How suitable are push-pull ventilation devices for energy-efficient home ventilation?

A study of the market situation for residential ventilation by the BDH and FGK (Figure 1) shows that for decentralized residential ventilation, the majority of ventilation devices that work alternately in pairs (pendulum fans or push-pull ventilation devices) are used. Installation in the outer walls without an air duct network makes this ventilation solution attractive not only for single-family homes, but also for use in apartments. The outside air volume flow and efficiency of the heat exchanger are also sufficient for funding as an energy-efficient ventilation system for residential buildings according to BEG. Due to their design, these ventilation devices have axial fans with a low delivery head. A study of a pair of devices approved by the building authorities is intended to show what wind-induced pressures these facade-mounted ventilation devices can be exposed to and whether energy-efficient operation is possible under these conditions.

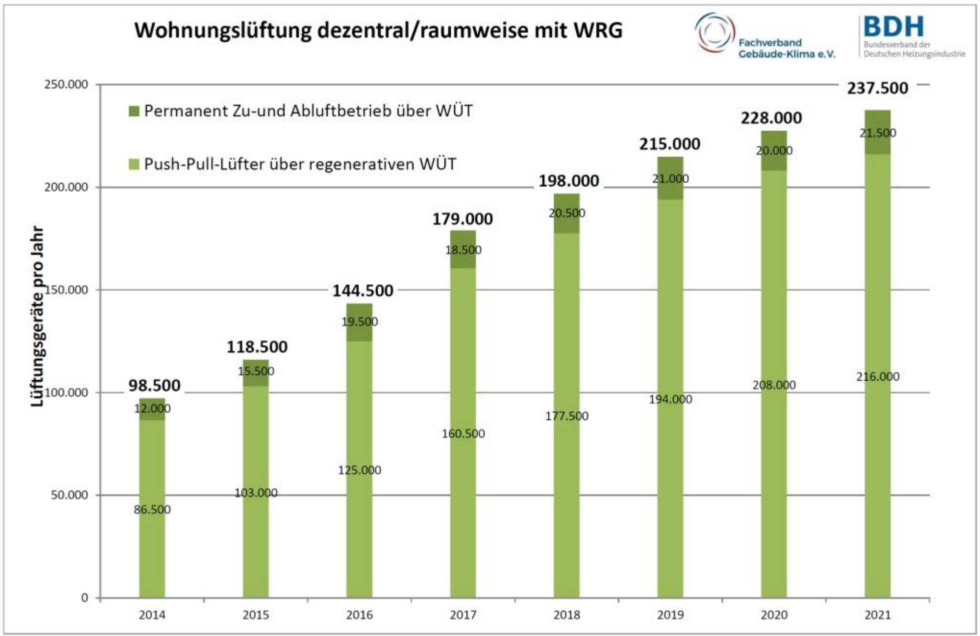

Figure 1: Development of the German market for decentralised domestic ventilation between 2014 and 2021 (Fig. © FGK/BDH)

For heat recovery, "push-pull" ventilation devices have a regenerative heat exchanger, which is heated using the heat from the exhaust air conveyed from the living spaces. After the direction of rotation of the fans in the device pair is reversed, the heat should be released from the heat exchanger to the supply air. For efficient operation, a volume flow balance between the device pairs is necessary, Figure 2.

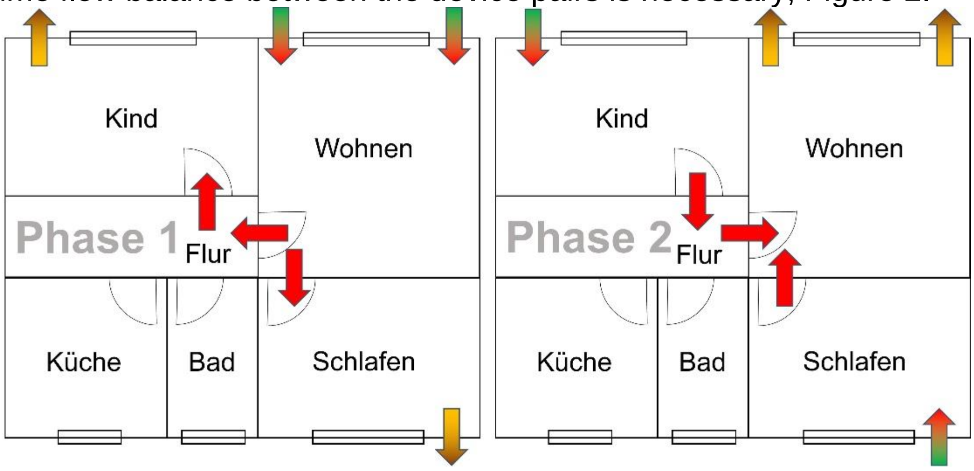

Figure 2: Ventilation phases of push-pull ventilation units in a 3-room flat, ventilation of kitchen and bathroom via manually opening windows.

Because they are mounted on the facade, these ventilation devices are exposed to wind loads, which is why a wind sensitivity test is required as part of the building approval and labeling of these ventilation devices in accordance with the Eco-Design Directive ERP Regulation 1254/2014 EU.

Wind sensitivity requirements

The wind sensitivity of decentralized ventilation devices is tested according to EN 13141-8 at a test pressure of ± 20 Pa. For classification, a maximum volume flow deviation of the supply air volume flow from the exhaust air volume flow of 30% may occur when testing under this test pressure, Table 1.

class	Maximum deviation of the supply air flow compared to the maximum air flow in %	
	at +20 Pa	at -20 Pa
S1	≤ 10	≤ 10
S2	≤ 20	≤ 20
S3	≤ 30	≤ 30
Not classified	> 30	> 30

Table 1: Classes of wind sensitivity of decentralised ventilation units according to EN 13141-8

The question arises as to how often these operational requirements are encountered in practice and what influence wind loads have on the energy-efficient operation of these ventilation devices. To this end, a pair of devices will be examined in a test setup under real and simulated wind loads in 2021 and 2022.

Examined ventilation devices and measurement technology

According to the building regulations approval, the ventilation units examined in pairs and working alternately have the following specifications:

Volume flow at a static pressure p_{stat} = 0 Pa:

– Level 1: 17 m³/h

– Level 2: 21 m³/h

– Level 3: 42 m³/h

– Level 4: 58 m³/h

Average degree of heat production η_{WRG} when operating the device pair in the volume flow range 17 m³/h to 58 m³/h at average wind speeds ≤ 5 m/s and p_{stat} = 0 Pa:

– η_{WRG} = 0.78

According to the product data sheet in accordance with ERP Regulation 1254/2014 EU, the ventilation devices have a sensitivity to pressure fluctuations of 29.4% and therefore correspond to class S3 according to EN 13141-8. The following measurement technology is used:

Wind speed

– LeWL, Pro-D anemometer

– LeWL, anemometer

– LeWL, Wind Logger

Differential pressure

– Minneapolis BlowerDoor DG 700

– Data logger iTEC 700 fan

– Minneapolis BlowerDoor Ductblaster B

Measurement setup for test series 1

On a garden plot in 14552 Michendorf, OT Langerwisch in the Potsdam-Mittelmark district, a free-standing measuring setup is being built on the western boundary of the property, Figure 3. The ventilation devices are installed in two 1 m³ airtight boxes. The boxes are connected on the inside via a sharp-edged panel with DN 68 mm. They stand on an approximately 1.5 m high platform, one ventilation unit is oriented to the west and the other to the east. According to the DIN 1946-6 classification, the Potsdam-Mittelmark district is considered a low-wind area with an average wind speed during the heating period ≤ 3.3 m/s. The setup of the measurement setup corresponds to an open location without shielding from neighbouring buildings.

The wind speed is measured at a height of approx. 3 m and approx. 7 m.

Figure 3: Measurement setup of the ventilation units operating in pairs

The ventilation devices work alternately: if ventilation device 1 is in supply air mode, ventilation device 2 is in exhaust air mode. After a time interval of approx. 70 seconds, the fans of both ventilation devices switch the direction of rotation.

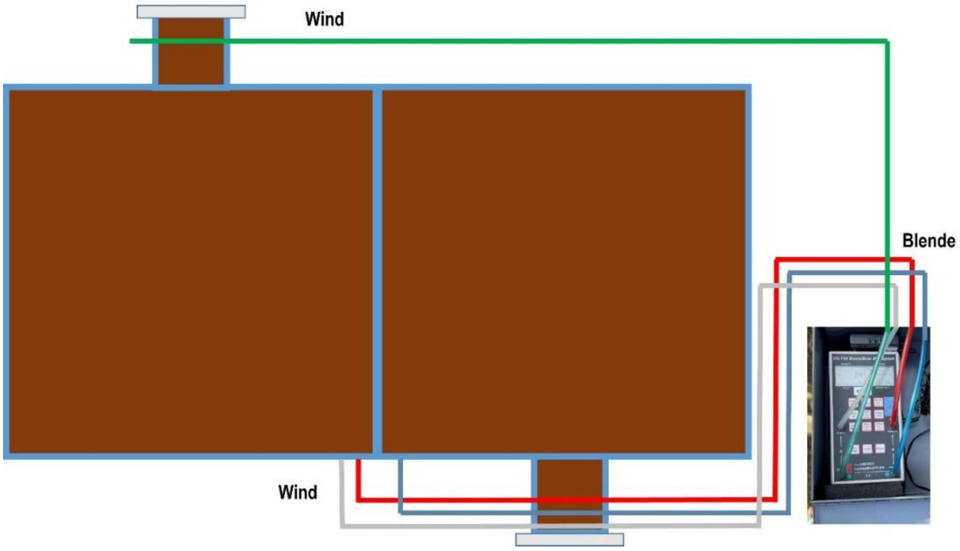

Figure 4: Recording the differential pressures, wind: green-grey, orifice plate: red-blue

The wind pressure on the measuring setup (green and gray tubes) and the differential pressure across the orifice (red and blue tubes) are measured using a differential pressure measuring device. A reversal of the sign of the recorded pressure across the measuring orifice indicates the reversal of flow across the orifice due to the change in direction of rotation of the fans. The volume flow through the measuring orifice can be determined using the following aperture equation.

$$q_{v,Blende} = 0{,}36 \cdot (2/\rho)^{0{,}5} \cdot c_d \cdot A \cdot \Delta p^{0{,}5}$$

with

$q_{v,orifice}$	Volume flow across the measuring orifice in m³/h
ρ	raw density of the air
c_d	air resistance value, 0.61 (sharp-edged opening)

A Area of the opening in cm²

Δp Differential pressure across the orifice in Pa

The volume flow conveyed by the pair of ventilation devices can be measured via the measuring orifice. For this purpose, the differential pressures across the measuring orifice at different operating levels of the ventilation devices are recorded every second via the data logger and converted into a volume flow using the above equation.

In Figure 5 to Figure 8, week 11 is shown as an example, in which the ventilation devices are operated at level 4. A positive differential pressure is shown as a positive volume flow (conveyance direction 1, green), a negative differential pressure as a negative volume flow (conveyance direction 2, purple).

However, with the volume flows determined via the orifice, it must be noted that the pressure drop across the measuring orifice has an influence on the calculated volume flow, which is not factored out in this first consideration. Particularly at high volume flows, this pressure drop becomes noticeable through a reduced calculated volume flow.

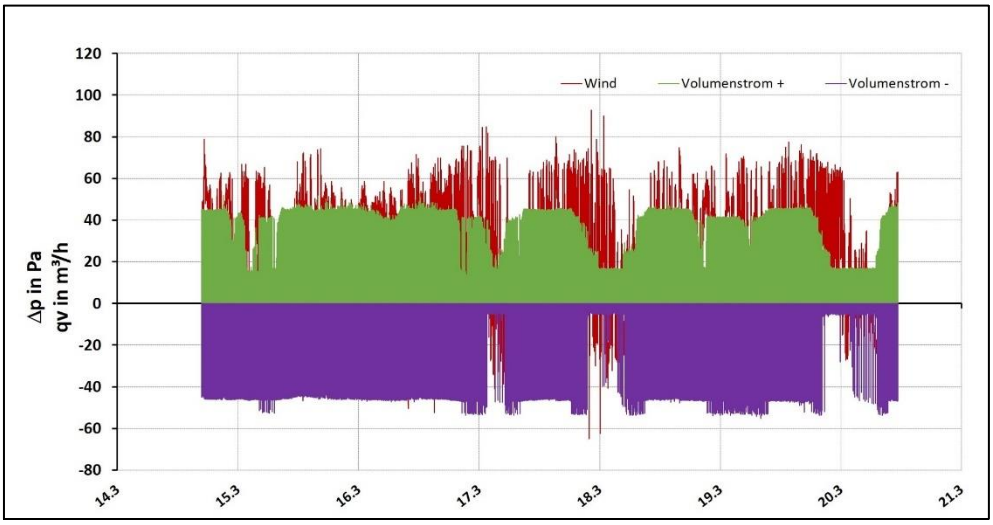

Figure 5: Effective wind pressure (red), volume flow measured via the orifice in delivery direction 1 (green) and delivery direction 2 (violet) at operating level 4: 21/3/15 to 21/3/20

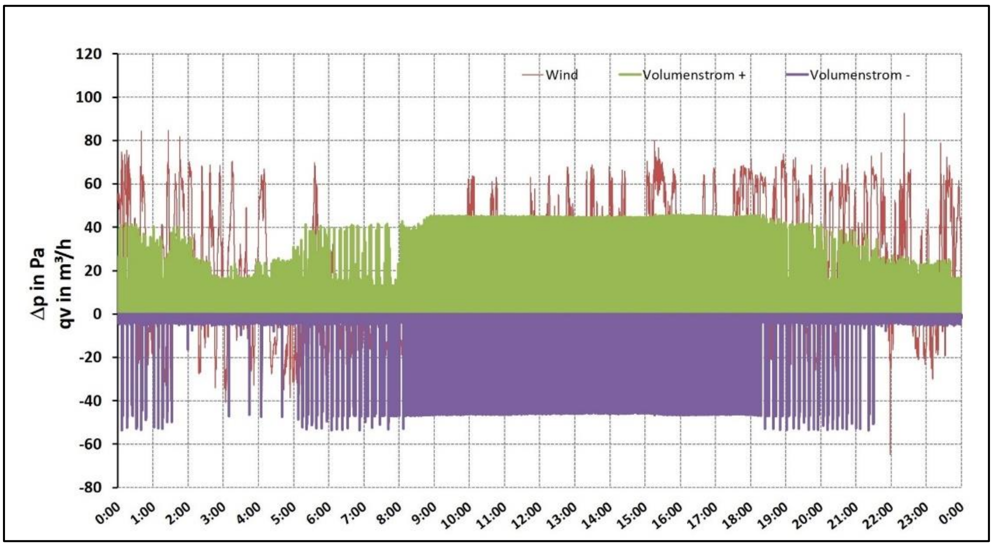

Figure 6: Effective wind pressure (red), volume flow measured via the orifice in delivery direction 1 (green) and delivery direction 2 (violet) at operating level 4: 21/3/18

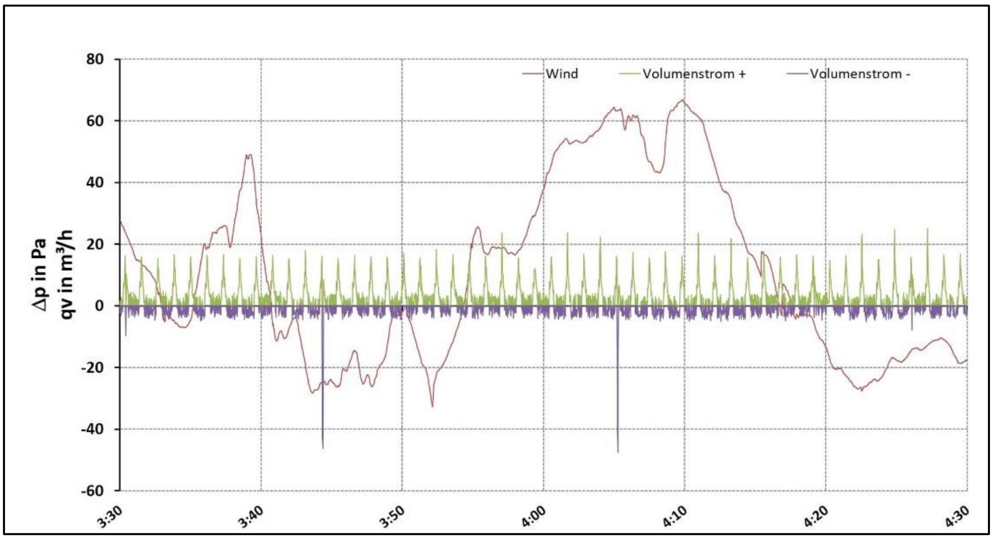

Figure 7: Effective wind pressure (red), volume flow measured via the orifice in delivery direction 1 (green) and delivery direction 2 (violet) at operating level 4: 21/3/18, 3.30 to 4.30 a.m.

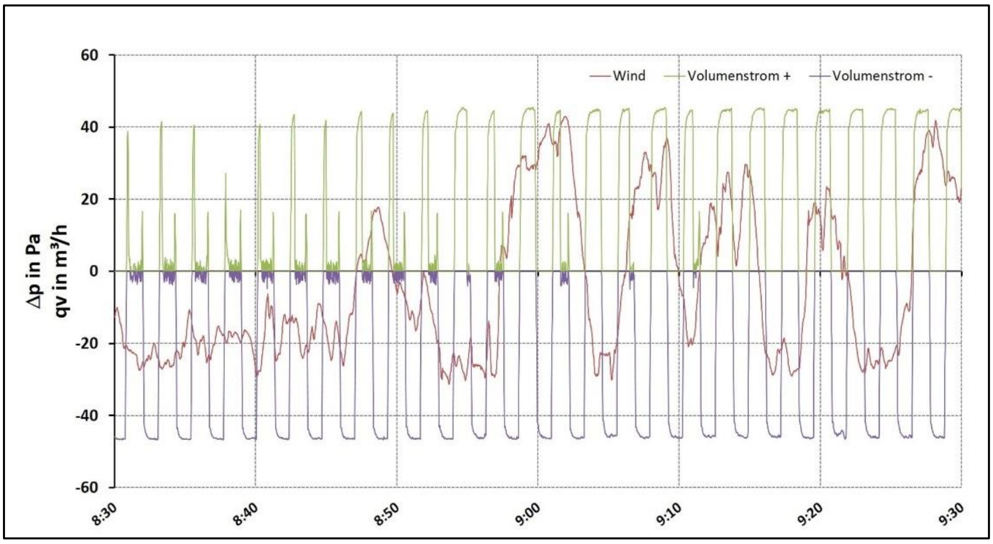

Figure 8: Effective wind pressure (red), volume flow measured via the orifice in delivery direction 1 (green) and delivery direction 2 (violet) at operating level 4: 21/3/18, 8.30 to 9.30 a.m.

It can be clearly seen in Figure 5 and Figure 6 that the delivery of the volume flow is not always uniform. What can be seen is an almost complete collapse of funding in both funding directions (Figure 7) or only in one funding direction (Figure 8). A connection with wind pressures above 20 Pa can be seen. The measured wind-induced differential pressures exceed 60 Pa at peaks.

A connection between wind speed, the resulting pressure on the measurement setup and the volume flows is shown for week 14 in Figure 9 and Figure 10. The wind logger records a wind speed every 10 seconds, and an average value is recorded every second for the differential pressure recording.

The ventilation devices are operated at level 3.

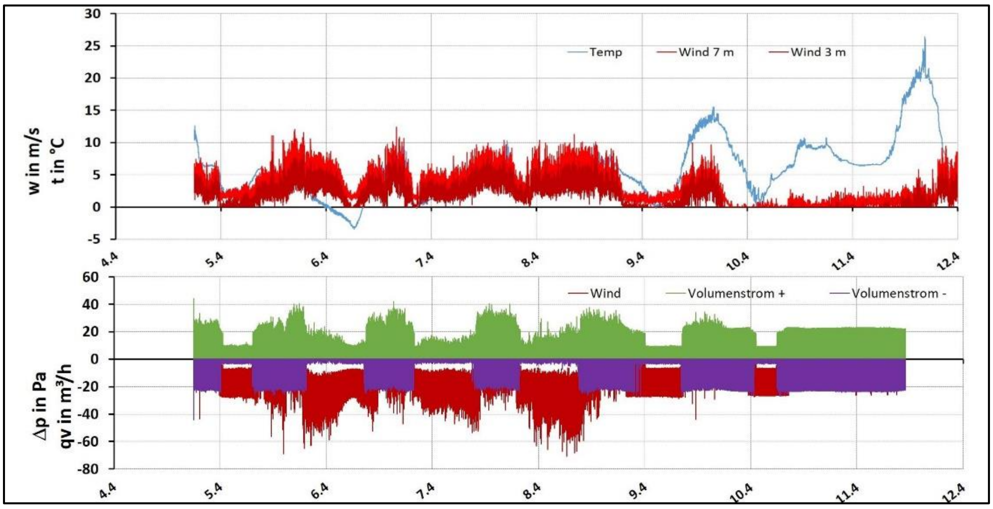

Figure 9: Wind speed at a height of 7 m (light red) and 3 m (dark red), effective wind pressure (red), volume flow measured via the orifice plate in delivery direction 1 (green) and delivery direction 2 (violet) at operating level 3 from 21/4/5 to 21/4/12

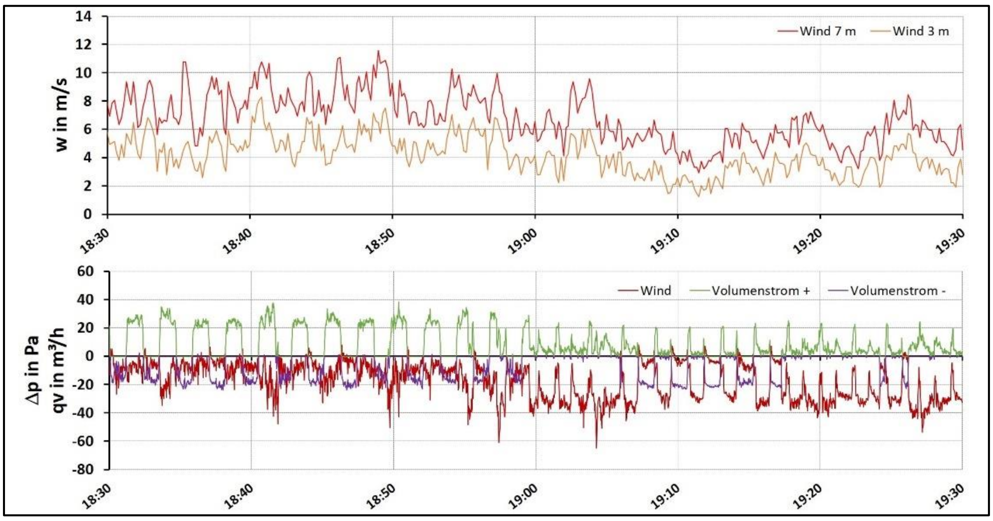

Figure 10: Wind speed at a height of 7 m (light red) and 3 m (dark red), effective wind pressure (red), volume flow measured via the orifice in delivery direction 1 (green) and delivery direction 2 (violet) at operating level 3 from 21/4/5, 6.30 to 7.30 p.m.

In Figure 9, longer periods of time are visible in which a balanced volume flow is not achieved. In addition, as can be seen in Figure 8, it can be seen here that the ventilation devices react very sensitively and spontaneously to the influences of wind. In Figure 10 it can be seen that the measured volume flows fluctuate greatly in both conveying directions, depending on the wind-induced differential pressures, which also fluctuate very strongly. The wind pressure exceeds 60 Pa at peaks.

In Figure 10 it can also be seen that no direct connection can be derived from this measurement between the measured wind speed and the wind pressure on the measurement setup or the volume flows conveyed. For example, from around 7 p.m. the measured wind speed decreases, but the wind pressure measured in the measurement setup increases. On the one hand, the possible cause could be the differences in measurement intervals and data recording; on the other hand, it cannot be ruled out that there is a time difference between the different data loggers for wind speed and differential pressure.

Since the aim of the study is to provide information about the volume flows of the ventilation devices under wind pressure, the connection between wind speed and the differential pressure generated is not considered further. In this study, an evaluation is carried out solely based on the wind pressure determined via the measurement setup.

In order to make precise statements about the influence on the volume flows conveyed, the measurement setup is expanded in such a way that a constant wind pressure can be simulated.

Frequency of wind loads

The wind-induced differential pressures will be measured every second from March 2021 to June 2021 using a data logger. Around 600,000 data sets are recorded every week, Figure 11.

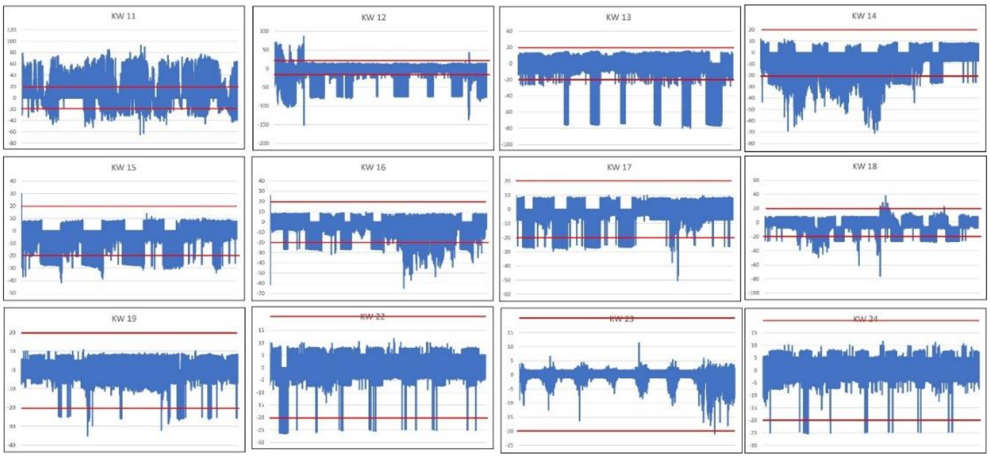

Figure 11: Recording of wind pressure from week 11 (KW 11) to week 24 (KW 24) 2021 with visualisation of the +/- 20 Pa range

Figure 12 shows the amounts of these differential pressures according to their frequency on a weekly basis.

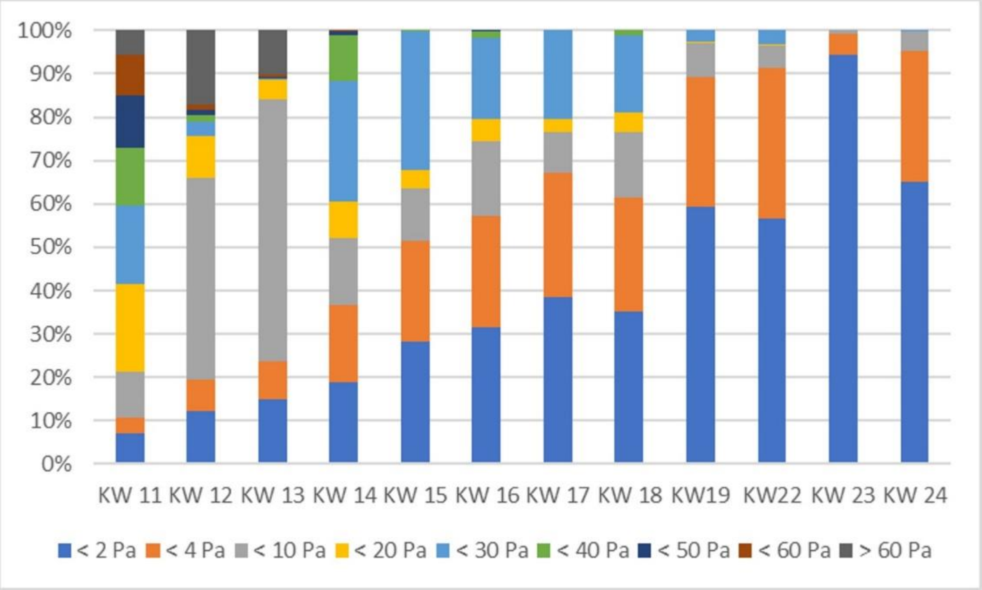

Figure 12: Frequency of absolute wind-induced differential pressures from week 11 (KW 11) to week 24 (KW 24) 2021

It is clearly visible that there is a very high frequency of high wind-induced differential pressures in March, which then decreases towards the warmer months.

The sensitivity of the air volume flow is classified according to DIN EN 13141-8 for ± 20 Pa. This wind pressure is exceeded approx. 60% of the time in week 11. In week 12 it is approx. 25%, in week 13 a little more than 10% of the time. Then the frequency increases again to 40% in week 14 and then decreases sharply in the summer.

Even if only the months of March and April fall within the heating period in this study, it can still be assumed that the wind pressures in the remaining months of the heating period behave similarly to those in March or that the wind influence is even higher.

Measurement setup for test series 2

In order to simulate different wind pressures using the measurement setup, a funnel is set up in front of the west-facing ventilation device, in which a controllable fan (Minneapolis Ductblaster) is installed, Figure 13.

The fan simulates a constant wind load and thus a constant wind pressure. The side opening of the funnel ensures that the ventilation devices operate under the simulated wind load.

Figure 13: Measurement setup with fan to simulate constant wind pressure

The differential pressure measuring device is used to measure the wind pressure simulated by the fan (Figure 14, green and grey tube) and the differential pressure across the orifice (Figure 14, red and blue tube).

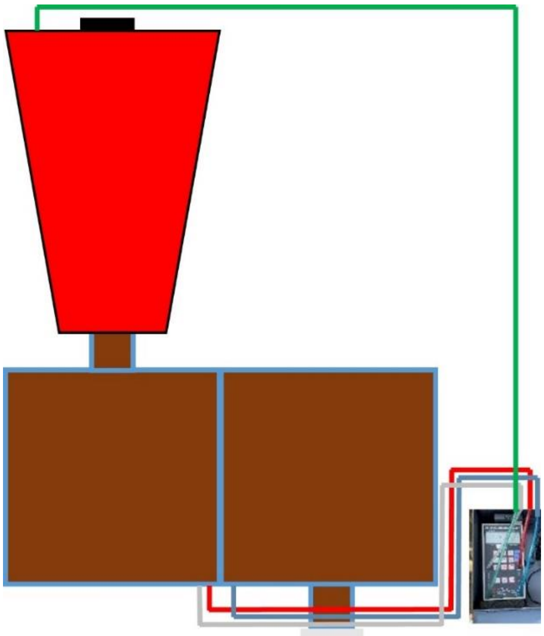

Figure 14: Recording of the differential pressures with simulation of the wind pressure through the fan

Measuring process

The ventilation devices are set to operating levels 4 to 1. In each operating level, the fan is adjusted so that there is an average differential pressure across the measurement setup of approximately 60 Pa. The speed of the fan is then gradually reduced so that the differential pressure steadily decreases. Since the ventilation devices work at an interval both in the conveying direction of the fan (wind direction) and against this conveying direction, a wave-shaped characteristic curve of the wind pressure results.

Wind pressure and energy efficiency

Figures 15 to 18 show the recordings of the 4 operating stages under changing differential pressures. A maximum differential pressure of 60 Pa is selected, which is reduced in steps to approx. 10 Pa (levels 4 and 3) or 0 Pa (levels 2 and 1).

When calculating the volume flow using the above-mentioned orifice equation, the measured differential pressure across the measuring orifice is corrected by the pressure drop across the orifice. Compared to the first evaluation, the volume flows determined are therefore higher.

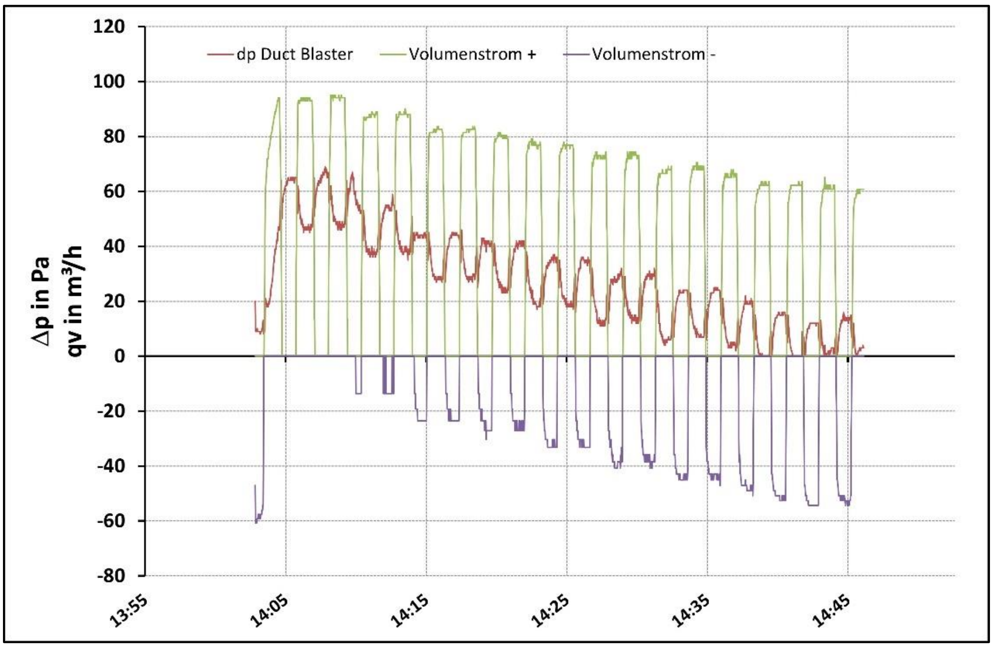

Figure 15: Volume flow under simulated wind pressure: Level 4, $q_{v,target}$ = 58 m³/h

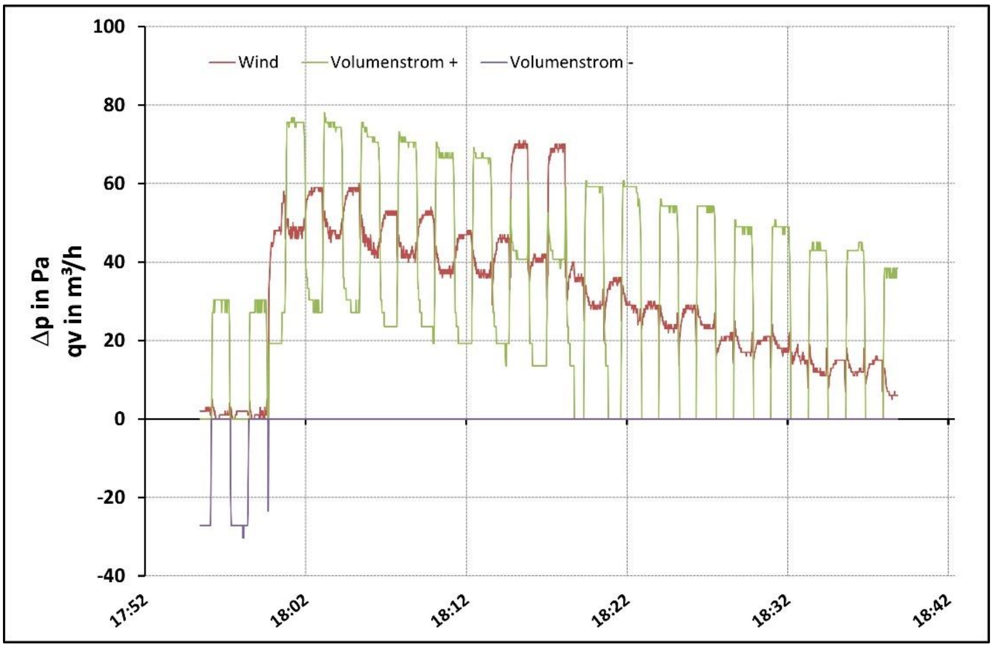

Figure 16: Volume flow under simulated wind pressure: Level 3, $q_{v,target}$ = 42 m³/h

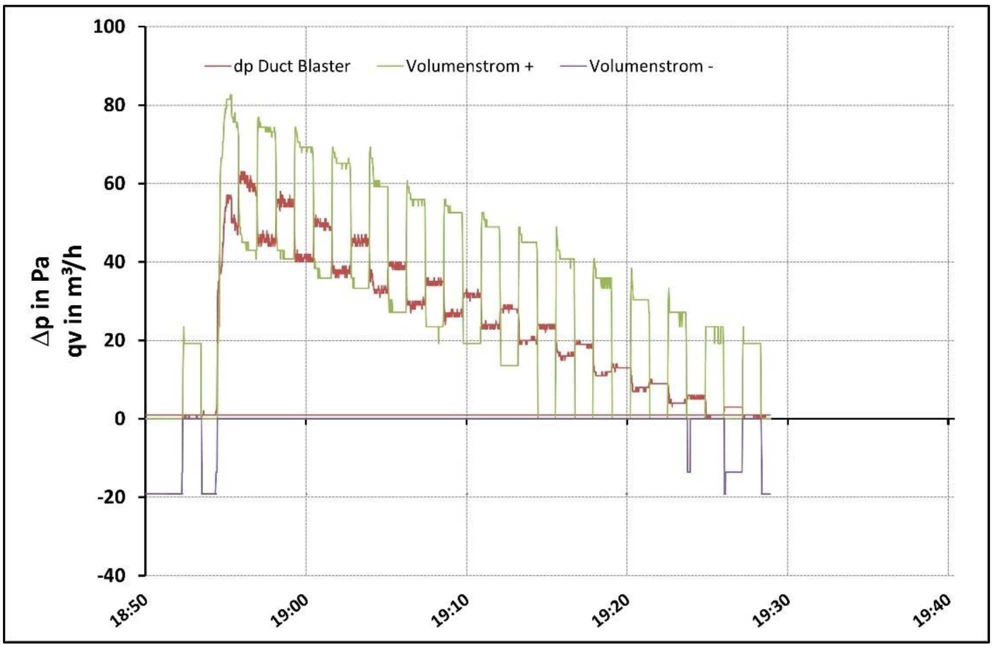

Figure 17: Volume flow under simulated wind pressure: Level 2, $q_{v,target}$ = 21 m³/h

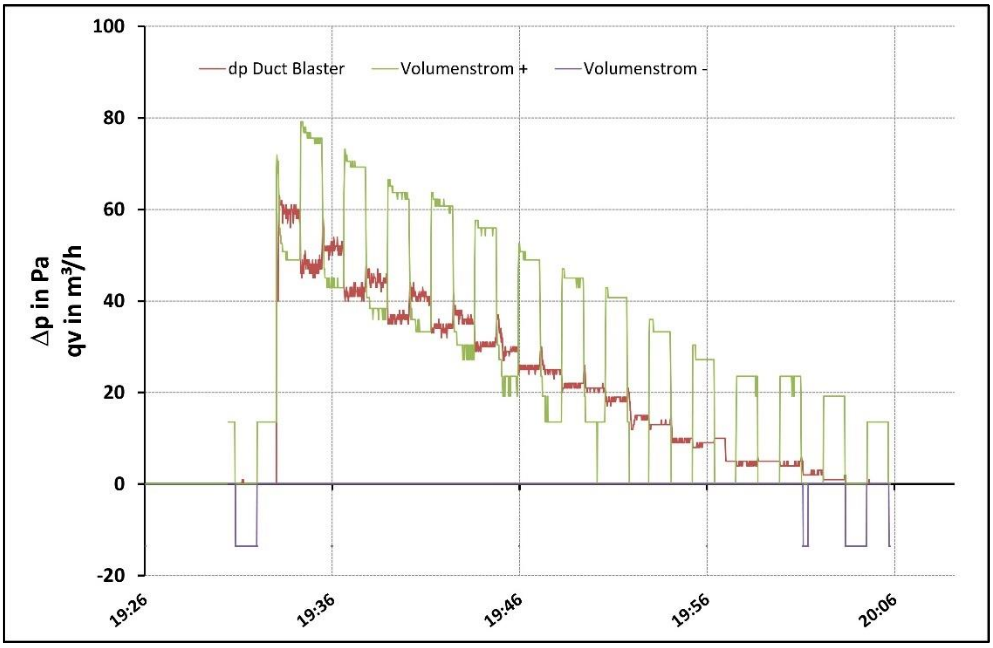

Figure 18: Volume flow under simulated wind pressure: Level 1, $q_{v,target}$ = 17 m³/h

The effect of wind load is clearly visible. At operating level 4 (Figure 15), with a wind pressure (red line) of 60 Pa, only a volume flow in one direction can be measured (green line). Only when the wind pressure falls does a volume flow in the opposite direction occur again (purple line). In operating levels 3 (Figure 16), 2 (Figure 17) and 1 (Figure 18), the influence of wind pressure is significantly higher, only when the wind pressure is below approx. 4 Pa (level 3) or approx. 2 Pa (levels 2 and 1) a volume flow can again be measured in the opposite direction (purple line).

An estimatation of the energy efficiency of the ventilation devices under wind load is carried out at operating level 4. For this purpose, the average positive and negative volume flows (supply air and exhaust air volume flows) are evaluated in certain time periods, Figure 19.

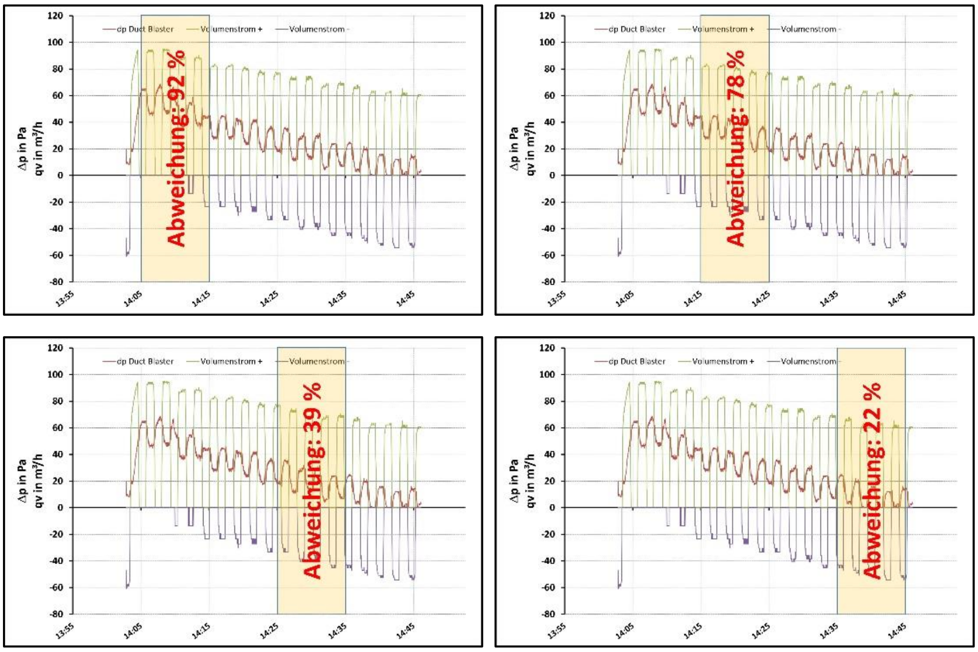

Figure 19: Percentage deviation of the supply air volume flow (green) from the extract air volume flow (violet) summarised in pressure bands at different simulated wind pressures (red) at operating level 4

An approximate reduction factor for the efficiency of the heat exchanger is derived from the percentage deviation of the supply air volume flow from the exhaust air volume flow, Table 2Table 2: Resulting, approximate efficiency of heat recovery depending on the pressure band. The pressure bands are combined in certain areas. For this approximate consideration, a linear relationship between the efficiency of heat recovery and the imbalance of supply and exhaust air volume flow is assumed.

When considering the energy efficiency of the ventilation devices, the increased outside air volume flow due to wind pressure is not taken into account.

Based on an efficiency of the ventilation device in balanced operation according to the building authority approval of 78% (η = 0.78), the following efficiencies result for the pressure bands:

0 to 4 Pa	4 to 20 Pa	20 to 30 Pa	30 to 40 Pa	40 to > 60 Pa
Deviation 0 %	Deviation 22 %	Deviation 39 %	Deviation 78 %	Deviation 92 %
η = 0,78	η_{res} = η x 0,78 η_{res} = 0,61	η_{res} = η x 0,61 η_{res} = 0,48	η_{res} = η x 0,22 η_{res} = 0,17	η_{res} = η x 0,08 η_{res} = 0,06

Table 2: Resulting approximate efficiency of heat recovery as a function of the pressure band

The frequency distribution (Figure 20; Table 3) then results in a resulting, approximate efficiency for the pressure bands in the corresponding period, which takes the wind-induced pressures and their frequency into account.

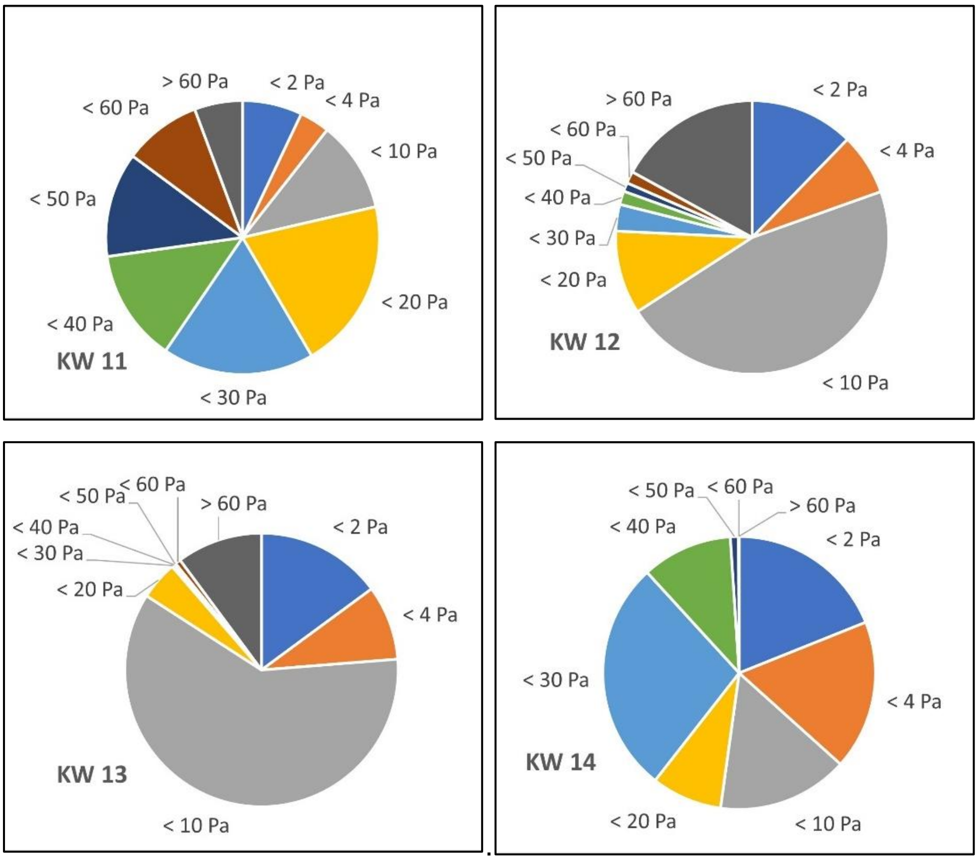

Figure 20: Frequency of wind-induced differential pressures in week 11 (KW 11), week 12 (KW 12), week 13 (KW 13) and week 14 (KW 14)

Percentage frequency n of pressure bands					
	0 to 4 Pa	4 to 20 Pa	20 to 30 Pa	30 to 40 Pa	40 to > 60 Pa
KW 11	11 %	31 %	18 %	13 %	27 %
KW 12	20 %	56 %	3 %	2 %	20 %
KW 13	24 %	65 %	0 %	14 %	11 %
KW 14	37 %	24 %	28 %	11 %	1 %

Table 3: Percentage frequencies of wind-induced differential pressures from week 11 to week 14, 2021, summarised in pressure bands

If the efficiencies η_∆p are taken into account with the respective frequency n_∆p, a resulting average efficiency for this KW can be derived. For operating level 4, the resulting efficiency for week 11 is as follows:

$$\eta_{res} = \frac{\sum(\eta_{\Delta p} \cdot n_{\Delta p})}{100}$$

$$\eta_{res,KW11,level\ 4} = \frac{0{,}78 \cdot 11 + 0{,}61 \cdot 31 + 0{,}48 \cdot 18 + 0{,}17 \cdot 13 + 0{,}06 \cdot 27}{100}$$

$$\eta_{res,KW11,level\ 4} = 0{,}4$$

In weeks 12, 13 and 14 there are slightly better efficiencies because the proportion of lower wind-induced differential pressures is higher.

Week 12: $\eta_{res,KW12,level\ 4} = 0{,}53$

Week 13: $\eta_{res,KW13,level\ 4} = 0{,}61$

Week 14: $\eta_{res,KW14,level\ 4} = 0{,}59$

If the ventilation devices are operated in operating levels 3, 2 and 1, the influence of wind pressure is significantly stronger, so that only times with wind loads < 4 Pa (level 3) occur with a frequency of 11% in week 11 or < 2 Pa (stages 2 and 1) can be taken into account in the efficiency of the heat exchanger with a frequency of 7% in week 11. This results in the following efficiencies for week 11:

$$\eta_{res} = \frac{\sum \eta_{\Delta p} \cdot n_{\Delta p}}{100}$$

$$\eta_{res,level\ 3} = \frac{0{,}78 \cdot 11 + 0 \cdot 89}{100}$$

$$\eta_{res,level\ 3} = 0{,}09$$

$$\eta_{res,levels\ 2/1} = \frac{0{,}78 \cdot 7 + 0 \cdot 93}{100}$$

$$\eta_{res,levels\ 2/1} = 0{,}05$$

In week 11, these ventilation devices can only achieve an approximate overall heat recovery efficiency of 0.09 at operating level 3 and 0.05 at operating levels 2 and 1. The efficiency increases in weeks 12 to 14 due to the higher proportion of lower wind-induced differential pressures in stage 3 to up to 0.29 and in stages 2 and 1 to up to 0.15.

Noise emissions from "push-pull" ventilation devices

According to the product data sheet in accordance with ERP Regulation 1254/2014 EU, the sound power level of this ventilation device is 35 dB(A) at reference air volume flow (level 3). Due to the design, the noise is emitted directly into the lounges.

According to DIN 4109, the minimum requirement for the sound pressure level of ventilation devices that are not switched off in your own living space and as intended when the living space is being used is 30 dB(A). An excess of 5 dB is permissible if the noise is continuous without any noticeable individual tones.

Increased requirements are defined in DIN 4109-5. A maximum standard sound pressure level of 27 dB(A) is required here, which may be exceeded by a maximum of 3 dB without noticeable individual tones. This requirement applies at night at the required air volume flow for the intended operation of the respective ventilation technology measure.

In the product information of the ventilation devices examined, a sound pressure level of 16 to 36 dB(A) is stated in the volume flow range from 17 m³/h to 58 m³/h without specifying the distance intended for sound measurement.

In order to comply with the minimum requirements for the outside air volume flow according to DIN 1946-6 or DIN EN 16798-1 of 15 m³/h per person in a bedroom, a supply air volume flow of 30 m³/h is necessary for an occupancy of 2 people. Since “push-pull” ventilation devices reverse the flow direction every 70 seconds, outside air is only pumped into the bedroom half the time. In order to comply with the requirements of DIN 1946-6, this ventilation device must therefore be operated at level 4.

However, due to the noise emissions, it can be assumed that these ventilation devices will not operate at levels 4 or 3 in the bedroom at night, but in practice they will rather be operated with a lower volume flow at the reduced operating levels 2 or 1.

Summary

Ventilation devices that work alternately in pairs (pendulum fans or push-pull ventilation devices) are very sensitive to wind. For operating level 4, a volume flow deviation of less than 30% of the supply and exhaust air volume flow can be determined up to a wind-induced differential pressure of 20 Pa. With higher wind pressure, the wind sensitivity increases; at a differential pressure of 60 Pa, a wind sensitivity of 100% is achieved.

However, this statement only applies to the highest operating level. In practice, these ventilation devices are more likely to be operated at level 2 or 1 due to the noise emissions into the living area.

At these reduced operating levels, wind sensitivity is significantly higher. Sufficiently balanced operation can only be guaranteed here with differential pressures of less than 2 Pa.

Due to the sensitivity to wind, the efficiency of the heat exchanger decreases. In the windier winter months, the heat recovery efficiency specified in the building approval is significantly lower, even at level 4. An approximate efficiency of 0.4 to 0.61 was demonstrated at operating level 4 for March 2021 instead of the building approval specification of 0.78.

At reduced operating levels, heat recovery is almost ineffective at wind pressures above 2 Pa.

Due to the high sensitivity to wind and the direct introduction of noise into the living space, the intended operation of these ventilation devices, as is required for calculating the energy requirement, is very questionable in practice.