows	always closed
Internal doors (bedrooms)	closed when occupant is in, otherwise open
Internal doors (bath, kitchen)	Always closes except 4 times 10 min. a day
Building leakage rate (infiltration)	n_{50} = 0.6 1/h
Occupants	
Number of occupant	2 adults (in master bedroom) and 1 child (under 10 years old)*
Schedule of occupancy	Approx. 8 hours sleep in the bedrooms Approx. 4 hours full occupancy of the living room.

* Exhalation rate for water vapor and carbon dioxide concentration according to the standards found in (International Energy Agency, 2002)

Key Performance Indicators:

Carbon dioxide (CO_2) concentration was chosen as an indicator for the global air quality inside the rooms. It is not the only contaminant in indoor spaces and also not the most toxic one, however, according to (Tappler et al. (2014)), it can be assumed as a sufficient indicator for the air quality in apartment rooms with mechanical ventilation. The impact of other contaminants in the air (for example TVOC) on the global air quality is therefore neglected in this study.

The relative humidity (H_2O) appears in several studies to be one of the most critical acceptance factors of the occupants in the winter time in central Europe (Wagner et al., (2012)). Therefore, it is retained as an indicator of the indoor climate in this study. Other comfort criteria like draft risk or temperature difference were neglected in this study.

The method to evaluate the CO_2-concentration and the relative humidity in the living room is developed in Rojas et al. (2012). This method is based on the evaluation of different criteria, defined through a target and a limit value. The evaluation method compares the concentration of the two surveyed species (CO_2 and water vapor) in the air to given target and limit values. These values are chosen according to several and well-spread literature sources and standards on comfort and health of the occupants.

Table 2:Evaluation criteria according to (Rojas et al., (2012)) CO2-concentration (IDA “Indoor air quality”) and rel. humidity taken from (DIN EN 13779:2007-09, 2005).

Evaluation criteria at 22°C	**CO_2 rel* (CO_2 abs) [ppm]**	**rel. humidity [%]**
Target value (IDA 2)	< 600 (1050)	> 30 %
Temporary acceptable (IDA 3)	600 to 1000 (1050 to 1450)	20 % to 30 %
Limit value (unacceptable: IDA 4)	> 1000 (1450)	< 20 %

* above outside air concentration

The evaluation of the CO_2-concentration is based on the frequency and the amplitude of exceeding of the target value over the surveyed period. This value is compared to the maximum possible deviation over this period. The resulting value called “relative deviation of the target value” (or: τ_{CO2}), represents a weighted percentage of time in which CO_2 concentration exceeds the target value. The relative overstepping of the target value is calculated as the ratio between the integral of the overstepping amplitude over the surveyed period (zone in light grey on figure 3), and the in integral of maximum overstepping amplitude (here the darker grey rectangle delimited by the target and limit values, and the period).

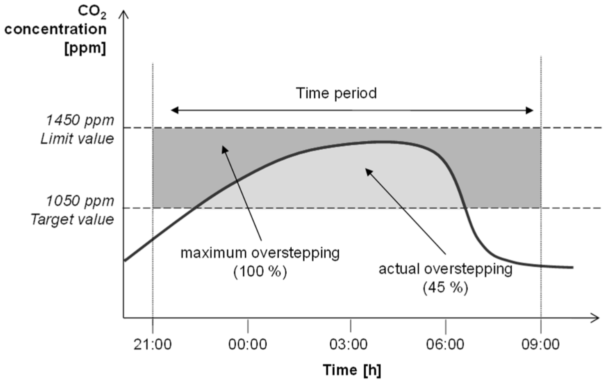


Figure 3: Illustration of the evaluation method for CO_2-concentration.

The relative deviation of the target value for CO_2 concentration is calculated with:

$$\tau_{CO2} = \frac{\int_T (\max(C_{CO2>C_{target},t} - C_{target,CO2}),0)dt}{T \cdot (C_{limit,CO2} - C_{target,CO2})} \cdot 100\ \% \qquad (1)$$

With τ_{CO2}, the relative deviation value of CO_2 concentration target value in [%]; T, the surveyed time period (by occupancy) in [h]; $C_{CO2>C_{target},t}$, value of the concentration of CO_2 at time t in [ppm]; $C_{target,CO2}$, the target value of CO_2 concentration, here 1050 ppm and $C_{limit,CO2}$, the limit value of CO_2 concentration, here 1450 ppm.

The lower the relative upper deviation (τ_{CO2}) is, the better is the effective contaminant removal in the living room, and thus the better is the air quality in the room.
The relative under-stepping value of the relative humidity in the room, τ_{H2o} is calculated accordingly:

$$\tau_{H2O} = \frac{\int_T (\max(C_{target} - C_{H2O<C_{target},t}),0)dt}{T \cdot (C_{target,H2O} - C_{limit,H2O})} \cdot 100\ \% \qquad (2)$$

With τ_{H2O}, the relative deviation value of relative humidity target value in [%]; $C_{H2O>C_{target},t}$, the value of the concentration of H_2O at time t in [%]; $C_{target,H2O}$, the target value of H_2O concentration, here 30 %; $C_{limit,H2O}$, the limit value of CO_2 concentration, here 20 %.

Again, the lower τ_{H2O} the more is relative humidity kept above the target value of 30 %.
The advantage of this method is that relative deviation of the target values for CO_2 concentration (τ_{CO2}) and relative humidity (τ_{H2O}) are both expressed as percentages, which allows for an evaluation of air quality and air humidity on the same scale.

Simulation results

Strategy 0:
With a main supply valve in the mixed air zone but no working AOE between this zone and the bedrooms, simulations show that when bedrooms doors are open (during daytime), there is enough air exchange between the zones to provide satisfying air quality and humidity in all the rooms. Though, as soon as bedroom doors close, fresh air supply in the rooms is insufficient and pollutant concentration and relative humidity increase dramatically.

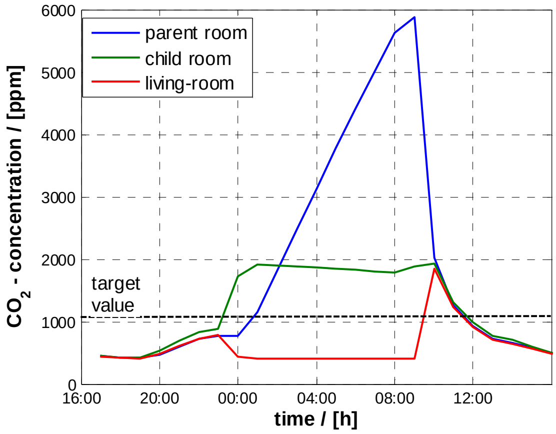


Figure 4: Simulation results of CO_2 concentration in parent bedrooms over night with no supply in the bedroom and no AOE between bedroom and mixed air zone.

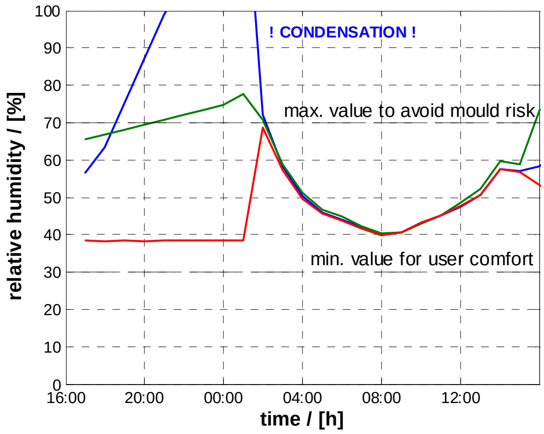
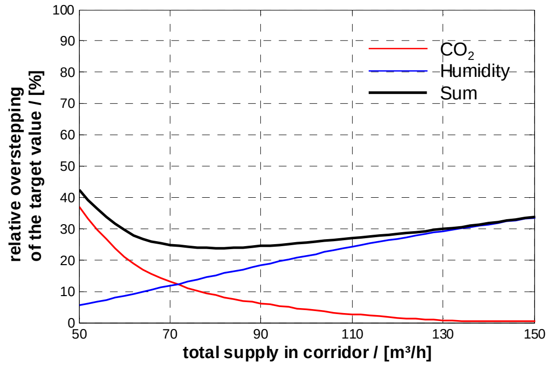


Figure 5: Simulation results of relative humidity in parent bedrooms over night with no supply in the bedroom and no AOE between bedroom and mixed air zone.

These simulation results were validated against measurements in (Sibille, 2015) and proof that this strategy is not a good solution for the ventilation of the rooms as the air quality is inacceptable and also because the high relative humidity in the bedrooms represents a mould risk.
The only way to ensure comfort and hygiene with this strategy is to ensure that the bedroom doors always stay open.

Strategy A:
An AOE is installed between the mixed air room and each bedroom and deliver a fixed airflow into the bedrooms when the door is closed. Following diagrams show the

deviation of the target values for comfort with different values of the airflow rate through the active transfers.



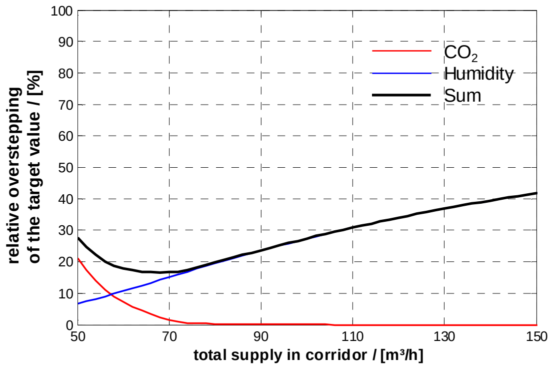


Figure 6: Relative deviation of the target values of carbon dioxide (1000 ppm) and humidity (30% relative humidity), as well as their sum in case of active transfers at 70 m³/h (above) and 150 m³/h (below) for varying global supply airflow rate in the corridor.

With increasing supply air in the corridor, the relative deviation of the CO_2-target value decreases, while relative deviation of relative humidity increases.

The black line on the diagrams represents the sum of the two types of relative deviation. This value can be interpreted as the deviation of the quality threshold of the indoor climate in the apartment by occupancy. The lower this indicator, the better the indoor air quality and hygrometric comfort. On both diagrams, a minimum of this indicator can be observed. Thus the minimum represents the best compromise between the air quality described by CO_2 concentration and air humidity. For example, when doors are closed and active transfers operate at 70 m³/h, global airflow rate should be set at approx. 80 m³/h in order to provide the best compromise (or optimum) of indoor climate to the occupants.

This optimum was determined for varying values of the air flow through the active transfers and for the two different floor-plan configurations. The resulting optimal global airflow rate is reported in the diagram in figure 7.

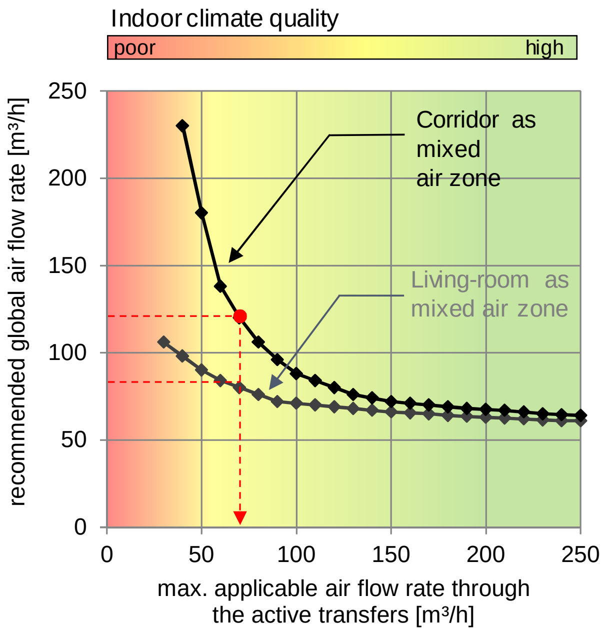


Figure 7: Map of the recommended global airflow rate according to the max. airflow rate through the active transfer for two types of floor plan configuration with standard occupancy pattern (two adults and one child).

The diagram shows that with higher airflow rate through the AOEs, supply airflow rate at the main valve in the mixed air room can be reduced.

This map can be directly used as a guideline by ventilation planners in order to design flow rates for a ventilation concept using AOEs. First, the maximal applicable airflow rate through the AOEs (x-axis) must be defined according to maximal tolerable sound level in the rooms (see section “Development of a Functional Model”. European Standards require a sound level under 25 dB(A). Though, experience have taught that a sound level under 23 dB(A) must be respected to meet occupant expectations. Eventually, the design value of global air flow rate which optimizes room indoor climate ca be directly derived from the diagram in figure 7.

The colors on the map give an indication of the average resulting quality of indoor climate in the apartment. Even if an optimum value (almost) always exists, the deviation of CO_2 target value is more significant with low values of airflow through the active transfers. Typically, for 2-bedroom apartments the active transfers should be planned with flow rates higher than 40 m³/h.

Strategy B:

This is the same as strategy A but in this case global air flow is controlled through CO_2 level in the mixed air zone. Relative deviation of the target values is represented in figure 8 for varying values of target CO_2 concentration in the corridor and varying airflows through the AOEs.

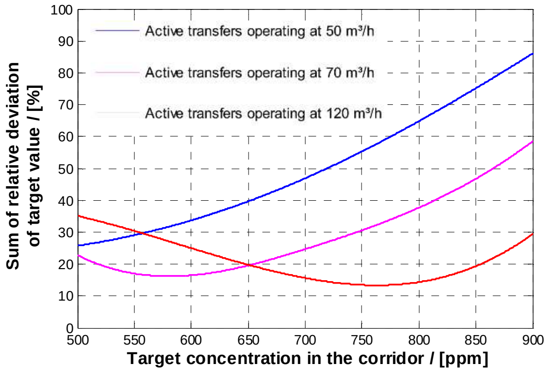


Figure 8: Sum of the relative deviation of the target values, for varying target CO_2 concentrations in the mixed air room (corridor).

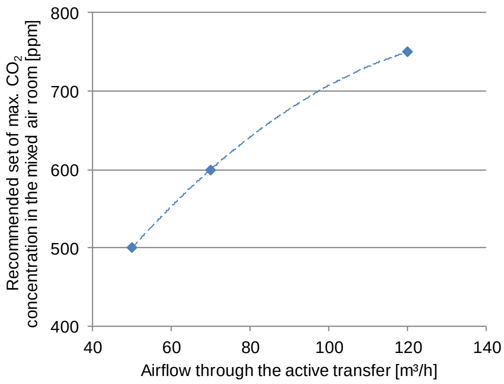


Figure 9: Planning guideline: recommended set point of max. CO_2 concentration in the mixed air room depending on the performance of the AOE.

Figure 9 shows that for each value of the airflow through the active transfer, a control value of CO_2 in the corridor exists that provides the best compromise between air quality and humidity.

Typically, for an AOE that can deliver 70 m³/h (by max. 23 dB(A) sound level in the room), target CO_2 concentration in the mixed air room (vestibule) should be set at 600 ppm to optimize air quality and relative humidity. In this case, this corresponds to an average value of 105 m³/h. This is lower than the recommended value in case of fixed airflow rates.

As a conclusion, a ventilation concept with AOEs, controlling the global airflow rate with the CO_2 concentration in the mixed air room contributes a reduction in the electricity consumption of the whole system in comparison to the strategy with fixed global airflow.

Development of a functional model

The previous section showed the impact of the airflow rate through the AOEs on the indoor climate of rooms that it ventilates. In the frame of the European Union funded project SINFONIA where more than 60 000 m² of social residential areas are being refurbished to a high level of energy performance, low-priced solutions are needed for the integration of the ventilation systems in the apartments. The concept of ventilation with AOEs is thus an attractive alternative to traditional cascade ventilation. This context contributed to start the development of a product adapted to refurbishment with minimal installation work.

Within the research project "SaLüH!" (Ochs, 2015) and together with the company Pichler-Luft (J.PICHLER Gesellschaft m.b.h., Klagenfurt, A), a solution for a product that can be integrated directly into the existing door without any drilling work was developed. The product consists in three small axial fans (CPU coolers) integrated in a metal frame on the top of the door. The air from the room flows back to the mixed air room through the gap below. The only work at the building site thus consists in cutting a slit at the top and at the bottom of the existing door to integrate the device. The panels on both sides ensure acoustic attenuation and an aesthetic finishing of the ventilation system.

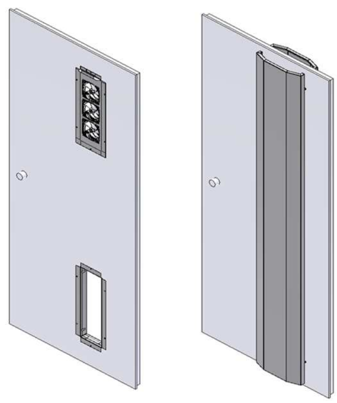


Figure 10: Sketch of the functional model of active transfer integrated directly into the door

The functional model was installed in a real door and measured in an acoustic test chamber at the University of Innsbruck. Airflow rate, electricity consumption, noise emission and transmission were measured. Based on the measured values, the expected sound level was calculated for a typical bedroom with 30 m², a reverberation period of 0,5 s and with a correction factor for external noise, according to Ö-Norm 8115-6.

Table 3 shows a summary of the performances of the product:

Table 3: measured performances of the functional model of active transfer. All values are average over several measurements.

Max. input voltage	12.0 V
Electricity consumption	1.08 W
Airflow rate	58.0 m³/h
Predicted noise level in bedroom	20.0 dB(A)
Predicted noise level in mixed air room	22.4 dB(A)
Reduction of noise attenuation of the door though the integration of AOE	5 dB

The measured performance of the functional model is promising. Particularly the predicted sound level in a typical room shows that acoustic comfort is ensured for the user. Through the measurement process, it has been noticed that the two cover panels produce a significant pressure drop directly after the fans and thus decrease their performance and the maximal achievable airflow rate. By providing more space between the door and the panel, it is expected that the performances of the fans can be further improved and that the optimal airflow of 70 m³/h for high user comfort can be reached.

Comparison with traditional air distribution

The operating costs of the air distribution for the concept using AOEs are compared to those of the "traditional" air distribution concept, the so-called "cascade ventilation", in which supply air valves are placed in each bedroom.
The results are presented in figure 11 with a suggestion of the ductwork for each situation. The resulting pressure drops due to ductwork derive from calculation made in (Sibille, 2015). The calculation for the concept with AOEs is based on the measured performances of the functional model.

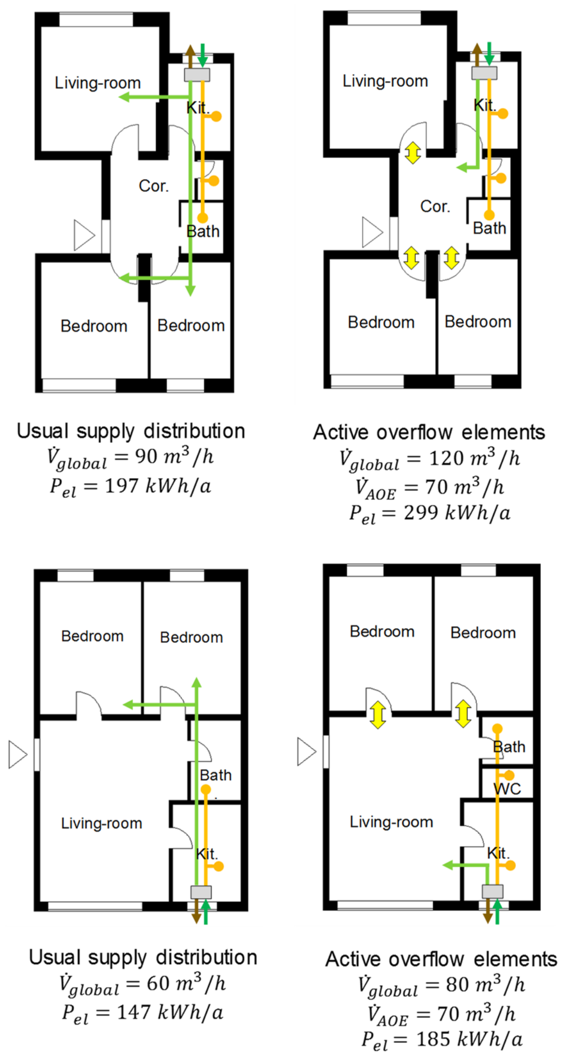


Figure 11: Results of the comparison between ventilation in cascade and with active transfers.

The results show that electricity consumption is 20-30 % lower, depending on floor plan configuration for cascade ventilation than for the AOE concept. Adding the own consumption of the AOE elements (approx. 1,1 W each) leads to an average difference of approx. 80 kWh/a. This difference can be neglected in regard to the important savings that can be expected in the investment and installation costs for the concept using AOEs, particularly in the case of retrofits where very little place is available for air ducts in the apartments.

Conclusions

The proposed solution with AOE has the potential to deliver the same IAQ and thermal comfort as the traditional ducted solution. The electric consumption is slightly higher. Considering that in the majority of cases ducted solutions are not implemented at all in renovations because of the high installation effort and the corresponding high disturbance of the tenants, the solution with AOE may be a cost efficient alternative that allow for high efficient ventilation with heat recovery.
Therefore, economic aspects are only of second order importance.
By means of dynamic simulation the technical feasibility of the concept was confirmed. Further simulations should address the optimal positioning of the main supply valve in the mixed air room, especially in case of open floor-plans, to avoid the mixing of fresh air with local odor sources (for example kitchen).

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