Passive window ventilation openings in every-day use

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ABSTRACT

In Switzerland, 70 % of building refurbishments are realised in stages. When only a window replacement is done, the new airtight windows can lead to a reduced infiltration air exchange and subsequently there may be moisture issues, e.g. mould. The integration of passive window ventilation openings (PWVO) with additional exhaust fans in the kitchen and bathroom(s) can ensure a user-independent basic air change rate. PWVO can be defined as small air inlets integrated in or near the window frame. These inlets enable a basic air exchange due to the pressure difference between inside and outside. This project is focused on how well buildings with PWVO work in real life.
Altogether, four newly built and eight refurbished building types (in total 28 buildings) are investigated by site visits, a survey among the inhabitants of the buildings and measurements in eight selected flats.
The survey is conducted in winter 2018 and addresses topics like user ventilation behaviour, thermal and acoustic comfort, IAQ, obtained information about the PWVO and user satisfaction. All questions refer to the winter period. The 270 answers to the survey allow tentative inferences for future ventilation concepts. It is found that the operation mode of the fan (permanently or intermittently) does not affect the user acceptance. If PWVO are combined with a heat distribution by radiators air draught is less likely than in connection with a floor heating. The air draught risk is also reduced by using PWVO in the window rebates (+ radiators) instead of PWVO top-frame. PWVO with fixed openings are rated similar to adjustable PWVO. However, users do not mask the latter. A user information helps to prevent occupants from opening the windows for a too long time in winter.
Two types of measurements followed winter 2018/19: firstly, short-term measurements with a focus on the volume flow rates (supply and exhaust air), the airtightness of the flats and the relative pressures in the flats. Secondly, long-term measurements comprise CO_2 concentrations, interior and exterior air temperatures and humidities and operation modes of the fans. In seven flats the fresh air supply rate per flat lies between 38 and 166 m^3/h (±5 %). Based on room use related requirements, one flat has an adequate air supply and one an oversupply. In five flats only between 35 and 81 % of the demand is covered. The airtightness of all flats is good (q_{a50}-values: 0.5 - 1.3 (±10 %)). CO_2 measurements show that in the sleeping rooms the mode (22:00 – 06:00 h mean) ranges between 700 - 800 and 1´000 - 1´200 ppm.

KEYWORDS

Passive window ventilation openings, measurements, survey, site visits, housing

1 INTRODUCTION

1.1 Overview

In Switzerland, 70 % of building refurbishments are realised in stages (Ott, Jakob, Baur, Kaufmann, & Ott, 2005). 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. Especially, if surface temperatures of walls are reduced locally as a result of thermal bridges. The risk of mould damage is usually higher in dwellings than in other building types such as office buildings due to higher humidity loads (produced e.g. by cooking or washing).

In dwellings, mould growth is found significantly more often in flats than in single-family homes (no data is given whether the housing is rented or owned). Within the flats, bedrooms and children's rooms are most frequently affected by the damages (Hartmann, Reichel, & Richter, 2002).

A possible solution to this problem is the integration of passive window ventilation openings (PWVO). A PWVO is a ventilation unit or element that is integrated into the window or is directly related to the window. Although there can be a fan within a WVO itself, this publication deals with passive window ventilation openings only. The PVWO themselves are part of a ventilation concept that uses them as an air inlet in combination with permanent or time-controlled local extract fans in the kitchen and bathroom(s). The benefits of such a ventilation concept are that the air-change is user independent and much more reliable than the rather primitive "method" of removing existing seals in new windows which is often adopted after moisture issues have occurred. Thus, PWVO can be an adequate means to enable a building renovation in stages without the drawbacks of building damages during intermittent use.

In recent years, PWVO have increasingly been included in ventilation concepts for newly built buildings in Switzerland. This is reflected by the fact that the recruitment of building owners to participate in this project yielded not only existing buildings but also newly built dwellings.

1.2 Project scope

A preceding project explored the determining factors for the successful use of PWVO in dwellings in Switzerland by means of transient simulations. An accompanying market research characterised and classified typical products (Hoffmann, Geissler, & Huber, 2015), (Hoffmann, Geissler, & Huber, 2016). On the basis of this theoretical analysis, the ongoing project focuses on realised buildings. Altogether, 13 types of dwellings (in total 28 buildings) with integrated PWVO are investigated. The 13 building types are split into four newly built and eight refurbished multi-family buildings and one mix of refurbished parts and new premises (ZH_5). For six of the eight refurbished building types the refurbishment is comprehensive as it includes window replacement and insulation of the walls. For the remaining two building types (ZH_4, ZH_2) only the windows are replaced. The ventilation concepts of all buildings include PWVO and a time-controlled or continuously operating ventilation via exhaust fans in the kitchen and bathroom(s). In five building types (ZH_2, ZH_4, ZH_5, DT-1 and DT_3) the evaporator of a heat pump utilises heat from the extracted air in order to increase efficiency.

How PWVO perform in real life is explored by answering the following questions:

a) How has the ventilation system been dimensioned? (evaluation of the planning concept)
b) Which rooms feature a PWVO? (evaluation of the planning concept/site visit)
c) Is there moisture damage in the flats? (survey, site visit)
d) Is thermal discomfort reported in the vicinity of a PWVO? (survey, measurement)
e) How are the ventilation habits of the inhabitants? (survey, measurement)
f) What air-change-rate is achieved by the PWVO? (measurement)

The first phase comprises a) through e) apart from the measurements. The second phase covers the measurements. These are done in two flats each of four multi-family houses (marked with an * in Table 1).

2 METHODOLOGY

2.1 Recruitment of buildings

Buildings were recruited by contacting building service engineers, architects, housing cooperatives and local authorities. The burden for the inhabitants is not negligible due to the site visits, the survey and (for a small selection) the measurements. For this reason the buildings must be considered a somewhat biased sample which favours committed building owners, property managers and tenants. Nine out of the 13 building types are owned by a housing cooperative (#1, 3, 4, 8 - 13).

Table 1: Analysed building types. Abbreviations: MFH = multi-family house, HH = high-rise building, NB = new built, T = total refurbishment, W = window replacement, PWVO = passive window ventilation opening, EAV = external air vent, TF = PWVO top-frame, WR = PWVO in window rebate, WF = window frame, N = no, Y = yes, (*) = two flats are measured in this building type

Code	#	Number, building type locality, measurement	N / T / W	Number flats	PWVO/ EAV	Product	Adjust-able?
ZH_1_1 to ZH_1_9	1	9 MFH Zürich	NB	278	PWVO (TF above WF)	Anjos, L 30 S	N
WT	2	1 MFH Winterthur	NB	10	PWVO (TF integrated into WF)	Invisivent EVO AKD, Renson	Y
ZH_2	3	1 MFH Zürich	W	10	PWVO (TF integrated into WF)	Trivent ZEF-S	Y
ZH_3	4	1 MFH Zürich (*)	NB	14	PWVO (TF integrated into WF)	Sonoslot –P475, Renson	Y
ZH_4	5	1 MFH Zürich	W	4	PWVO (TF integrated into WF)	Aerex AL_db_450	Y
GS	6	2 MFH Gasel	T	22	PWVO, WR	Ego Kiefer Secco without filter	N
SD	7	2 MFH Studen	T	30	PWVO, WR	Regelair "Forte"	Y
ZH_5	8	2 MFH Zürich (*)	NB/T	26	PWVO, TF, above WF	Siegenia Aeromat VT, Typ DF2	N
BB	9	3 MFH Biberstein (*)	NB	22	PWVO (TF integrated into WF)	ALD Aerex AL-dB-450-40	Y
DT_1	10	2 HH Dietikon	T	78	PWVO (TF integrated into WF) / EAV (wal)	Helios ALEFS 45 / Helios ZTV-100	N / Y
DT_2	11	1 MFH Dietikon	T	35	PWVO (TF integrated into WF)	Helios ALEFS 45	N
DT_3	12	2 HH Dietikon (*)	T	32	PWVO (TF integrated into WF)	Helios ALEFS 45	N
HO	13	1 MFH Horw	T	12	EAV (wall)	Helios ALD ZLA 100	Y

2.2 Site visits

The site visits took place from 26.02. to 26.03.2018 and included two or three flats per building type. During the site visit, the ventilation system is verified, the numbers and locations of the PWVO and/or cross-flow elements are assessed and it is checked whether the PWVO are manipulated (e. g. masked) and if there is any mould in the flat.

2.3 Survey and statistical methods for evaluation

The questionnaires are distributed during the site visits as printouts to be returned within four weeks. An online version is also provided. Data collection took place from 26.02. to 24.05.2018. In the buildings ZH_1_1 to ZH_1_9 the survey is an add-on to a survey organised by the property manager on a regular basis. This survey took place from 24.04. to 24.05.2018. For building ZH_2 the refurbishment was not concluded until October 2018.
The questionnaire refers to wintertime experience and consists of 19 questions exploring different topics (Table 2). Anonymous participation is possible. Wherever a rating is asked for

(Topics 2, 3 and 5) a five-point assessment is offered (Likert scale): e. g. “unsatisfied”, “slightly unsatisfied”, “neutral”, “slightly satisfied” and “satisfied”. The data is analysed using the statistical program IBM SPSS Statistics (Version 25). Depending on the level of measurement the analysis includes the calculation of the mode (D), the median ($\tilde{x}$), the mean ($\bar{x}$), the standard deviation (s), the sample variance (S^2) and Kendall’s tau-b correlation coefficient (τ_b). The correlation is assessed according to (Brosius, 2018) as: > 0 to 0.2 = very weak, > 0.2 to 0.4 = weak. The significance is indicated by an * (= significant) for a 5 % level and by ** (= highly significant) for a 1 % level. A more detailed explanation of the above mentioned statistical methods can be found in (Hoffmann, Primas, Geissler, & Huber, 2018).

Table 2: Structure of the questionnaire. Used abbreviations: OM = optional mention

1. Housing related features	Number of rooms (OM) / Number of persons in the flat (OM) / Floor number / Years lived in the flat / Mould
2. Communication	About the PWVO and the exhaust ventilation / Ventilation habits with PWVO and exhaust ventilation
3. Level of contentment	While answering the questions / With the flat in general / With the PWVO
4. Ventilation habits in winter	incidence and type of manual ventilation / Adjustment of PVWO
5. Thermal comfort, indoor air quality and accoustic comfort in winter	Humidity / Temperature / Indoor air quality / Draught / Noise from outside and / or the exhaust ventilation

One of the central questions focused on is whether the inhabitants are satisfied with the PWVO. Because PWVO and the ventilation concept are connected, the following question is asked: “If it were up to you, would you move into a flat with exhaust ventilation system and PWVO again?” The evaluation labels this question as “PWVO satisfaction”.

2.4 Measurements

Table 3: Measurement instruments. Used abbreviations: s = short term measurement, l = long term measurement, d = distance from window, h = height from window, r = room, m = minutes, * = for some weeks

Measurement	s / l	where	Time step	Instrument	Accuracy
Air flow rate (supply and exhaust air)	s	PWVO (supply air) air intake (exhaust air)	-	FlowFinder	<20 m^3/h: ±4 m^3/h 20-50 m^3/h ±5 %, min. 2 m^3/h
airtightness	s	Flat with open/closed PWVO; no further measures in regard to adjacent flats etc.	-	Minneapolis BlowerDoor DuctBlaster B / DG-700	Windless < ±10 %
Extract fan induced pressure in flat	s	Flat	-	DG 700	± 1 % m.v. resp. ± 0,15 Pa
Draught rate (air temperature, velocity and turbulence)	s	Living r. / sleeping r. (d: 0.5 m + 1.0, h: 0.1 m, 0.6 m, 1.1 m + 1.7 m)	-	Dantec ComfortSense	± 0.06 m/s / DR ± 5 % / ± 0.2 °C
CO_2 concentration / air temperature / humidity	l	Living r. and bedroom	15 m	Opus	± 50 ppm +3 % m. v. / ± 0.3 °C (0..40°C) / ± 2% r.h.
Interior air temperature / humidity	l	Bathroom	15 m	MSR	±0,1 °C (+5..+45 °C) ±2 % r. h. (10..85 %, 0..+40 °C)
Exterior air temperature / humidity	l	Individual	15 m	MSR	±0,2 °C (-10..+58 °C) ±2 % r. h. (10..85 %, 0..+40 °C)
Operating range of fan	l*	Flat (individual unit)/ plant room (central ventilation system)	15 m	Clamp-on ammeter	Not specified

In four building types short- and long-term measurements are made in two flats, each. Table 3 summarizes the apparatus used and the metrics considered.
The short-term measurements focus on the volume flow rate, the airtightness of the flat and the pressure difference in the flat induced by the extract fan of the ventilation system. The draught rate is also measured. The measurements are performed in each flat for a duration of approximately eight hours between the 19th of October 2018 and the 20th of November 2018.
The long-term measurements comprise CO_2-concentration, interior and exterior air temperatures and humidities and the operation mode of the fan. Data collection took place continuously from October / November 2018 to April / May 2019.

3 RESULTS

3.1 Site visits

A random sample filter check during the site visits revealed that filters in PWVO and fans are rarely changed or cleaned. This implies that the users themselves are not aware of the fact that the technical equipment needs regular maintenance. However, cleaning and maintenance proves to be reliably done when the janitor is in charge, which is the case in some of the larger buildings owned by housing cooperatives included in the study.

3.2 Survey

Out of a total number of 570 distributed questionnaires, 270 were returned. The return rate varied among the buildings from 1 % (DT_2) to 68 % (WT), the average was 42 %. Buildings with only one participant (ZH_4 and DT_2) are included into the sample, but excluded from evaluations focused on the individual buildings. Except for questions related to the ventilation system, HO is excluded because it features external air vents instead of PWVO. The following two chapters provide a short overview on the survey results and reflect some features of the technical building concept by means of the survey. A more detailed presentation of the survey can be found in (Hoffmann et al., 2018).

3.2.1 Ventilation habits, comfort and level of contentment

Most of the residents open the windows during daytime between one and five minutes (60 %, N = 157/252). Less people open the window between six and 20 minutes (36 %). In both groups, just a few sleep with their window open (5 %).
More than half of the participants (60 %) “sometimes” or “always” feel draught next to the PWVO ($\bar{x}$ = 2.0 (2 = sometimes, 3 = always), s = 1.6 N = 212). Roughly 30 % do not complain. Also more than half of the participants (xx %) perceive the room temperature as “agreeable” ($\bar{x}$ = 2.8 (2 = cold, 3 = agreeable), s = 1.2, N =126/217) and one third (26 %) assess the room temperature as “cold” or “too cold”. A minority of 16 % reports it as “warm” or “too warm” (N = 8 and 26). The air humidity is “agreeable” for 53 % of the participants ($\bar{x}$ = 3.8 (3 = agreeable, 4 = dry), s = 1.0, N =114/215). Nine percent (N = 19) judge the air as “dry” and 38 % (N = 81) as “too dry”. Indoor air quality (IAQ) is “satisfying” or “slightly satisfying” for more than half of the participants ($\bar{x}$ = 3.9 (3 = mediocre, 4 = slightly satisfied), s =1.2, N =115/207).
Noise from outside is perceived by 46 % as “sometimes” ($\bar{x}$ = 1.6 (1 = never, 2 = sometimes), s = 1.3, N = 90/197) and by 13 % (N = 26) as “always” disturbing. About 70 % of the participants “never” experience disturbing noise by the exhaust fan in the bathroom and toilet ($\bar{x}$ = 0.6 (0 = never, 1 = rare), s = 1.1, N = 232).
Mould is reported by 8 % of the participants (N = 21/263). In 95 % of the cases the mould is located in the bathroom.
Almost half of the participants (47 %) would move into an apartment with PWVO and an exhaust fan again ($\tilde{x}$= 1.00, D = 2 (1 = perhaps, 2 = yes), N =251). It can be deduced that they

are satisfied with the system. Almost 80 % are “slightly satisfied” or “satisfied” ($\bar{x}$ = 4.5 (4 = slightly satisfied, 5 = satisfied), s = 0.8, N =213).
Except for the IAQ all the above described parameters do not show any statistically significant correlations with the user behaviour (e. g. window opening). The IAQ shows a significant, but very weak correlation between a very intense window ventilation and the perceived air quality. This implies that those who are not satisfied with the IAQ open the windows more often and for a longer time (group unsatisfied with IAQ and a) frequency of window opening τ_b.= -0.150*, b) duration of window opening: τ_b = -0.182**, c) window opening during daytime > 30 minutes: τ_b=-0.153*).

3.2.2 Technical building concepts with PWVO

The survey can be used to reflect some aspects of the technical building system based on the assessment of the users. One topic is the mode of operation of the exhaust ventilation system. The participants are grouped into two categories, i.e. continuously and intermittently running exhaust fans. The comparison shows no differences between the groups in regard to thermal comfort, IAQ and the level of contentment. However, a very weak but highly significant correlation between the operation mode of the fan and the noise level suggests that an intermittently operating fan leads to more disturbing noise (intermittent / continuous fan and disturbing noises: τ_b= -0.187**, Figure 2).
Other issues are the type and (supplementary) equipment of the PWVO. The survey results suggest that PWVO in the window rebate have less draught issues and therefore lead to a better thermal comfort than PWVO in the top frame (PWVO top-frame: $\bar{x}$ = 2.2, N =191; PWVO in widow rebate: $\bar{x}$ = 0.48, N =21; for interpretation: 0 = never, 1 = almost never, 2 = sometimes, τ_b =-0.371**, Figure 1). Unfortunately, it cannot be tested whether this is also true for flats with a floor heating, because the investigated building types are equipped with radiators.

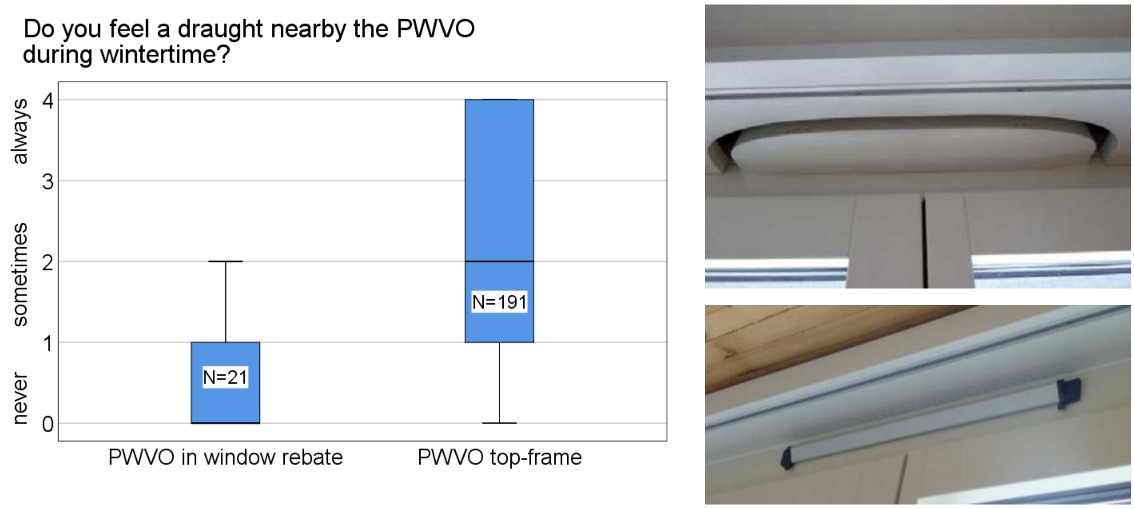
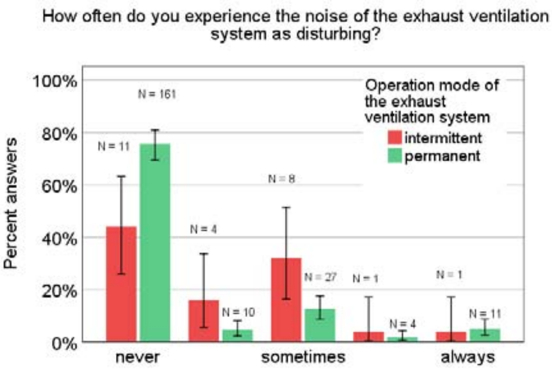


Figure 1: Left: Boxplot satisfaction with draught corresponding to the position of the PWVO. The box indicates the range between the 25 %- and the 75 %-percentile. The horizontal line in the box indicates the median. The whiskers show the minimum and the maximum. Right: two types of PWVO top-frame.

Generally, a heat distribution with radiators together with PWVO is more advantageous than a heat distribution by floor heating, because less draught is reported by the users (draught with a) radiators: $\bar{x}$= 1.5, N = 56 and b) floor heating: $\bar{x}$= 2.3, N = 156; τ_b.= -0.207**; for interpretation: 1 = never, 2 = rarely, 3 = sometimes), Figure 2).
Whether the PWVO have filters or are adjustable by the users has no significant influence on the assessment of the thermal comfort, IAQ or the level of contentment. It can, however, be shown that adjustable PWVO are not masked by unsatisfied users, which speaks in favour of

adjustable PWVO (non-adjustable / adj. PWVO $N = 216 / 35$, masked non-adj./adj. PWVO, $N = 19 / 0$).
Around 30 % of the participants received detailed instructions on the ventilation system and how to operate the windows and the PVWO correctly ($N = 72/247$). Around one third received some information on both topics ($N = 84$). According to the survey, a user information may cause a slight adaptation in window ventilation habits towards a less continuous ventilation (“some or detailed information” on either on or both topics $N = 213$, “no information” $N = 34$ and windows opened > 30 minutes during daytime τ_b.= -0.147*).
User information does not affect the satisfaction with the PWVO. Nonetheless, the authors are convinced that a user information is an essential part of a successful building concept.
A correlation between building type and comfort can be found with IAQ (τ_b= 0.171**), disturbing noise from the exhaust fan (τ_b= -0.213**) or from outside (τ_b = 0.235**) and with satisfaction with the flat in general (τ_b= -0.120*). No correlation can be found with the assessment of the temperature, draught, humidity and contentment with the PWVO.



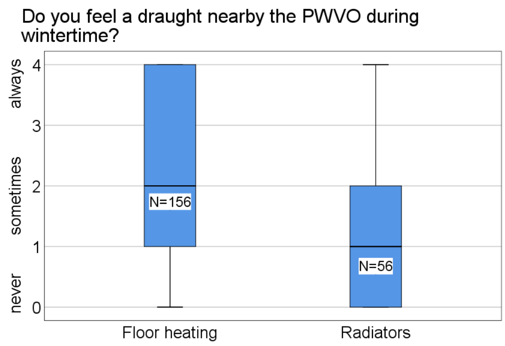


Figure 2: Left: Disturbing noise according to the operation mode of the exhaust ventilation system. Right: Assessment of draught according to the heat distribution. Indication of error bars on 95 %-level.

3.3 Measurements

3.3.1 Short term

Due to high exterior temperatures at the scheduled dates for the measurements the temperature difference between inside and outside is not high enough to comply with a rigorous quality check of the collected data in regard to the draught rate. Therefore, no findings can be presented.
The airtightness of the buildings (q_{a50}) lies in the range between 0.5 (BB) and 1.3 ±10 % $m^3/(h\ m^2)$ (ZH_3). The median is 0.7 $m^3/(h\ m^2)$. According to SIA 180 (SIA 180, 2014) the threshold value for buildings with a ventilation system is 1.6 $m^3/(h\ m^2)$ and the target value is 0.6 $m^3/(h\ m^2)$. Four out of eight buildings meet this target value.
According to Table 4, the volume flow rate (VFR) per flat lies between 38 and 166 m^3/h (±5 %). In compliance to SIA 382/1 (SIA 382/1, 2014) the VFR should be dimensioned depending on the room use. Taking this into consideration, only one flat shows an oversupply of fresh air (138 %) and in one flat the demand and supply match. In the remaining five flats (one couldn’t be measured due to unfavourable wind conditions) only between 35 and 81 % of the demand is covered. This points in the same direction as the study of (Caillou & Van den Bossche, 2016) where in many cases the measured VFR fell below the required air flow rates. If the air supply is evaluated in relation to the current occupancy of the flat, the fresh air supply rate per person is found to be between 8 and 63 m^3/h, where 23 to 115 m^3/h fresh air should be provided. One flat has an insufficient air supply (-63 %), two flats meet the demand and four show an oversupply (+65 % to +174 %).

Considering the measured VFR per PWVO, it can be seen that the VFR varies between the products. In building types ZH_3 and ZH_5 the VFR varies between 8 and 20 m^3/h, in building types BB and DT_3 the VFR can reach up to 30 m^3/h.

Table 4: Comparison of specified/planned and measured volume flow rates (VFR) per PWVO and per flat. The measurements are performed under varying outdoor conditions and resulting pressure differences, so no pressure difference for the PWVO measurement can be specified. this is also reflected in the given spread of the measured values. If the planned VFR for the supply and exhaust air differ, the higher value is relevant and thus indicated in the table. Used abbreviations: F1 = Flat 1, F2 = Flat 2

Measurement	**ZH_3**	**ZH_5**	**BB**	**DT_3**
Product PWVO	Sonoslot –P475, Renson	Siegenia Aeromat VT, Typ DF2	ALD Aerex AL-dB-450-40r	Helios ALEFS 45
Specified VFR PWVO (m^3/h)	@ 2 Pa: 8.3, @4 Pa: 11.8, @ 8 Pa: 17.0, @10 Pa: 19.2	Not specified	@4 Pa: 14.0, @ 8 Pa: 20.0, @10 Pa: 22.0	@10 Pa: 34.0
Measured VFR PWVO (m^3/h)	8 (± 4 m^3) - 20 m^3/h (±5 %)	9 (± 4 m^3) -18 m^3/h (±5 %)	18 -30 m^3/h (± 5%)	8 (± 4 m^3) -28 m^3/h (± 5%)
Planned VFR flat (m^3/h)	F1: 80, F2: 90	F1: 80	F1: 120, F2: 120	F1: 120, F2: 120
Measured VFR flat (m^3/h)	F1: 79, F2: 81 (± 5%)	F1: 48 (± 5%)	F1: 138, F2: 98 (± 5%)	F1: 66, F2: 35 (± 5%)

3.3.2 Long term

In all bed- and living rooms the CO_2-concentration, the air temperature and the humidity are recorded. In the bathrooms only the air temperature and the humidity are measured. Figure 3 shows a typical time-series of CO_2-concentrations, air temperatures and relative humidities from the 25th through 30th of November 2018 in a bedroom in the building type BB. The progression of CO_2-concentration and relative humidity are similar. An abrupt drop of the air temperature indicates additional window ventilation by the residents (refer to the arrows at the 26.11.2018 @ 07:12 h or the 27.11.2018 @ 12:00 h).

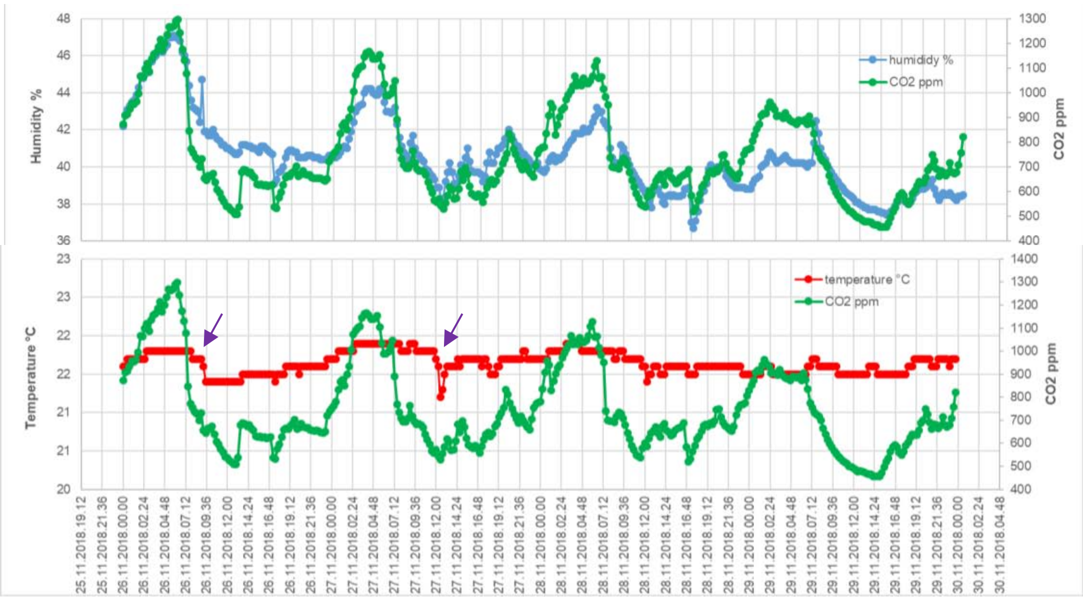


Figure 3: Measurement values from 25th through 30th November, 2018 from a bedroom in building type BB. Top: Humidity and CO_2-concentration, bottom Temperature and CO_2-concentration.

The indoor air quality can be assessed by filtering the measured CO_2-concentrations by magnitude and time of the day (Figure 4). As seen in section 3.2.1 in regard to the volume flow rate, the air quality in the building BB is satisfying. SIA 382/1 demands CO_2-concentrations not exceeding 1´000 to 1´400 ppm for typical dwellings. The CO_2-concentrations found vary between the building types. The best values for the night can be found in ZH_3 and BB with the modus at 700-800 ppm, the highest modus is recorded in ZH_5 with 1´000-1´200 ppm.

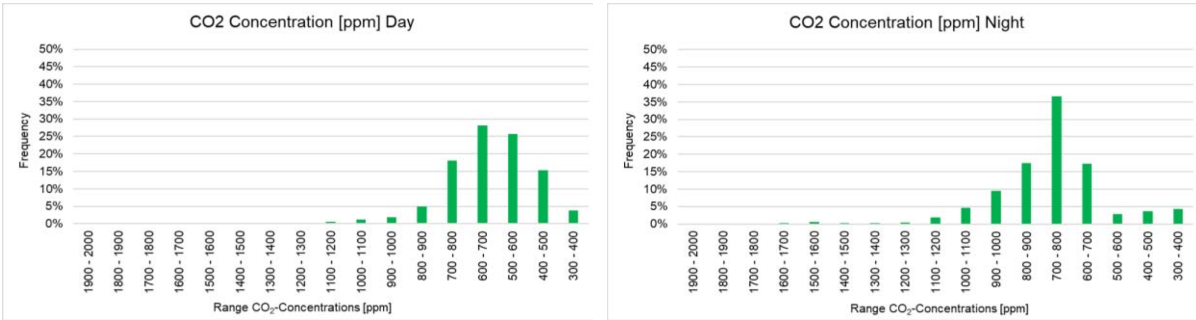


Figure 4: Left: CO_2-concentrations during daytime (07:00-21:00) in a bedroom in building type BB (same flat as Figure 3) for the period of 19th of October 2018 to 29th of March 2019. CO_2-concentrations during night time (22:00-06:00)

The mean air temperature in the flats is found to be between 22 and 24 °C (±0.1 °C) which is an expectable range. This is also true for the mean of the measured relative humidity with values found in the range of 31 % to 45 % (±2 %).

4 DISCUSSION AND CONCLUSIONS

The results of the conducted survey provide information on user behaviour and allow for tentative inferences for future ventilation concepts. User acceptance is not shown to be affected by the operation mode of the fan (permanently or intermittently). Air draught caused by the PWVO is less probable by applying two planning principles: Firstly, combining PWVO with a heat emission by radiators (placed below the windows) is preferable in terms of thermal comfort to a combination with floor heating. Secondly, the air draught risk is reduced by using PWVO in the window rebates (+ radiators) instead of PWVO top-frame. PWVO with fixed openings are rated similar to adjustable PWVO. However, users do not mask the latter. A user information helps to prevent occupants from opening the windows for too long periods of time in winter.

In two flats the fresh air supply exceeds respectively meets the demand. In five flats only between 35 and 81 % of the demand are covered.

Comparing the measurement results with the survey it is striking that in the building DT_3, where the measurements of the air supply indicate an undersupply, the rating of the air quality is the best of the survey ($\bar{x} = 4.8$, $N = 5$). Because the number of the answers is very small this result should be treated cautiously. As the size and occupancy of the flats varies, one assumption could be that the fresh air supply in the other apartments is sufficient for the number of occupants. The overall satisfaction with the PWVO is very high in three of the measured buildings (BB: $\bar{x} = 1.7$, $N = 14$; ZH_3: $\bar{x} = 1.7$, $N = 6$; ZH_5: $\bar{x} = 1.7$, $N = 18$). Interestingly, this is not reflected the measured air supply, which is found to be sufficient only in building type BB. One explanation could be that when the inhabitants are for several hours in one room they do not "smell" a high CO_2 content. Without inhabitants and CO_2 emissions the air is gradually purged by means of the PWVO and the extract fans. When returning to the room the air is "fresh" again. Thus the impression of the air quality is good which is reflected in the overall satisfaction with the PWVO.

The airtightness of all flats is good (q_{a50} values: 0.5 - 1.3 (±10 %)). Four out of eight buildings meet the target value of 0.6. CO_2-concentration measurements reveal that in the sleeping rooms the mode (22:00 – 06:00 mean) lies between 700 - 800 and 1´000 - 1´200 ppm and can thus be deem acceptable.

5 NOMENCLATURE

N	Quantity of observations	$\tilde{x} = X_{\frac{N-1}{2}+1}$	Median (odd number of sorted values)
τ_b	Kendall's tau-b correlation coefficient	D	Mode
$\bar{x} = \frac{1}{N} \cdot \sum_{i=1}^{N} X_i$	Mean	$s = \sqrt{S^2}$	Standard deviation
$\tilde{x} = \frac{1}{2} \cdot \left(X_{\frac{N}{2}} + X_{\frac{N}{2}+1} \right)$	Median (even number of sorted values)	$S^2 = \frac{1}{(N-1)} \sum_{i=1}^{N} (x_i - \bar{x})^2$	Sample variance

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