Passive window ventilation openings for building refurbishment

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Abstract

A thorough building refurbishment generally includes window replacement and thermal insulation of the opaque building envelope. However, quite often only a window replacement is done and the building envelope is left uninsulated. If there is no mechanical ventilation system installed which ensures continuous air exchange, new airtight windows usually lead to a reduced infiltration air exchange and subsequently there may be moisture damage. A possible solution can be the integration of passive window ventilation openings (PWVO). This raises two questions: Firstly, can PWVO guarantee the necessary ventilation rate to avoid moisture damage? Secondly, how do PWVO compare to a ventilation system with heat recovery in terms of heating demand? This Article deals with passive window ventilation openings without heat recovery in flats with cross ventilation. Based on transient building simulations of a typical dwelling unit it is shown that the PWVO by themselves cannot guarantee a sufficient ventilation rate for moisture control. With additional exhaust fans in the kitchen and bathroom(s) the required ventilation rate can be achieved. However, PWVOs with high air flow rates (approx. 15 m^3/h @ 2 Pa) must be used. Compared to PWVO the installation of a ventilation system with heat recovery leads to energy savings of approx. 20% in an uninsulated building. In a building where the building envelope has also been insulated, the savings would be approx. 60%.

Keywords: passive window ventilation openings, ventilation rate for moisture control, moisture, building refurbishment, window replacement

1. Introduction

1.1 Project context and issues

Estimations on housing construction in Germany show that in about 10% of households a problematic mould growth occurs, which is, amongst others, due to insufficient ventilation conditions [1]. Often, old buildings with new windows and without external wall insulation are affected. Thereby, mould growth appears significantly more often in flats than in single-family homes. Within flats, bedrooms and children's rooms are most frequently affected by the damages. Since mould is often associated with new, airtight windows, the idea of replacing old windows by specifically leaky new ones suggests itself. Apart from the hands-on "method" of removing existing seals in new windows, the required leakage can be achieved with so called passive window ventilation openings (PWVO). There are window frames available on the market which have directly integrated PWVO, however some products can also be retrofitted. As PWVO are also being used in flats without a mechanical extract ventilation, two substantial questions arise:

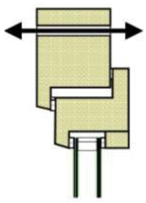
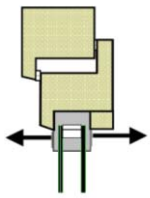
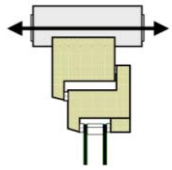
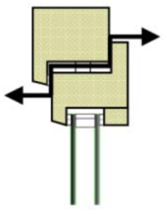
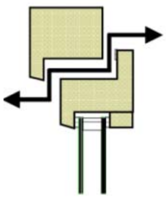
- How high is the air change rate that can be achieved in a flat with PWVO and cross-ventilation? Is it possible to guarantee the air exchange rate necessary to avoid moisture issues?
- How high are the potential energy savings of a ventilation system with heat recovery in comparison to PWVO?

This text summarises the results of a research project, which has been carried out for the City of Zurich, Switzerland.

2. Definition of PWVO

A passive window ventilation opening is a ventilation unit or element which is integrated into the window or is directly related to the window [2]. Table 1 shows types of PWVO referred to in this paper. For further information and definitions please refer to [3]. Primarily, PWVO belong to the group of outdoor air apertures.

Table 1: Passive window ventilation opening (PWVO): schematic diagrams taken from [2]

Term	Schematic diagram and example		
PWVO top-frame	  Source: RENSON	  Source: SIEGENIA AUBI AG	  Source: Schüco International KG
PWVO in window rebates		 Source: REGEL-air (INNOPERFORM GmbH)	
PWVO window fitting		 Source: WERU AG	

The following text deals with ventilation concepts based on PWVO or on a combination of PWVO and one or more time-controlled local extract fans in kitchen and bathroom.

3. Literature and standards

Within this project a review of available literature and standards was conducted. Only a few literature sources could be found which deal specifically with PWVO or outdoor air apertures. The same goes for standards and guidelines in Germany and Switzerland. Both reviews can be found in [4]. Derived from the review, the following will be used as basis for the evaluation of the thermal simulations in regard to moisture control:

SIA 180:2014 [5] as well as DIN 1946-6:2009-5 [6] recommend a minimal outdoor airflow for moisture control. For a flat with 100 m^2 NFA (definition according to [7]), the following values are given:

- DIN 1946-6:2009-05: 0.38 $m^3/(h \cdot m^2)$ for a refurbished existing building, 0.5 $m^3/(h \cdot m^2)$ for an existing building as is
- SIA 180:2014: 0.22 - 0.74 $m^3/(h \cdot m^2)$.

The values refer to the NFA or to the net volume, respectively. Especially for renovations including window replacement a minimum air exchange rate makes good sense.

4. Market study

There is a broad range of PWVO available on the market. The market research conducted (not all-encompassing) includes 20 manufacturers with 50 products. The companies are mostly from Germany, a few come from France, Belgium, Liechtenstein and Austria. The most common types are PWVO top-frame (27 products) and PWVO in window rebates (10 products). The following section focuses on the performance data in regard to air flow. Further aspects of interest such as maintenance and sound reduction are covered in [4].

4.1 Airflow data

Concerning PWVO in window rebates a pressure difference between 2 and 10 Pa usually leads to an air flow rate of 2 - 6 m^3/h. The airflow rate is significantly higher in top-frame PWVO (4 - 60 m^3/h). Roughly, two groups can be identified here: The first group contains devices with airflow rates between 5 and 25 m^3/h, the second group includes appliances with air flow rates in the range of 29 - 65 m^3/h (both ranges for 2 – 10 Pa pressure difference across the PWVO). Due to comfort reasons PWVO with the latter, very high airflow rates are presumably not designed for standard applications in residential buildings. The findings of the market study are used to generate performance data as an input for the building simulations. Three types are defined, each representing the mean of a specific PWVO group: window rebate PWVO (category 1), small top-frame PWVO (category 2) and big top-frame PWVO (category 3) (Figure 1).

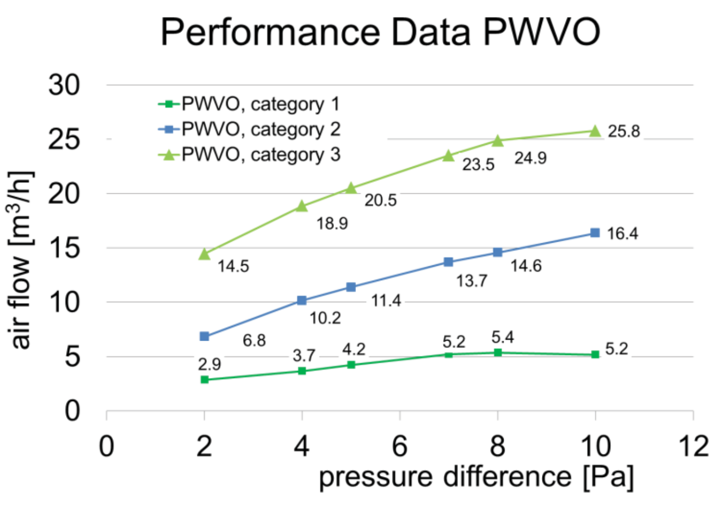


Figure 1: Performance data for the simulated PWVO. The data points show average values from the market study. The group entitled 'PWVO, category 3' (big top-frame PWVO) represents the average values of 17 top-frame PWVO (incl. Renson TH100). The average values of 16 top-frame PWVO with a smaller airflow were chosen for the group entitled 'PWVO, category 2' (small top-frame PWVO). The curve for the group entitled 'PWVO category 1' (window rebate PWVO) is based on 8 window rebate PWVO.

5. Simulation model and results

5.1 Simulation model

The aim of the simulations is to examine the effect of PWVO on the basis of a typical flat built in the 1960s or 1970s. Three PWVO with different performance data are compared with each other (see figure 1). The simulation model is based on an uninsulated building, retrofitted with new airtight windows. The flat (figures 2 and 3) has a NFA (net floor area, definition according to [7]) of 79 m^2.

The simulation model which includes an air flow network is used to answer the following questions:

- Which air change rates can be achieved?

  To answer this, three PWVO types (see figure 1) are compared. The sensitivity to the boundary conditions for the simulation is determined by the relative position of the flat to the wind direction (V1.1-V1.3 and V2.1-V2.3), the degree of exposure with regard to the elevation of the flat within the building (Ground floor, 3rd floor (V3.2)), and the flat's degree of exposure to wind depending on the building context.

- How is the heating demand affected?

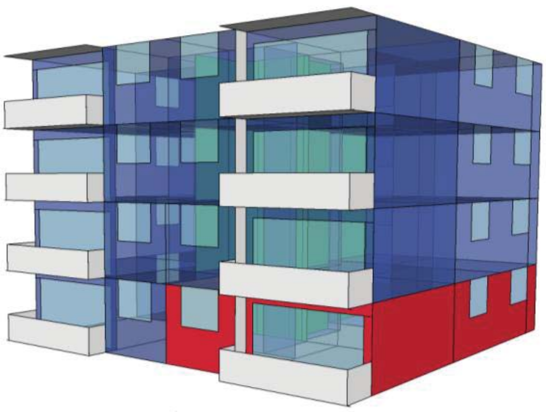
  Firstly, the heat demands of the flats equipped with the different PWVO categories are calculated. Secondly, the heat demand of an identical flat equipped with a ventilation system with heat recovery and with insulated or non-insulated exterior walls is calculated (V4.1, V4.4). The resulting values are compared.

Table 2 contains a summary of the simulated variants.

*Table 2: Simulation cases; abbreviations used: heat – assessment of heat demand; ach – assessment of air change rates. *) The air change rate can be derived from V1 and V2 (insulation is not relevant here)*

	Building envelope uninsulated, new windows			**Building envelope insulated, new windows**	
	1. Direction with strong wind (SW)	2. Direction with weak wind (SE)	3. Exposition	4. Direction with strong wind (SW)	5. Direction with weak wind (SE)
PWVO cat. 1 +pulse ventilation +exhaust fans	V1.1 heat ach	V2.1 LW Heiz		V4.1 *ach from V1.1 heat	V5.1 *ach from V2.1 heat
Window ventilators cat. 2 + pulse ventilation +exhaust fans	V1.2 heat ach	V2.2 heat ach	V3.1 heat V3.2 ach	V4.2 * ach from V1.2 heat	V5.2 * ach from V2.2 heat
Window ventilators cat. 3 + pulse ventilation +exhaust fans	V1.3 heat ach	V2.3 heat ach		V4.3 * ach from V1.3 heat	V5.3 * ach from V2.3 heat
ventilation system with heat recovery	V1.4 heat			V4.4 heat	
Comment:	Flat on ground floor, sheltered, urban location	Flat on ground floor, sheltered, urban location	V3.1: wind-exposed location, flat on ground floor V3.2: flat on 3rd floor, sheltered, urban location	Flat on ground floor, sheltered, urban location	Flat on ground floor, sheltered, urban location

The ventilation concept of the flat (figure 5) consists of the PWVO as permanent air inlet, five minutes intermittent ventilation in the morning by opened windows and the occasionally running exhaust fans in kitchen and bathroom. Airflow rates and operation periods of the exhaust fans are shown in figure 6. During daytime (7 am until 8 pm), the doors within the flat are open. During nighttime, the doors are closed but seven millimeter wide gaps remain ("passive overflow"). The floor plan of the flat enables cross ventilation. The air change rate via air leaks in the building envelope is 0.02 h^{-1} @ 4 Pa [8], [9]. The air exchange rate is calculated with a coupled air flow network within the thermal simulation model. The model comprises a total of eight zones (one zone for each room). The simulation program used is ESP-r [10]. The average year in Zurich according to MeteoSwiss [11] is used as climate.



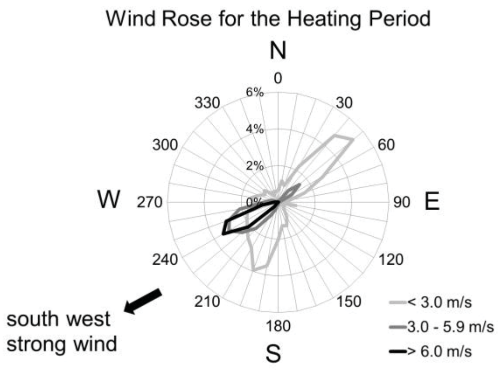


Figure 2: Left: the building with the simulated demonstration flat on the ground floor; right: prevailing wind directions during the heating period (15 October–15 April) from official Swiss weather data (MeteoSwiss) for Zurich, Design Reference Year (DRY) according to [11]: the prevailing wind is from the south-west; the least wind blows from the south-east

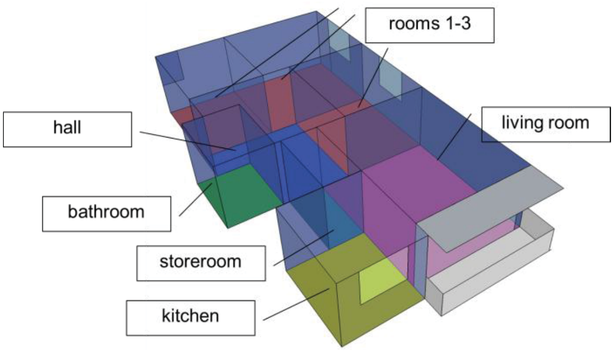


Figure 3: The rooms in the demonstration flat

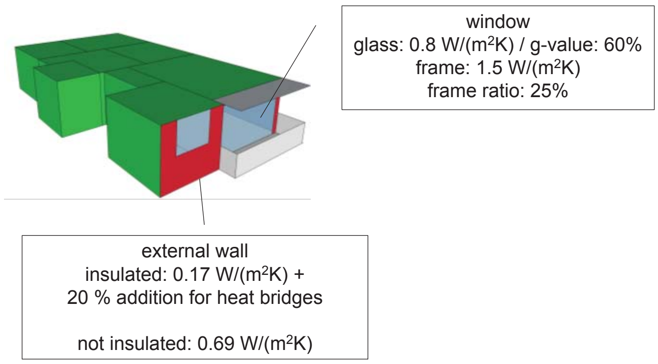


Figure 4: U-values and g-values for walls and windows

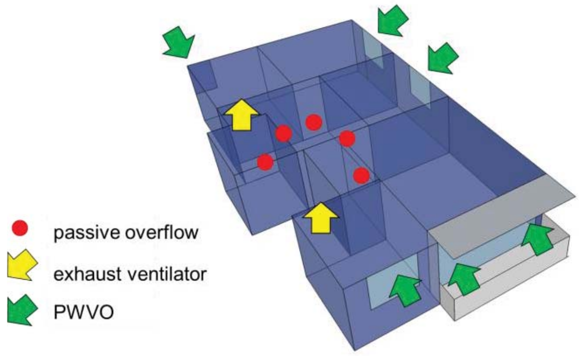


Figure 5: Ventilation design for the flat

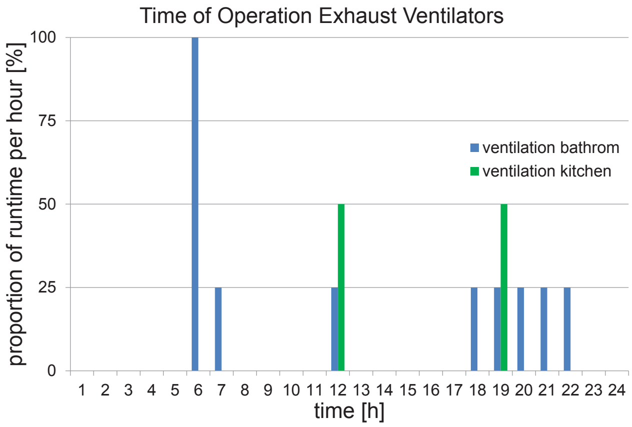


Figure 6: Operation of extract fans in bathroom/toilet and kitchen. The extract flow rate is 300 m^3/h for the kitchen and 50 m^3/h for the bathroom/toilet.

5.2 Methodology for analysing and results

5.2.1 Methodology for analysing

For the analysis of the calculation results two types of air change rates are used as a benchmark. Firstly, the hygienic air change rate according to [12], [13] (for this flat 90 m^3/h) and, secondly, the user-independent air change rate suggested in [5] to avoid moisture issues. Since fans mechanically extract moisture from the kitchen and bathroom, the moisture generation by persons is decisive. In a worst case scenario 3 persons permanently stay in the flat. This leads to an average moisture production of 161 g/h (10 h of lying, 14 h of sitting or standing). According to [5] the minimum fresh air flow rate under these conditions lies within the range of 0.25 - 0.53 $m^3/(m^2\ h)$ or 19.9 – 41.9 m^3/h for the flat under consideration. Consequently, the air change rate necessary to guard against moisture is between 0.10 and 0.22 h^{-1}. We consider this air change rate as user-independent since the PWVO and the (automatic) exhaust fans are used. The air exchange caused by manual opening of the windows in the morning, however, is user-dependent.

When determining the volume based airflow rates in the flat via the mass flow rates calculated, the ambient air temperature serves as reference. This represents the worst case, as using the indoor air temperatures as reference always results in larger volumetric airflows.

The evaluation period used is the heating period: October 15th through April 15th. Within this period, every hour of every day is taken into account.

5.2.2 Air change rates

Air change rates to guard against moisture

If solely the air change rate via the PWVO is evaluated, the resulting airflow rates are in the range of 9.1 to 39.8 m^3/h, depending on the type of PWVO and the average annual wind exposure (V1.1-V1.3, V2.1-V2.3 und V3.1-V3.2). The desired air change rate to guard against moisture cannot be achieved in any of the variants using only the PWVO (Figure 7). If the main façade of the building is moved from the direction with strong wind (south west) to the direction with weak wind (south east), the air change rates via the PWVO and the overall air change rates decrease by 18 to 24% and 7 to 13%, respectively (V1.1-V1.3 und V2.1-V2.3). Due to the underlying assumptions, the mentioned results are on the safe side: There are people permanently staying inside the flat, the flat is located on the ground floor (except for V3.2) and in an urban area with heavy shielding (except for V3.1).

If the extract ventilation from the kitchen and bathrooms is included in the analysis, the air change rates desired to guard against moisture can be achieved with PWVO of category 3. This applies to the variant with strong wind exposure as well as to the one with weak wind exposure (V1.3 and V2.3). If the flat is located on an upper floor, the average airflow rate via the PWVO (V3.2 with regard to V1.2) doubles throughout the heating period. This difference between ground floor and 3rd floor might be slightly lower in reality, for example if there are leaks between flats due to exhaust air ducts (internal pressure equalisation). In that case, the air change rates would slightly increase on the ground floor and slightly decrease on the 3rd floor. If the building is moved from a sheltered, urban position to a wind exposed site, the average airflow rate via PWVO increases by about 60% (V3.1 compared to V1.2). Both on the 3rd floor as well as in an exposed position, the air change rate desired to guard against moisture issues can be achieved with PWVO of category 2 (along with the exhaust air system).

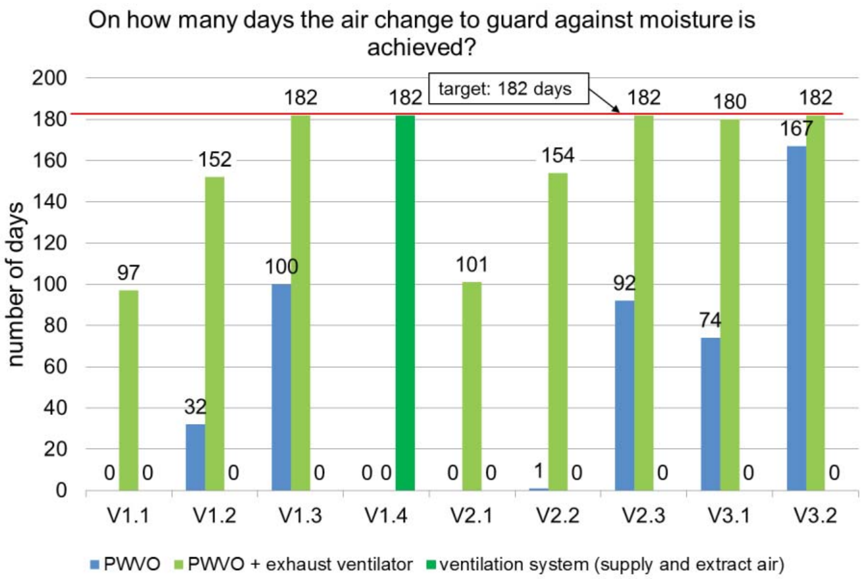


Figure 7: Compliance with air change rates desired to guard against moisture issues during the heating period. Comment: This is based on the daily evaluation required under SIA 180

Hygienic air change rate

The necessary 90 m^3/h are only achieved on higher floors with PWVO of category 2 or 3 (7 m^3/h @ 2 Pa), in combination with intermittent window opening and exhaust fans.

5.2.3 Heating demand

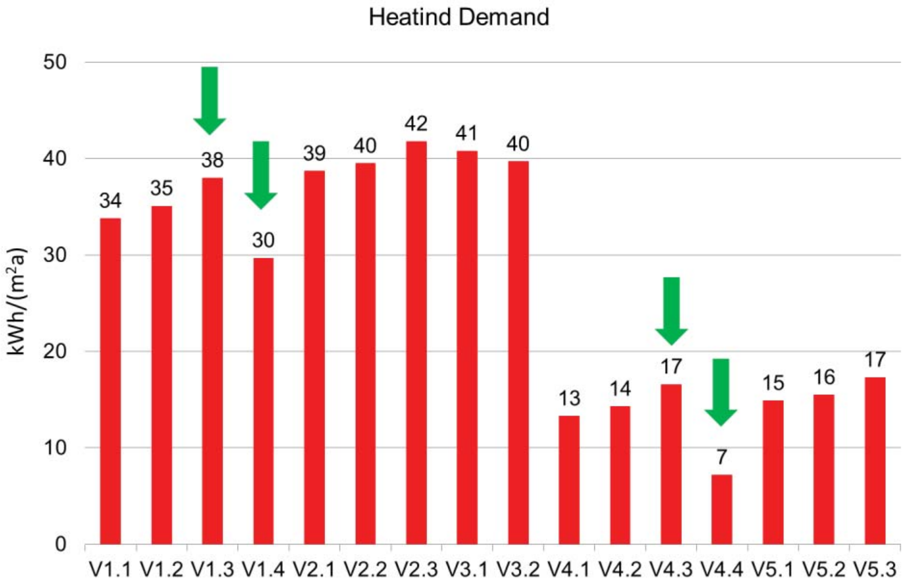


Figure 8: Heat demand for all variants studied. The variants V1.3 and V4.3 feature PWVO, the variants V1.4 and V4.4 are the corresponding variants with ventilation system with heat recovery.

Figure 8 shows the heat demand of all variants with insulated or non-insulated exterior walls. As expected, the heat demand increases with an increase in the air change rate via the PWVO. Assuming that the PWVO should at least guarantee the air change rate desired to guard against moisture issues, a ventilation system with heat exchanger reduces the heat demand by approximately 20 % (V1.3 compared to V1.4). Only the PWVO of category 3 along with the exhaust fans in kitchen and bathroom accomplish this air change rate. Provided the building envelope is insulated, a ventilation system with heat recovery reduces the heat demand by close to 60 % compared to using PWVO. This number also refers to a sufficient air change rate to guard against moisture issues (comparison between V4.3 and V4.4). Another advantage of a ventilation system with heat recovery is that the hygienic air change rate is achieved as well. The disadvantages of a ventilation system are higher investment costs, space requirements and constructional interventions in case of renovation.

6. Discussion and conclusions

Preliminary simulations done show three basic requirements for the functioning of PWVO:

- Cross ventilation within the flat must be feasible
- In order to avoid high pressure differences the exhaust fans in kitchen and bathroom need sufficiently dimensioned air inlets. Usually, the openings of PWVO are not sufficient.
- Only with room doors opened during the day, noteworthy air change rates can be achieved via PWVO. In principle, sufficiently dimensioned passive overflows should work as well, however, in the simulation, only 7 mm wide passive overflows below the doors (not sufficient) as well as open room doors (sufficient) were examined.

The following conclusions can be drawn from the conducted simulations on the variants according to Table 2:

- PWVO alone can rarely ensure a sufficient air change rate to guard against moisture issues. In combination with exhaust fans in kitchen and bathroom sufficient air change rates can be realised, though. However, the PWVO must ensure a certain airflow rate (minimum 15 m^3/h @ 2 Pa). There may arise a conflict with thermal comfort. The solution might be the use of several small PWVO in window rebates, but this possible solution was not covered in this study.

- Ground floor flats in highly dense urban areas may not be suitable for PWVO. Even PWVO with high performance data together with exhaust fans in kitchen and bathroom cannot provide the necessary air change rates.
- The hygienic air change rate can only be achieved on higher floor levels using PWVO with at least medium performance data (approx. 7 m^3/h @ 2 Pa, in Figure 1 cat. 2), along with intermittent ventilation and exhaust fans in kitchen and bathroom.
- As expected, the orientation of the façades with PWVO to the main wind direction has a clear impact on the attainable air change rate. The reduction of air change rates in case of the direction with low wind exposure in comparison to the direction with strong wind exposure is approx. 20% (South west: strong wind / south east: weak wind)
- The strong influence of the building's exposure on the air change rate is confirmed: Compared to the sheltered situation, the air change rate via PWVOs is increased by about 60% in a wind-exposed situation. The influence of the flat´s vertical position (floor number) is even stronger: compared to the ground floor, the air change rate via PWVO is 100 % higher on the 3rd floor. It can be assumed that the air change rate difference between ground floor and 3rd floor is in fact slightly lower, due to internal pressure equalisation. However, this has not been confirmed in the scope of this work.
- PWVO should not be used in sheltered ground floor flats, as for example in a courtyard situation.
- If a ventilation system with heat recovery is used instead of PWVO, the heat demand is reduced by approx. 20 % in existing (uninsulated) buildings. In an insulated building, the reduction can reach 60 %.

In addition to the above, the planning process should also consider topics such as thermal bridges and noise reduction.

7. Acknowledgement

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8. Literature

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