OVERFLOW ELEMENTS: IMPACTS ON ENERGY EFFICIENCY, INDOOR AIR QUALITY AND SOUND ATTENUATION

Gabriel Rojas Kopeinig[*1], Mattias Rothbacher[1], Rainer Pfluger[1]

1 AB Energy efficient housing, University of Innsbruck
Technikerstrasse 13,6020 Innsbruck, Austria
**Corresponding author: gabriel.rojas-kopeinig@uibk.ac.at*

ABSTRACT

When planning ventilation systems for energy efficient housing, an appropriate design of the overflow elements between rooms is important as it influences ventilation losses, indoor air quality and sound attenuation between rooms. Based on calculation results of the natural in- or exfiltration rates through the building envelope as a function of the overflow element's flow resistance, this work proposes a maximal pressure drop of 2-3Pa for overflow elements in energy efficient buildings. Measurement data on sound attenuation and pressure drop for simple door or doorframe integrated overflow solutions is presented. It shows that a volume flow of 40m³/h can be achieved with a pressure drop ≤2Pa with simple and cost effective modifications to a standard door construction, while still complying with a normal sound attenuation requirement of 30dB.

KEYWORDS

Overflow elements, sound attenuation, pressure drop, flow resistance, infiltration, exfiltration, air distribution

INTRODUCTION

How does the design of an overflow element (OFE) influence the in- and exfiltration rates, and therefore the energy efficiency, the indoor air quality and the sound transmission? This work establishes pressure drop requirements for overflow elements of energy efficient houses. It also provides so far unavailable experimental data of sound attenuation and pressure drop for various simple and cost effective overflow solutions.

METHOD

Numerical calculations to determine the requirements regarding flow resistance

A numerical multi-zone model is used to calculate the natural and forced in- or exfiltration rates and the supply air distribution depending on the pressure loss of the overflow elements connecting the zones. Results shown herein are based on a 3-zone model in steady state as depicted in Figure 1. The following set of coupled power law equations [1] are solved using Newton's method:

$$\dot{V}_{IN} - \dot{V}_{OFE1} + \sum_j \dot{V}_{AP1j} = 0 \quad (1)$$

$$\dot{V}_{OFE1} - \dot{V}_{OFE2} + \sum_j \dot{V}_{AP2j} = 0 \quad (2)$$

$$\dot{V}_{OFE2} - \dot{V}_{OUT} + \sum_j \dot{V}_{AP3j} = 0 \quad (3)$$

With $\dot{V}_{IN}$ and $\dot{V}_{OUT}$ being the supply and the exhaust volume flow, $\dot{V}_{APij}$ and $\dot{V}_{OFEi}$ being the volume flow through the respective air path or overflow element. They can be calculated as follows:

$$\dot{V}_{OFEi} = C_{OFEi} \cdot \left| p_{Ri} - p_{R(i+1)} \right|^{n_{OFEi}} \cdot Sign\left(p_{Ri} - p_{R(i+1)}\right) \quad (4)$$

$$\dot{V}_{APij} = C_{APij} \cdot \left| p_0 + p_{Wij} - p_{Ri}(h_{ij}) \right|^{n_{APij}} \cdot Sign\left(p_0 + p_W - p_{Ri}(h_{ij})\right) \quad (5)$$

With p_0 being the ambient pressure, p_{Wij} being the wind pressure at the respective air path according to [2] or [3] and $p_{Ri}(h)$ being the pressure in room/zone i at a given height h:

$$p_{Ri}(h) = p_{Ri}(0) - \rho(T_i) \cdot g \cdot h \quad (6)$$

T_i is the temperature in zone i and g the gravitational acceleration. Note that for simplicity, the set of equations is based on a volume flow balance rather than on a physically correct mass balance. The validity of the model and the assumed parameters was checked with transient simulations with CONTAM, a multi-zone airflow analysis software [3]. Figure 1 shows the comparison with the results obtained with CONTAM for a two bedroom flat with 80 m² with a transient weather file generated with Meteonorm 6.1 [4] for Vienna. The used parameters for 3-zone model are as presented below.

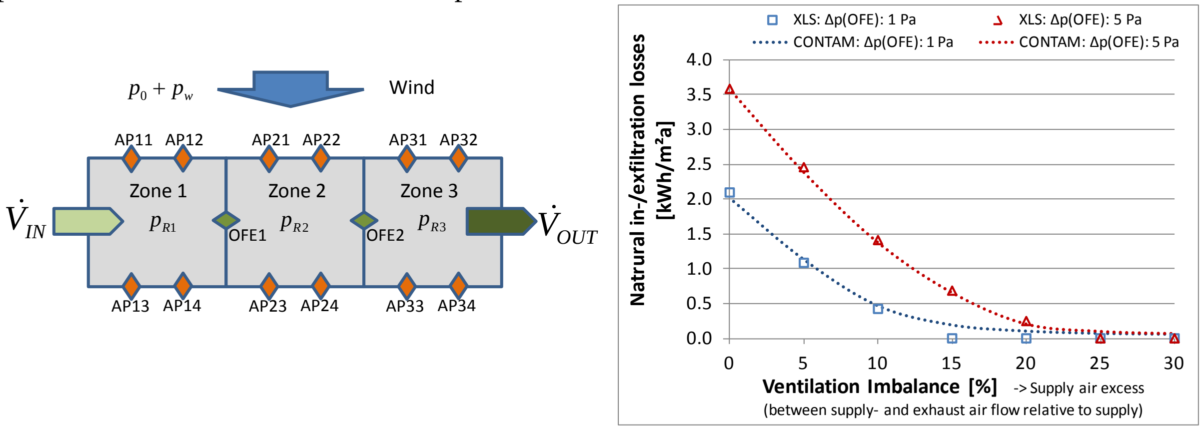

Figure 1: Left: Schematic sketch of 3-zone-model used for airflow analysis. Right: Comparison of natural in-/exfiltration losses calculated with the presented 3-zone-model (steady state) and with CONTAM (transient).

Experimental setup to measure flow resistance and sound attenuation

The tested overflow elements were installed in a double chamber test lab at the University of Innsbruck. The test lab, suited for sound attenuation measurements according to ISO 140-3, was also supplemented for pressure drop measurements. The test samples were mounted in an opening (205 x 85 cm) of the double shell concrete wall. If necessary, the remainig area was closed with a high sound-insulating dry-wall construction. A diffuse sound field was generated in one chamber. The averaged sound pressure levels were measured in both chambers. By determining the absorption area of the receiption chamber, the sound reduction index and the standardized sound level difference can be determined.

To determine the airflow resistance, one side of the opening of the double shell concrete wall was closed with an airtight board, producing a 230 x 140 x 25cm pressurizable air volume as illustrated in Figure 3. A low volume „blower door tester“, type J225, from SI-special instruments GMBH, was used to apply a pressure difference across the test objects and to measure the volume flow. If required, an additional ventilator was used to „boost“ the volume flow to up to 100 m³/h. The additional flow was determined with a pressure loss measurement over an initially calibrated tube.

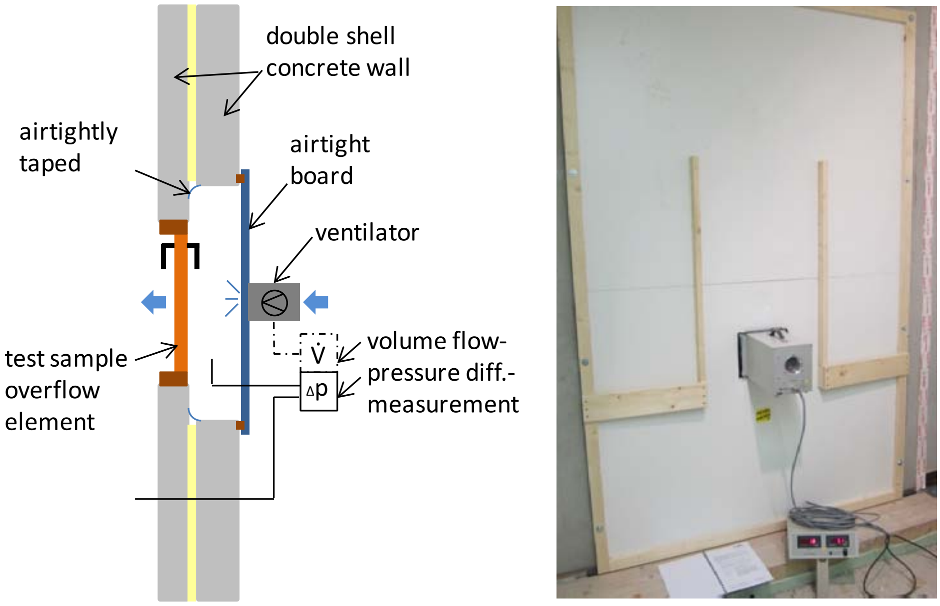

Figure 2: Experimental setup for measurement of the flow resistance

REQUIREMENTS ON OVERFLOW ELEMENTS

Energy efficiency

For the design of the ventilation system one needs to be aware that overflow elements influence the ventilation losses. The ventilation losses for a building with mechanical ventilation are determined by losses due to the mechanical ventilation system (i.e. ineffective heat recovery and forced in-/exfiltration due to imbalanced supply and extract flows), and due to the natural in-/exfiltration through the building envelope. They are shown in Figure 4 in dependence of the ventilation imbalance. The natural in/-exfiltration is driven by the difference of inside and outside pressure. The pressure difference in a natural ventilated building is imposed by vertical density gradients (stack effect) and wind pressure. For mechanically ventilated buildings the pressure difference is also affected by the flow resistance of the overflow elements (see Figure 1). Note, that the in- or exfiltration due to this flow resistance of the overflow elements could, in a semantic sense, be added to the forced in-/exfiltration. But for calculation and further analysis it is advantageous to include it in the natural in-/exfiltration, as it is done for the calculations of this paper.

The natural in-/exfiltration losses as a function of the ventilation imbalance are calculated for different flow resistances at the overflow elements, see Figure 4. The flow resistance is given as pressure drop at nominal volume flow per overflow element.
To determine the pressure drop requirements, the results are plotted versus the nominal pressure drop of the overflow elements in Figure 5. The natural in-/exfiltration rates for an airtightness level of n_{50}=0.5h^{-1}, increase from 0.02h^{-1} for a situation with no flow resistance, to about 0.03h^{-1} for OFEs with a pressure drop of Δp=3Pa. That is equivalent to an inrease of 10% of the total ventilation losses of an energy efficient system (heat recovery rate of 80%) and therefore tolerable. If the flow resistance across the overflow element is increased further, the in-/exfiltration losses augment even stronger (higher gradient), which is even more pronounced for buildings with little airtightness standards. E.g. if an overflow element with a pressure drop of 5Pa instead of 2Pa is used for a building with a n_{50}-value of 0.5h^{-1}, the total ventilation losses would be equivalent to a building with an airtightness level of 0.8h^{-1}.

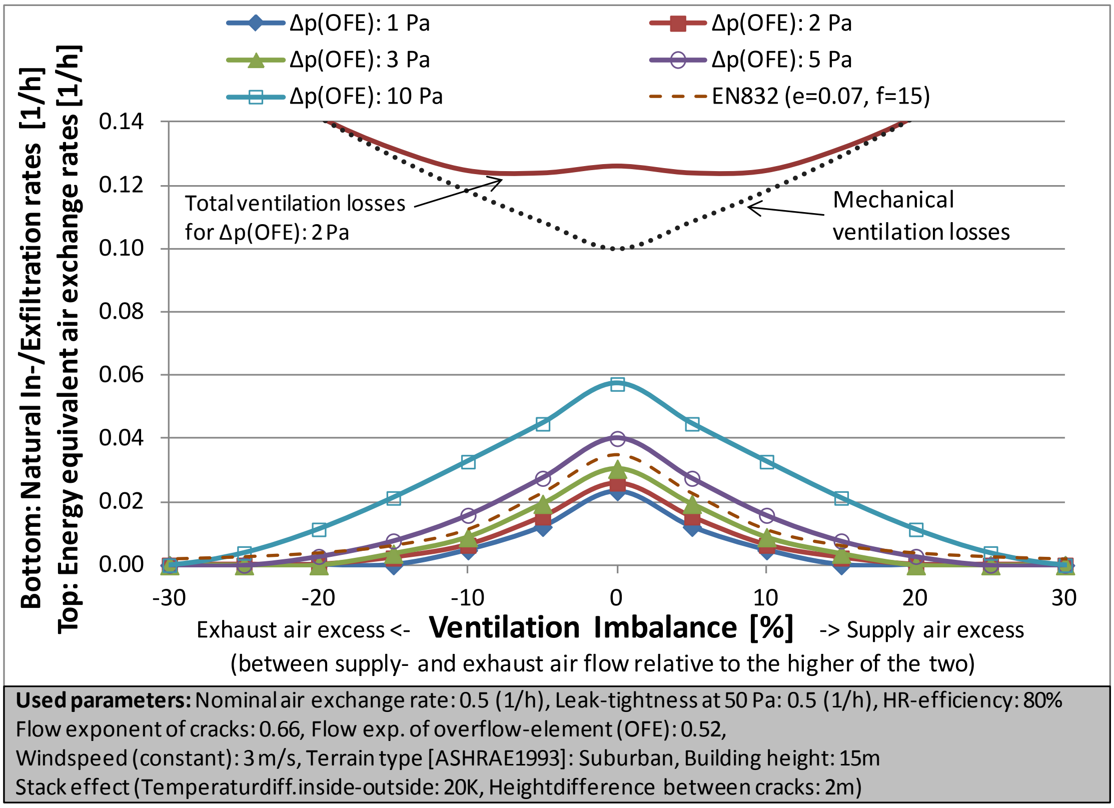

Figure 3: Natural in-/exfiltration rates for different pressure drops across the overflow elements (OFE). Also shown are the mechanical ventilation losses and the total ventilation losses for OFEs with a Δp of 2Pa.

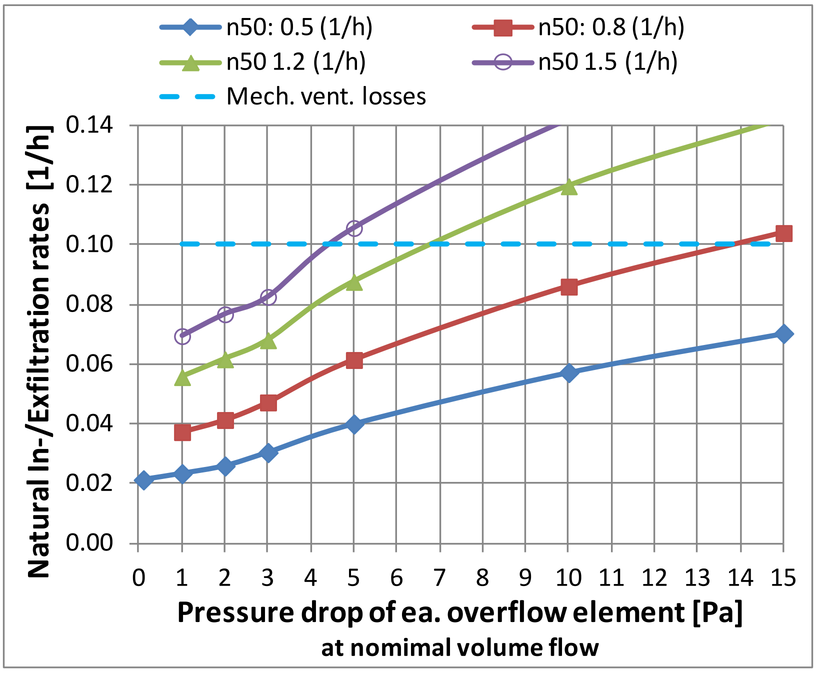

Figure 4: Natural in-/exfiltration as a function of the pressure drop for different airtightness levels.

Indoor air quality

Another aspect to consider when defining the specification for overflow elements is their effect on indoor air quality (IAQ). The supply air distribution is altered if the door to one of the supply air rooms is opened, see Figure 6. This is also true for the exhaust air distribution and exhaust air rooms.

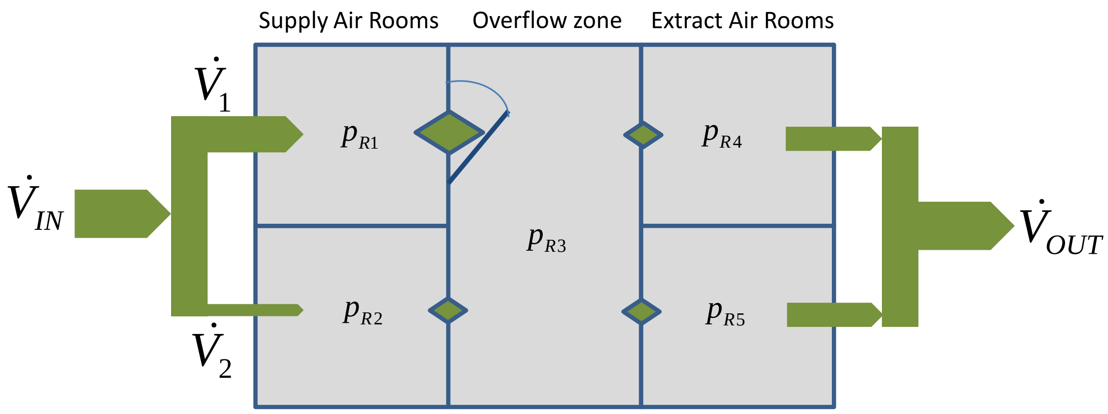

Figure 5: Schematic illustration of change in supply air distribution when a door is opened.

Figure 7 shows the misadjustment of the supply air volume flow in the room with closed door relative to its nominal volume flow. As the misadjustment is also dependant on the pressure drop over the supply air nozzle, the results are shown for different supply air nozzle pressure drops. To minimize electric consumption of the ventilators, the air distribution system for energy efficient housing should have little pressure losses. Recommendations for the pressure drop of supply air nozzles for passive houses are given with 10-15 Pa. If the misadjustment of the supply air is to remain below 10% (for a supply air nozzle with a Δp of 10 Pa), the pressure drop of the overflow element should be kept below 2-4 Pa, depending on the number of supply air rooms.
As a generalizable statemente we recommend a maximal pressure drop of 2-3Pa.

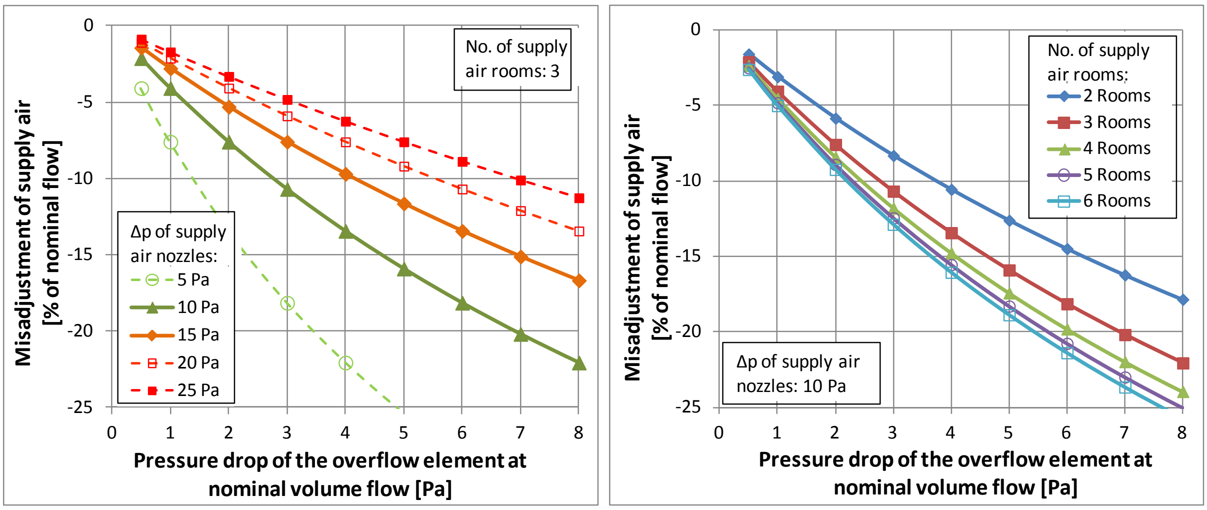

Figure 6: Misadjustment of the supply air flow for various supply air nozzle pressure drops (left), and for different numbers of supply air rooms (right). Shown is always the worst case scenario, i.e. the misadjustment in the room with closed door while the doors of the other rooms are open.

Sound attenuation requirements

In most countries there are no compulsory reglementation for acoustic attenuation requirements within a housing unit. Nevertheless, according to a recommendation in DIN 4109 (1989) the acoustic attenuation R'_w between rooms of different usage within in one housing unit (calculated for a 8.26 m² wall and a 1.74 m² door) should be ≥30 dB for normal requirements and ≥35 dB for higher demands.
By nature, sound attenuation requirements are always opposed to low flow resistance requirements. Nevertheless, limited possibilities for increasing the attenuation, while keeping the pressure drop at an acceptable level, exist, even for simple overflow solutions. To improve the acoustical performance, the geometry of the inlet and the outlet of overflow-elements can

be designed to minimize the entry of sound waves. The sound propagation in the flow channel can be reduced by increasing the absorption area and by implementing directional changes.

Other requirements

Further requirements on overflow elements not quantified in this paper could arise from aspects like design, passing light, cleanability, possibilities of short-circuited air flow and draft risk. By limiting the pressure drop and therefore the air speed, a draft risk issue might only arise if the overflow element is placed close to the occupant's regular position, e.g. close to the standing area in the bathroom.

MEASUREMENT OF FLOW RESISTANCE AND SOUND ATTENUATION

To give ventilation planners and architects the necessary data for proper layout of the overflow elements, sound attenuation and pressure drop characteristics of typical and novel door or doorframe integrated solutions were determined experimentally. The tested OFE were selected out of an initial literature and market study, focusing on solutions that can be realized by simple modifications to a standard door construction and for which no measurement data was available. A description of the measured overflow solutions is given below. A summary of the parameterized results are listed in Table 1.

Tested overflow elements

- **Door gap (1):**

  This very simple solution is widely used, but often arbitrarily dimensioned, resulting in high pressure drops or an excessive deterioration of the sound attenuation.

Figure 7: Measured door gap without (left) and with carpet (right).

A series of measurements with gap heights from 5 to 20 mm was performed to give the following formulas as a layout aid to calculate the volume flow in *[m³/h]* as a function of the desired pressure difference Δp *[Pa]* as a planning aid:

$$\dot{V} = C * (\Delta p)^n \quad (1)$$

The parameters C *[m³/h/Pa^n]* and n can be calculated in dependence of the gap height h *[mm]* and the gap-length l *[m]* (=door width).

$$C = (k * h + d) * l \quad (2)$$

$$n = \frac{A}{h - B} + 0.5 \quad (3)$$

Note that the roughness of the gap surface does have an notable influence. The dependence of the gap depth (=thickness of door) can be neglected.

Modified wooden door frame (2):

This also quite popular solution was first published in [5] and consists of leaving a gap between lintel and wooden frame and to cut air in-/outlets into the top portion of the door frame. (Alternatively or additionally, it could also be realized at the sides of the door frame.)

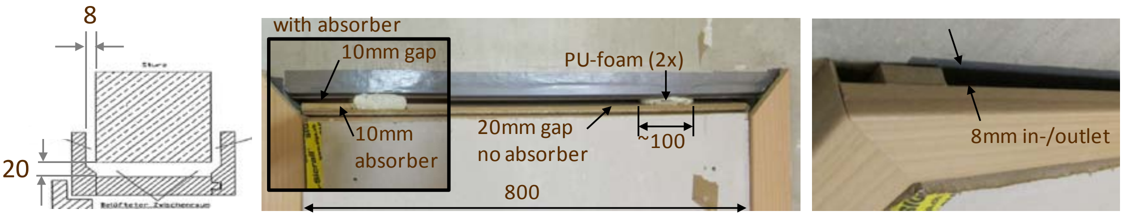

Figure 8: Modified wooden door frame. Left: Schematic drawing.
Right: Pictures of the test situation.

The volume flow *[m³/h]* for the tested design (2) can be estimated for a given pressure difference by

$$\dot{V} = C' * l * (\Delta p)^n \qquad (4)$$

with *l [m]* being the gap length, i.e. the door width. Note that the measured parameters might vary for other frame designs.

- **Modified metal door frame with shadow gap (3):**
  This design was developed within this work at the University of Innsbruck and aims to combine an unobtrusive and simple design with a decent sound attenuation.

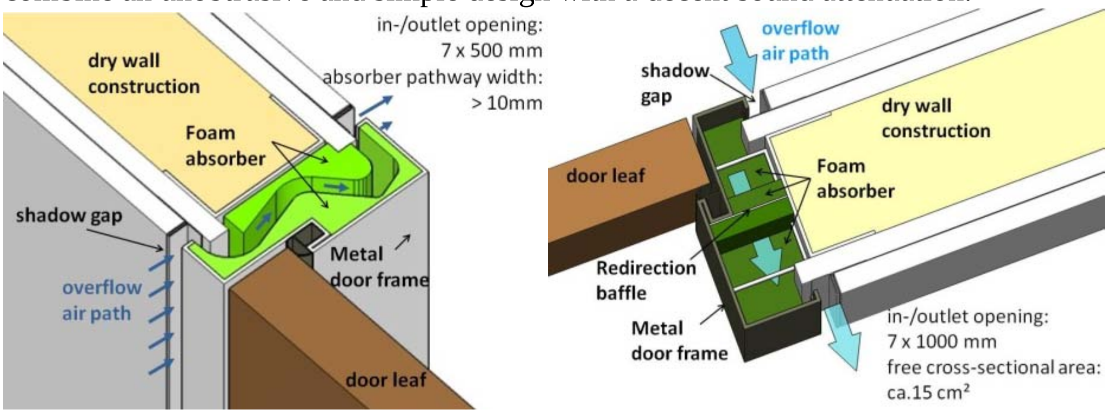

Figure 9: Two different versions of the modified metal door frame, as developed at the University of Innsbruck. The air in- and outlets are hidden within the shadow gap.

The volume flow *[m³/h]* for this design is given by Eqn.(4) with *l [m]* being the gap length. Design details are will be published in the final report of [6].

- **Special ventilation door frame (4):**
  A solution developed and manufactured by Keller Zargen AG (Switzerland). So far no measurement data was available. The included supply air outlet was closed during the measurements. For a given pressure difference the volume flow *[m³/h]* can be calculated with Eqn.(1).

- **Rabbet gap (5):**
  This solution has a reduced rabbet width at the top, leaving a gap between door-rabbet and door seal. In an "extended" version the rabbet was cut thinner all around, leaving only some short segments for a door to seal contact.

Figure 10: Picture showing the reduced rabbet at the top of the test door, leaving a gap between door and frame when closed.

For a given pressure difference the volume flow *[m³/h]* can be calculated via Eqn.(1).

- **Perforated door (6):**

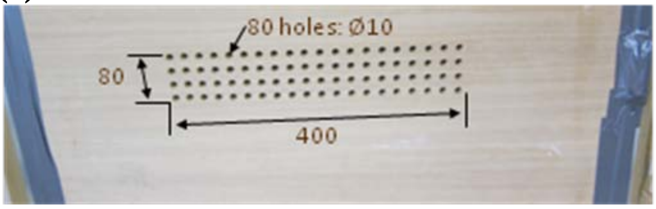

Figure 11: Picture of a door with a number of through holes at the lower region of the door as measured.

This simple solution consists of four rows of each 20 through-holes with Ø10mm. The resulting volume flow *[m³/h]* can be estimated via Eqn.(4) with x being the number of hole-rows (with 20 holes each).

- **Z-Blind (7):**

Figure 12: Picture of the measured Z-blind.

This overflow element is also an alternative to regular door grilles, and consists of a door blind (4) where the air flow is directed in z-shaped path supplemented with an 1 cm thick foam-absorber lining. The resulting volume flow *[m³/h]* can be calculated with Eqn.(1).

Measurement Results

The parameters obtained from the pressure drop and sound attenuation measurements are summarized in Table 1.

	Overflow element / Overflow solution	**A**	**B**	**k**	**d**	**C/C'**	**n**	**$D_{n,e,w}$ [dB]**
1a	Door with bottom gap	0.12	1.17	3.21	-0.08	-	-	-
1b	Door with carpet in bottom gap	0.12	1.17	2.51	-2.17	-	-	-
2a	Wooden door frame	-	-	-	-	20.2	0.58	36
2b	Wooden door frame with foam absorber	-	-	-	-	18.2	0.57	40
3a	Metal frame V1	-	-	-	-	7.0	0.59	37
3b	Metal frame V2	-	-	-	-	8.1	0.49	44
4	Special ventilation door frame	-	-	-	-	11.6	0.50	45
5a	Top rabbet gap with (door B)	-	-	-	-	4.5	0.57	34
5b	All-around rabbet gap (door B)	-	-	-	-	21.8	0.52	30
6	Perforated door (door A)	-	-	-	-	18.7	0.54	32
7	Z-blind (door A)	-	-	-	-	19.8	0.52	30

Table 1: Parameters of pressure drop (A, B, k, d, C, C'and n) and of sound attenuation ($D_{n,e,w}$) measurements.

For better comparison the measured data is used to calculate the resulting acoustic attenuation (R'_w) for a typical construction situation. The resulting R'_w and the achievable volume flow at a pressure difference of 2 Pa are listed in Table 2, Table 3 and Table 4. A typical construction situation was defined here as a 10m² dry-wall construction with a R_w of 41 dB and with a 80 cm wide door, resulting in a 8.26 m² wall and 1.74 m² door surface.

	Overflow in bottom door gap	R'$_w$ of door with gap [dB]	Resulting* R'$_w$ [dB]	Vol. flow [m³/h] at Δp=2Pa
1a	Door with 5mm bottom gap	23	30	18.4
1b	Door with 10mm bottom gap	20	27	36.4
1c	Door with 15mm bottom gap	18	25	54.4
1d	Door with 20mm bottom gap	15	23	72.4
1e	Door with carpet in bottom gap (remaining gap 10mm)	(23)	(30)	26.1

Table 2: Resulting acoustic attenuation and volume flow at given pressure drop for a door with bottom gap. R'$_w$ of door itself is 30dB. *Resulting acoustic attenuation as defined in the text.

	Door or door frame integrated overflow solutions including a 5mm bottom door gap	R'$_w$ of door with gap [dB]	Resulting* R'$_w$ [dB]	Vol. flow [m³/h] at Δp=2Pa
2a	Wooden door frame	23	29	41.5
2b	Wooden door frame with foam absorber	23	30	40.9
3a	Metal frame V1	23	29	39.7
3b	Metal frame V2	23	30	41.3
4	Special ventilation door frame	23	30	34.9
5a	Top rabbet gap with (door B)	23	(28)	19.0
5b	All-around rabbet gap (door B)	23	27	41.7
6	Perforated door (door A)	23	28	45.7
7	Z-blind (door A)	23	27	47.0

Table 3: Resulting acoustic attenuation and volume flow at given pressure drop for various door or door frame integrated overflow solutions in combination with a 5mm wide bottom door gap.
*Resulting acoustic attenuation as defined in the text.

	Door or door frame integrated overflow solutions without bottom door gap	R'$_w$ of door [dB]	Resulting R'$_w$ [dB]	Vol. flow [m³/h] at Δp=2Pa
2a	Wooden door frame	30	33	23.1
2b	Wooden door frame with foam absorber	30	35	22.4
3a	Metal frame V1	30	34	21.2
3b	Metal frame V2	30	36	22.8
4	Special ventilation door frame	30	36	16.4
5a	Top rabbet gap (door B)	31	32	6.7
5b	All-around rabbet gap (door B)	31	29	31.2
6	Perforated door (door A)	30	30	27.2
7	Z-blind (door A)	30	29	28.5

Table 4: Resulting acoustic attenuation and volume flow at given pressure drop for various door or door frame integrated overflow solutions without bottom door gap. This realization would require a floor rabbet seal or a drop down seal. *Resulting acoustic attenuation as defined in the text

CONCLUSION

A proper overflow element layout is important to avoid:

- excessive in- and exfiltration through the building envelope and therefore a decrease in energy efficiency,
- maladjustment of the supply air distribution when interior doors are opened and therefore an impairment of indoor air quality,
- needless deterioration of the sound attenuation between rooms and therefore a lowering of the acoustic comfort.

For energy efficient buildings with mechanical ventilation, overflow elements should be designed and dimensioned for pressure drops <2-3 Pa at nominal ventilation rates.
For a typical construction (10m² dry-wall), the following can be stated:

- Volume flows of 30-40 m³/h can be achieved with simple and cost effective door and door frame integrated solutions while still complying with normal sound attenuation recommendation of 30 dB according to DIN4109 (1989).

- A door gap of 5mm in combination with a modified door frame (No. 2b or 3b) will fulfill these requirements.
- A door gap of 10 mm by itself allows a volume flow of 35m^3/h, but it reduces the sound attenuation between rooms to about 27 dB.
- Higher acoustic attenuation requirements (≥35 dB) require a door with a floor rabbet seal or a drop down seal in combination with some form of an overflow element. Depending on the desired volume flow and on the desired sound protection a wall or ceiling integrated overflow element might be necessary.

ACKNOWLEDGEMENTS

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