Natural Pressure Differential – Infiltration Through Wind Results of a Long-Term Measurement

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ABSTRACT

Topic
Wind pressure and thermal forces are driving forces for pressure difference on the building envelope. In European and German standards infiltration is calculated using wind speed, temperature difference and wind pressure coefficients resulting from upstream and downstream flow on the building envelope. This long term measurements shall present measured pressure differences on the building envelope in comparison to those calculations.

Approach
Measurement of pressure differences over the building envelope over a year. Samples are a dwelling in a multi-family-house in Berlin-Friedrichshain and a dwelling in a multi-family-house on the island Helgoland. Pressure was logged for one year with capillary pipes over the gate folds of several windows. Wind speed was measured close to the building.

Results
The recorded pressure differences show a great dependence on the wind speed and the direction of flow on the building. Pressure differences fluctuate strongly at very short intervals. A constant pressure over a certain time could not be observed. The temperature differences play a subordinate role or no role in these measurement objects.

KEYWORDS

Infiltration, wind pressure, leakage, differential pressure

1 INTRODUCTION

The purpose of this long-term study is to record pressure differences on the building envelope. On the one hand, the influences of wind, temperature difference and ventilation systems as well as the user behavior can be made visible, and on the other hand there is the idea that the measured values can be matched with theoretical assumptions. At present we are still in the evaluation of the measured data and present an interim work.

2 INFILTRATION CALCULATION

The differential pressure on the building envelope is the result of wind pressure and thermal buoyancy. In European and German standards, infiltration calculations include figures on wind speed, temperature difference and wind pressure coefficients from upstream and downstream flow on the building envelope.

Together with the air permeability measurement of the building envelope, the differential pressure can then be used to derive a flow rate under environmental conditions that is applied toward determining energy requirement and ventilation needs.

3 BOUNDARY CONDITIONS – OBJECT 1

3.1 Measurement Object: Berlin

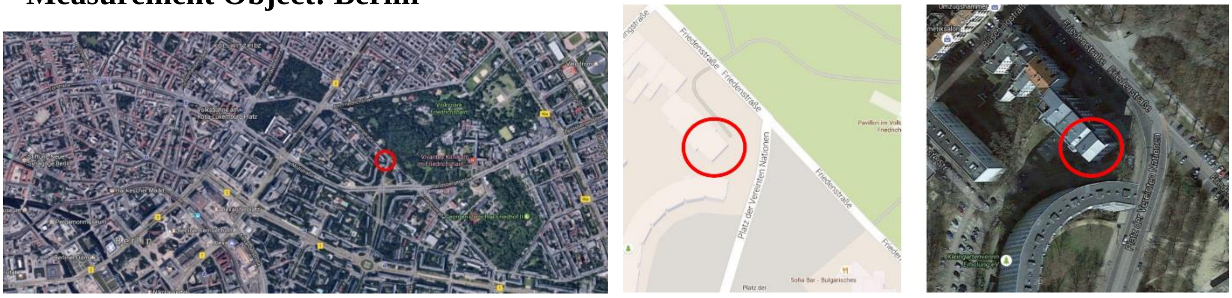


Figure 1: Location of measurement object, Berlin Source: Google Maps

Address:	Friedenstrasse 17, 10249 Berlin, Germany
Apartment location:	2nd story, finished floor level 11 m above the ground three faces: NE park, SE open, SW prefab building around 30 m high, 10 to 15 m away
Ventilation style:	Apartment-central, humidity-controlled ventilation system with outside air apertures in the window, ventilation fans switches off every 1.5 hours for a duration of 1.5 hours
Airtightness of apartment:	n_{50} = 1.3 1/h Leakages at the balcony door, at penetration of the outgoing duct, at penetration of incoming duct of the fireplace, and at all installation shafts
Wind measurement:	logicenergy LeWL Windlogger Speed kit Measurement point: bedroom balcony to the northeast The log interval is 1 minute. The values measured continuously over this interval are added up each minute and saved as an averaged value called Wind_mittel. The maximum wind speed during this interval is also saved as a value called Wind_max.
Outside temperature:	logicenergy LeWL Windlogger Speed kit Measurement point: bedroom balcony to the northeast The log interval is 1 minute. The values measured continuously over this interval are added up each minute and saved as one value.
Inside temperature:	Not recorded; room temperature during heating period at 20–22°C
Differential pressure:	Two measurements using TEC DG-700 with TEC Wifi Link Office, located to the northeast Combined living/kitchen area, located to the southeast, southwest Analysis conducted using Teclog3 The log interval is 1 second for Measurement Configuration 1 and 5 seconds for Measurement Configuration 2. The values measured continuously over these intervals are added up and saved every 1 second for Measurement Configuration 1 and every 5 seconds for Measurement Configuration 2.
Measurement period:	February 2016 to February 2017

3.2 Measurement Configuration

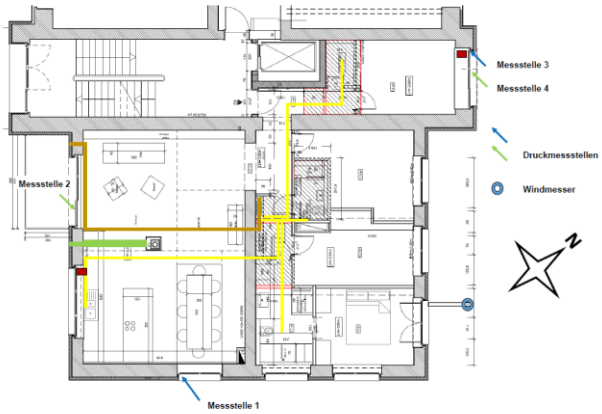


Figure 2: Measurement Configuration 1
(Key: *Messstelle* = measuring point;
Druckmessstellen = pressure measuring points;
Windmesser = wind gauge)

Figure 3: Measurement Configuration1, pressure recording

Figures 2 and 3 show the first measurement configuration. At differential pressure gauge 1, channel A records the differential pressure between measuring point 1 and the reference pressure inside, while channel B records that between measuring point 2 and the reference pressure inside. At differential pressure gauge 2, channel A is used to record the differential pressure between measuring point 3 and the reference pressure inside while channel B is used to record that between measuring point 4 and the reference pressure inside. Measuring points 3 and 4 are situated at the window door at 1.6 m height. Measuring point 3 is ap. 10 cm away of the window reveal, Measuring points 3 and 4 are ap. 0.8 m apart.

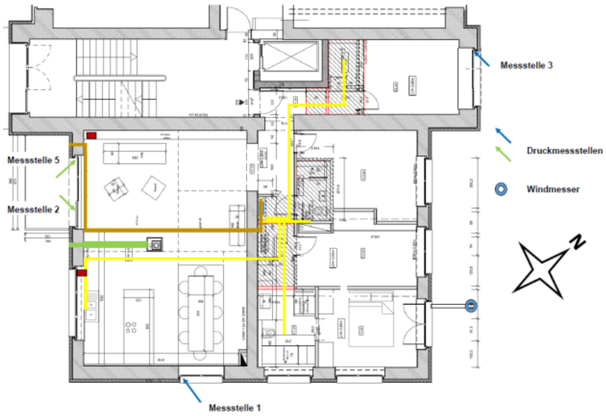


Figure 4: Measurement Configuration 2
(Key: *Messstelle* = measuring point;
Druckmessstellen = pressure measuring points;
Windmesser = wind gauge)

Figure 5: Measurement Configuration 2, pressure recording

Figures 4 and 5 show the slightly altered second measurement configuration. Compared to the first configuration, measurement at the differential pressure gauge 2 has been changed so that channel A measures the differential pressure between measuring point 5 and the reference pressure inside while channel B measures that between measuring point 3 and the reference pressure inside.

Recording pressure at the windows takes place in the upper windows through capillary tubes threaded through the window reveal to the outside. Wind pressure on the façade is recorded as positive pressure. When the ventilation system is activated, the apartment will be under negative pressure, but the pressure recorded at the measuring points will nonetheless show positive.

Because the apartment is equipped with demand controlled residential ventilation in the form of an exhaust system regulated by room air humidity, and this system cannot be shut off during the measuring period, the central apartment exhaust fan is turned off in 1.5-hour intervals using an automatic timer. The exhaust system therefore runs for 8 x 1.5 hours a day and is switched off for 8 x 1.5 hours a day. For the periods when it is off, differential pressures at the measuring points are affected only by wind and thermal buoyancy.

Measurement Configuration 1 aims to use the first differential pressure gauge to determine how wind inflow behaves in a room. The second differential pressure gauge aims to discover whether a difference can be shown between the pressure recorded at the window reveal and the window surface. Using the modified Measurement Configuration 2, the second differential pressure gauge attempts to record a two-sided pressure situation through the apartment.

4 MEASUREMENT RESULTS: BERLIN

4.1 Influence of Exhaust System

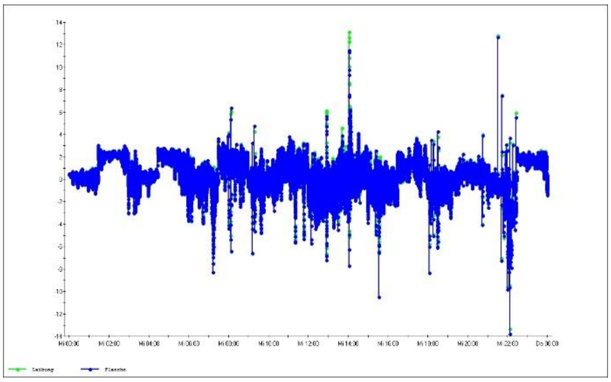


Figure 6: Measuring points 3 and 4, differential pressure Pa, March 23, 2016

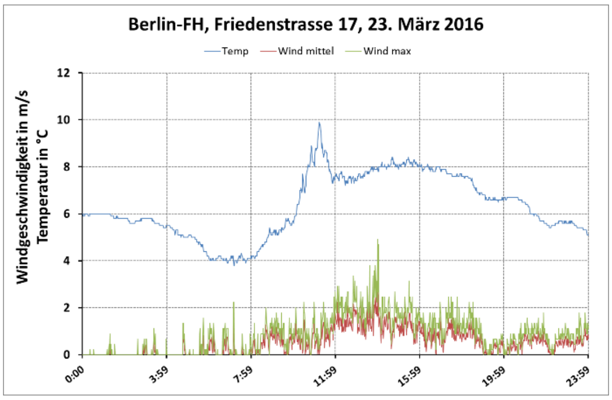


Figure 7: Local wind speed (*Windgeschwindigkeit*) m/s and temperature °C, March 23, 2016

The effect of the exhaust system on the pressure ratios in the apartment is clearly visible in Figure 6. The exhaust system is on at the following times:

Winter time

- 1:30 a.m. to 3:00 a.m.
- 4:30 a.m. to 6:00 a.m.
- 7:30 a.m. to 9:00 a.m.
- 10:30 a.m. to 12:00 noon
- 1:30 p.m. to 3:00 p.m.
- 4:30 p.m. to 6:00 p.m.
- 7:30 p.m. to 9:00 p.m.
- 10:30 p.m. to 12:00 midnight

Summer time (Mar. 27th to Oct. 30th 2016)

- 2:30 a.m. to 4:00 a.m.
- 5:30 a.m. to 7:00 a.m.
- 8:30 a.m. to 10:00 a.m.
- 11:30 a.m. to 13:00 p.m.
- 2:30 p.m. to 4:00 p.m.
- 5:30 p.m. to 7:00 p.m.
- 8:30 p.m. to 10:00 p.m.
- 11:30 p.m. to 1:00 a.m.

Figure 7 shows a low wind speed between midnight and 8:00 a.m. By 4:00 a.m., its maximum speed was 0.5 m/s. By 8:00 a.m., the wind speed had not exceeded 1 m/s. Excluding the effects of the exhaust system, the differential pressure fluctuates by –1 Pa to +1 Pa. When the exhaust system is on, the differential pressure fluctuates by +2 Pa, up to +3 Pa.

After 8:00 a.m., local wind speed is measured at 1 to 2 m/s. The diagram levels “ventilation system on/off” are no longer clearly recognizable and are obscured by the effects of wind. Differential pressures are measured from –4 to +4 Pa. Higher peaks are visible up to +/- 14 Pa. A relation from measured pressure difference to high wind speed is visible, though due to the measuring interval from 1 Minute not all wind peaks are recorded. It is only visible the largest wind speed within that interval. Measuring interval of pressure at this configuration is 1 second. A specific comparison between peaks of pressure difference and wind speed is not possible.

The influence of the ventilation system on the measured differential pressure is visible at low wind speeds and accounts for around 2 to 3 Pa. Since the flow rate of the exhaust system was not measured, however, there is still uncertainty here. The humidity regulation adapts the exhaust flow according to its needs: should high humidity levels be emitted, more air is expelled. Varying differential pressure occurs inside the apartment depending on the exhaust flow rate. This connection was not recorded, however.

Exhaust ventilation system was designed for maximum pressure difference of 8 Pa at maximum exhaust air flow. Nevertheless externally mounted air transfer devices are mounted without internal façade yet, leading to a lower pressure drop at same air flow. This can be recognized in measured values.

4.2 Pressure Recording at Window Reveal / Window Surface

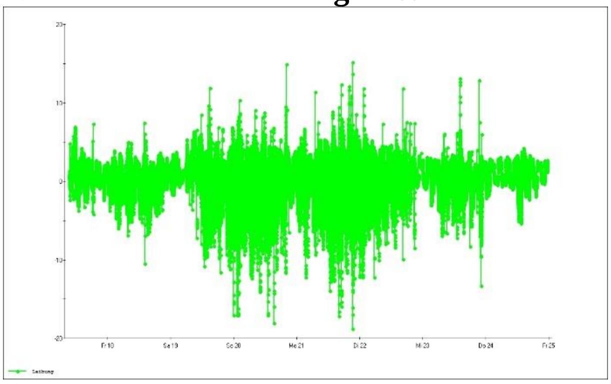


Figure 8: Measuring point 3 (reveal), differential pressure Pa, March 18 to 25, 2016

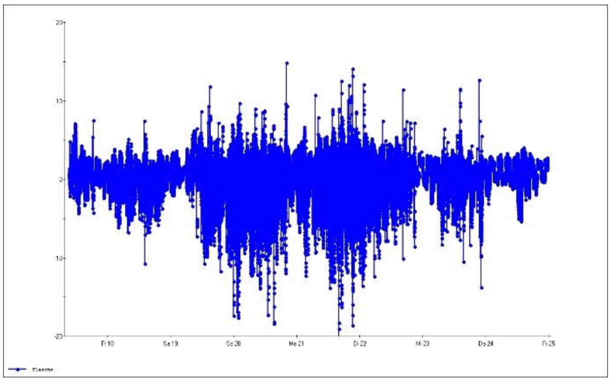


Figure 9: Measuring point 4 (surface), differential pressure Pa, March 18 to 25, 2016

	Avg [Pa]	Min [Pa]	Max [Pa]
Laibung	0,49	-18,76	15,18
Flaeche	0,44	-22,26	14,87

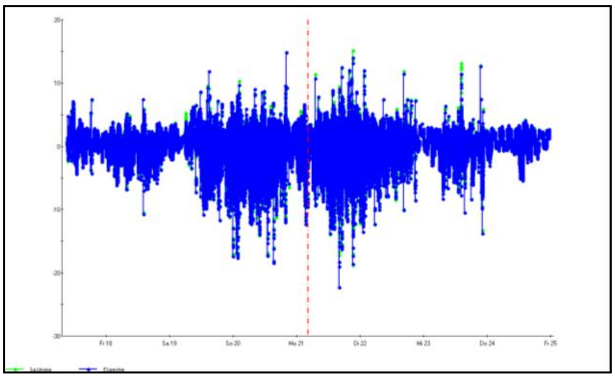


Figure 10: Measuring points 3 and 4, differential pressure Pa, March 18 to 25, 2016 (*Laibung* = reveal; *Flaeche* = surface)

	Avg [Pa]	Min [Pa]	Max [Pa]
Laibung	0,94	-13,96	3,72
Flaeche	-1,01	-13,8	4,1

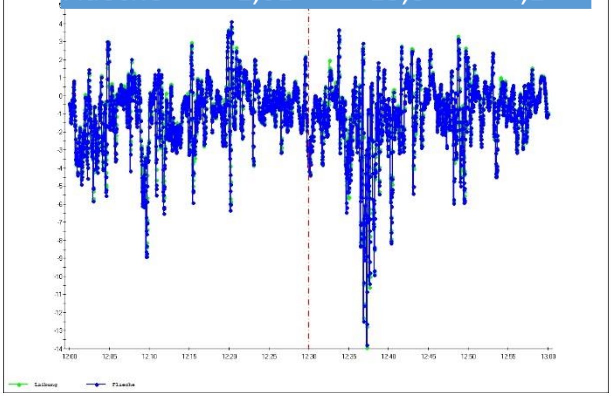


Figure 11: Measuring points 3 and 4, differential pressure Pa, March 21, 2016, noon to 1:00 p.m. (*Laibung* = reveal; *Flaeche* = surface)

The measurement between measuring points 3 and 4 aims to calculate whether a difference arises between the window reveal and the window surface. No significant pressure difference was discovered.

4.3 Two-sided pressure recording

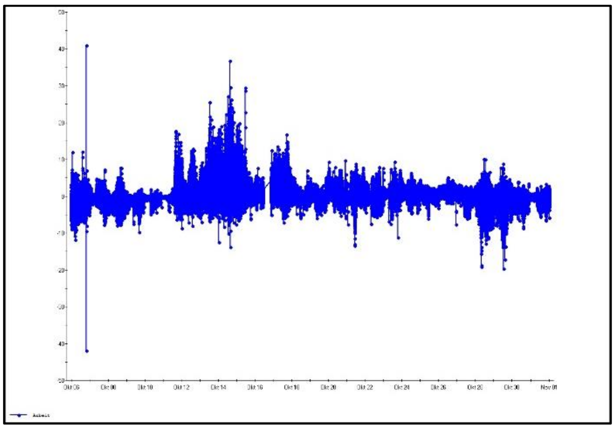


Figure 12: Measuring point 3, differential pressure Pa, October 6 to 31, 201&

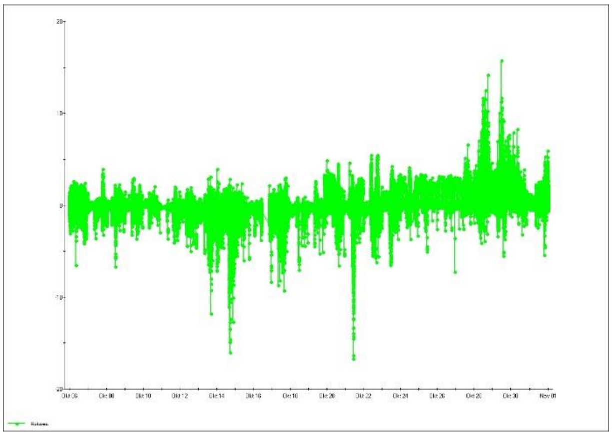
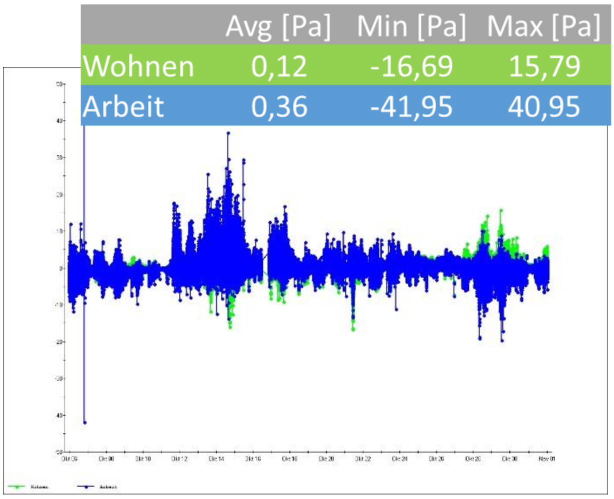


Figure 13: Measuring point 5, differential pressure Pa, October 6 to 31, 2016



	Avg [Pa]	Min [Pa]	Max [Pa]
Wohnen	0,12	-16,69	15,79
Arbeit	0,36	-41,95	40,95

Figure 14: Measuring points 3 and 5, differential pressure Pa, October 6 to 31, 2016

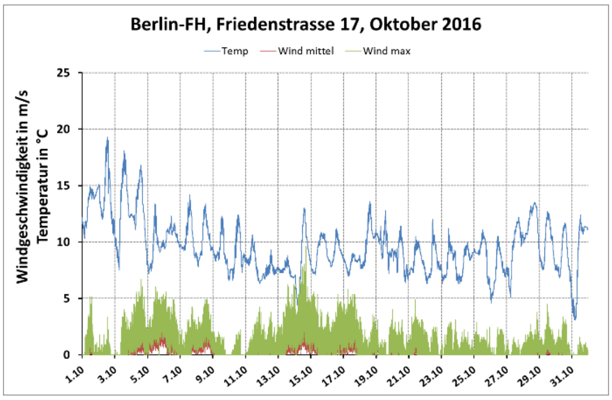


Figure 15: Local wind speed (*Windgeschwindigkeit*) in m/s and temperature in °C, Oktober 2016

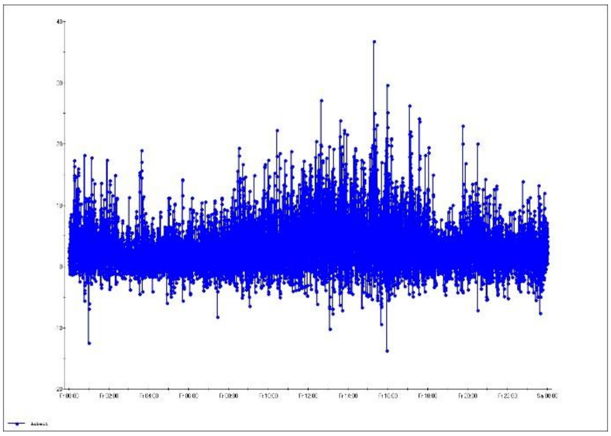


Figure 16: Measuring point 3, differential pressure Pa, October 14, 2016

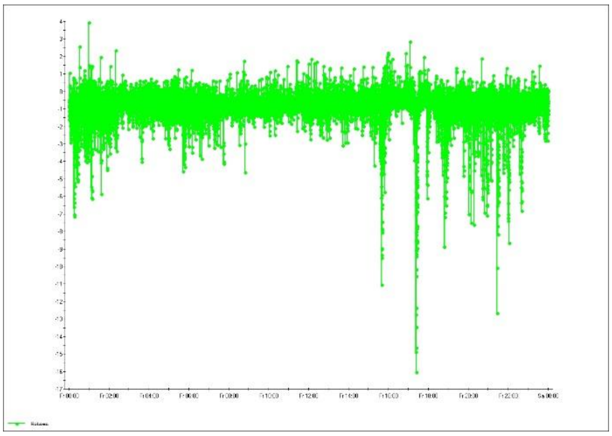
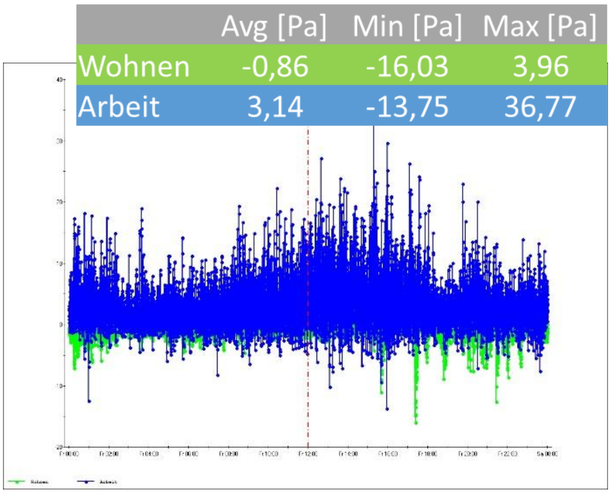


Figure 17: Measuring point 5, differential pressure Pa, October 14, 2016



	Avg [Pa]	Min [Pa]	Max [Pa]
Wohnen	-0,86	-16,03	3,96
Arbeit	3,14	-13,75	36,77

Figure 18: Measuring points 3 and 5, differential pressure Pa, 14.10.2016

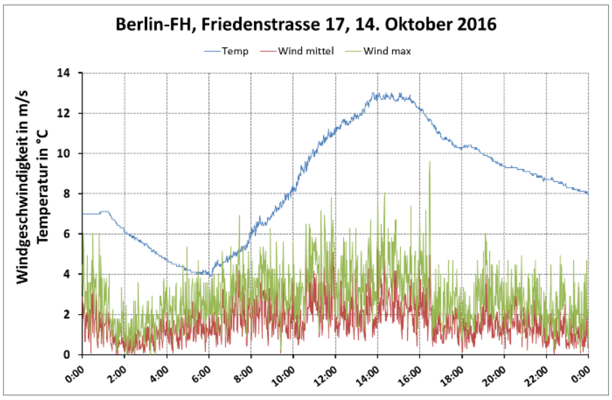


Figure 19: lokale Windgeschwindigkeit m/s and Temperatur °C, 14.10.2016

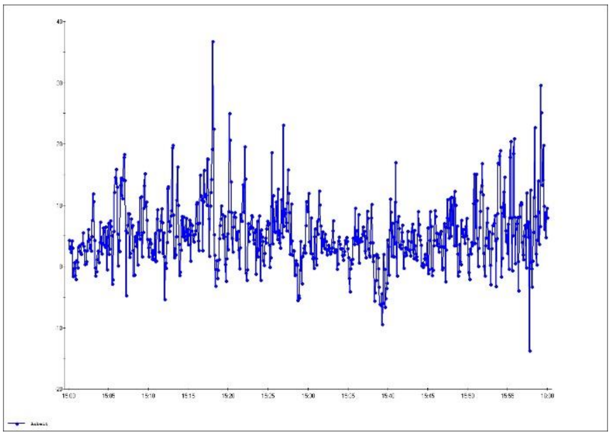


Figure 20: Measuring point 3, Differential pressure Pa, 14.10.2016, 3:00 to 4:00 p.m.

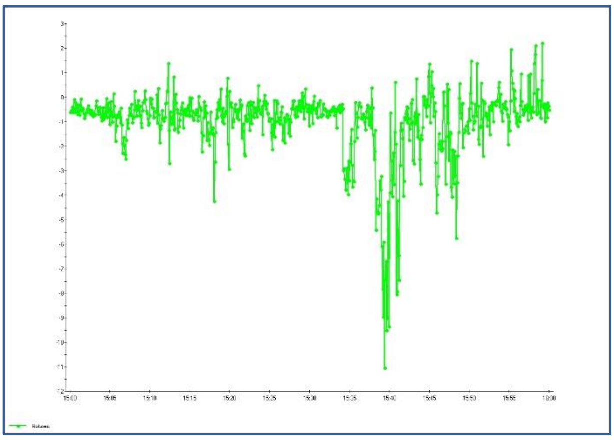
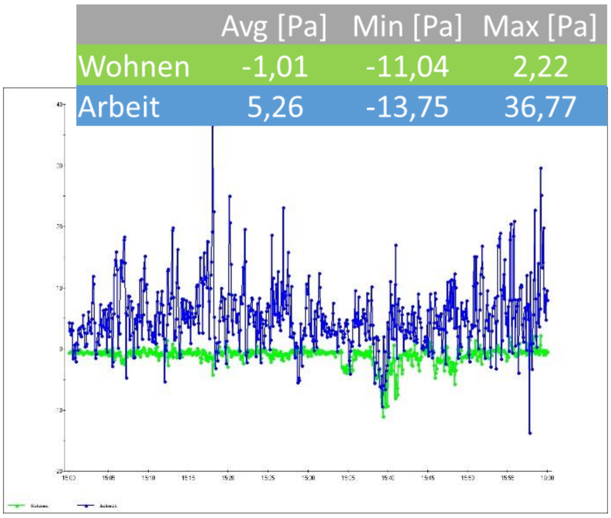


Figure 21: Measuring point 5, Differential pressure Pa, 14.10.2016, 3:00 to 4:00 p.m.



	Avg [Pa]	Min [Pa]	Max [Pa]
Wohnen	-1,01	-11,04	2,22
Arbeit	5,26	-13,75	36,77

Figure 22: Measuring points 3 and 5, differential pressure Pa, October 14, 2016, 3 p.m. to 4 p.m.

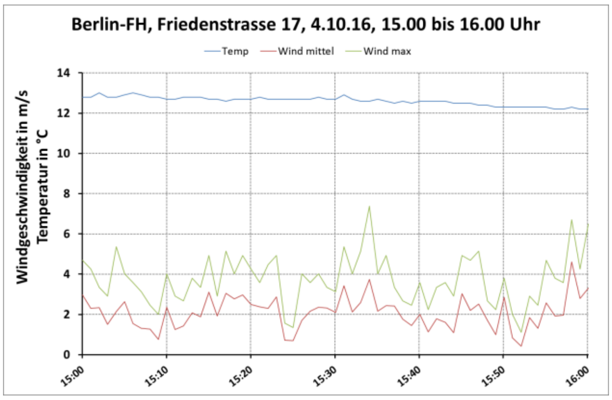


Figure 23: Local wind speed (*Windgeschwindigkeit*) in m/s and temperature in °C, October 14, 2016, 3 p.m. to 4 p.m

Figures 12 to 16 show the increased effect of the wind on measuring point 3 of the façade facing the park. Here, differential pressures are measured from +/–5 to +/–10 Pa, while at measuring point 5, which faces a neighboring building, differential pressures are shown from +/–2 to +/–5 Pa. The extremes are also much lower: –16 Pa at the courtyard side (measuring point 5) compared with +36 Pa at the park-facing side (measuring point 3). Maximum local wind speed is at 5 to 10 m/s.

A somewhat more precise observation can be seen in the example day of October 14, 2016, and Figures 17 to 23. Figure 16 shows substantially stronger positive wind pressure on the park-facing side (measuring point 3) while Figure 17 shows a slighter, negative pressure at the courtyard side (measuring point 5). Maximum local wind speed is at 5 to 10 m/s.
The hourly diagram in Figure 22 clearly shows the strong influence of the wind on the park-facing side: An average of +5.26 Pa (minimum –13.75; maximum +36.77 Pa) was recorded here. On the courtyard side, the average differential pressure during this hour was –1 Pa (minimum –11.04 Pa; maximum +2.22 Pa).

Because only local wind speed was recorded, however, information is missing on the direction from which the wind approached the building.

Influence of exhaust ventilation system (in operation from 2:30 p.m. till 4:00 p.m.) can not be recognized in the recorded pressure differences.

4.4 Frequency and Average Differential Pressure

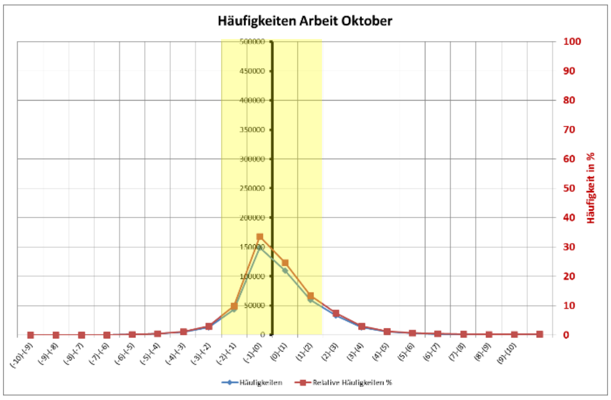


Table 24: October 2016, measuring point 3, frequency of differential pressures

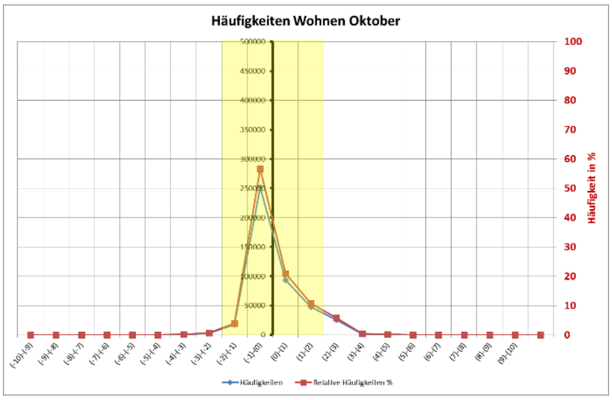


Table 25: October 2016, measuring point 5, frequency of differential pressures

		Avg [Pa]	Min [Pa]	Max [Pa]
October 2016	Living	0.12	–16.69	15.79
	Working	0.36	–41.95	40.95
October 9–15, 2016	Living	–0.4	–16.03	3.96
	Working	0.75	–13.75	36.77
October 14, 2016	Living	–0.86	–16.03	3.96
	Working	3.14	–13.75	36.77
Oct. 14, 2016, 3:00–4:00 p.m.	Living	–1.01	–11.04	2.22
	Working	5.26	–13.75	36.77

Table 1: October 2016, average, minimum and maximum differential pressure

It makes sense to calculate an average differential pressure over a period of time. Nevertheless the smaller this period, the higher the influence of individual values. Table 1 displays this clearly.

When the frequency is added up of values occurring within the range of –2 Pa to +2 Pa (area shaded yellow in Figures 24 and 25), measuring point 3 (work) produces a value of 81% and measuring point 5 (living) a value of 92%.

Largest frequency was recorded for negative pressure differences between 0 to -1 Pa. Due to the exhaust ventilation system and having the internal pressure as reference pressure highest frequency would be expected at positive pressure differences.
Any calculation of frequency or averages, however, includes the constant, intermittent, substantially stronger wind pressures to an only marginal extent, given their lower frequency of occurrence. The

fluctuation between positive and negative differential pressures also results in the pressures offsetting each other. Although strong fluctuations were shown between differential pressures, the average appears quite low.

Pressure extremes nevertheless result in infiltration/exfiltration over the building envelope that is well above the average differential pressure. They generate additional outflow/exhaust flow at ventilation system components. In this respect, it is insufficient to view averages alone without consideration of the pressure extremes. It is necessary to look more closely at the effects of these pressure peaks on the airflow over the building envelope.

5 BOUNDARY CONDITIONS – OBJECT 2

5.1 Measurement Object: Helgoland

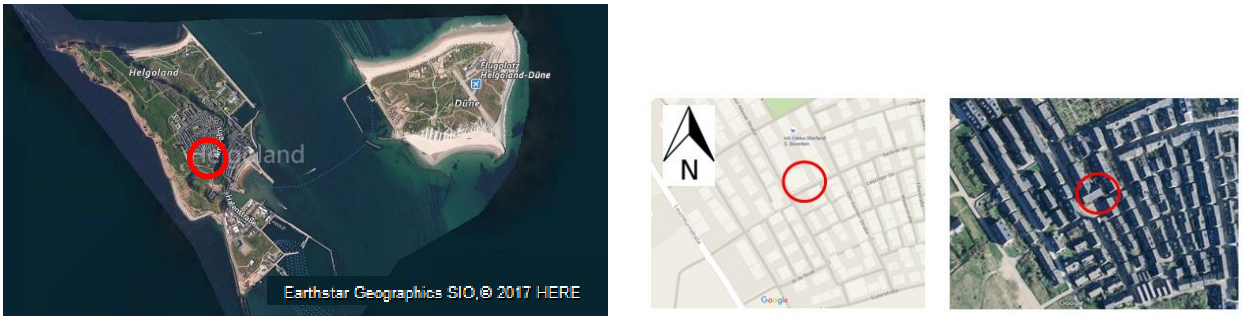


Figure 1: Location of measurement object, Helgoland Source: Google Maps and Earthstar Geographics SIO

Address:	Helgoland, Germany
Apartment location:	1st floor of a 3-storey more family house. The Southeast side faces to a place and a 2-storey building, the Northeast side to a 2.5-storey building, the Northwest side to a court and the Southwest side to a neighbor apartment.
Ventilation style:	Natural ventilation
Wind measurement:	logicenergy LeWL Windlogger Speed kit Measurement point: SE side of the building (balcony)
Outside temperature:	logicenergy LeWL Windlogger Speed kit Measurement point: SE side of the building (balcony)
Inside temperature:	Device: TEC APT and temperature sensor. Recording with TECLOG3
Differential pressure:	Devices: DG-700 with TEC WiFi Link and TEC APT. Recording and analyses with TECLOG3. Sample interval: 1 second Resample interval for this study: 5 seconds
Measurement period:	March 2016 to February 2017

5.2 Measurement Configuration

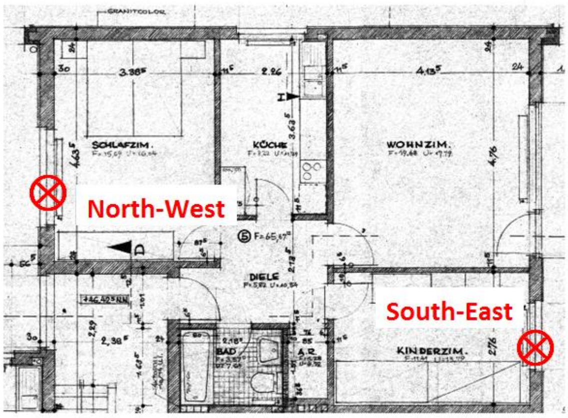


Figure 2: Location of Test Points for measuring the pressure differences

Figure 3: Test Point of Northwest-Side (left), Test Point of Southeast-Side (right)

Figures 2 and 3 show the locations of the two test points. One test point is located on the northwest side and the other on the southeast side of the apartment. At each side a differential pressure gauge measures the pressure difference between inside and outside at a window. Each gauge has two channels A and B that both are used in order to have a backup, if one channel shows problems (for example: water in a tube because of rain).
A capillary tube is placed between the window wing and window frame to get the outside pressure. In these tests the reference pressure is outside of the building. If the gauge or the graph shows a negative pressure inside of the room is a depression and outside of the facade an overpressure. A positive pressure means outside of the façade is depression and inside is an overpressure.

6 MEASUREMENT RESULTS: HELGOLAND

6.1 Wind Pressure

The diagrams in figure 4 show the building pressure differences of one apartment (1. floor) in a more family building on the island Helgoland in October 2016. The red graph shows the pressure differences of the room on the northwest side, the blue graph of the room on the southeast side. The sample interval is one second.
Figure 5 shows the wind speed in m/s (average per hour) for October 2016 from the DWD (Deutschen Wetterdienst) on Helgoland.

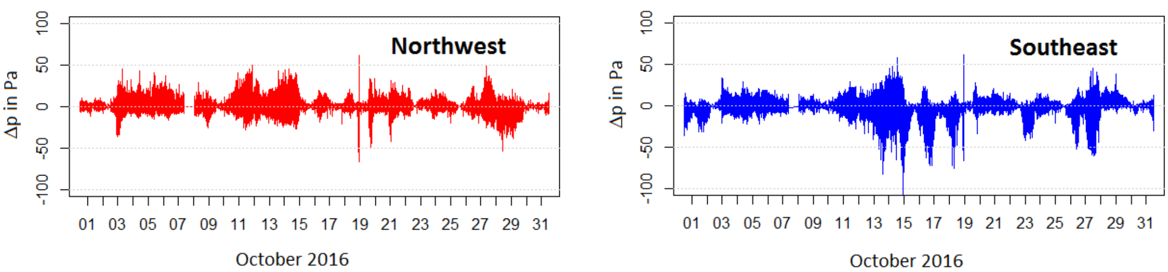


Figure 4: Pressure differences caused by wind on the façade of the building. Negative pressure differences = depression inside and overpressure outside. Positive pressure difference = overpressure inside and depression outside.

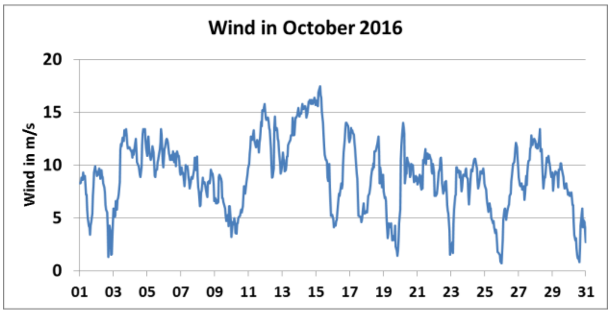


Figure 5: Wind on Helgoland in October 2016 (average per hour) (Source: DWD)

The pressure differences at the façade are mainly caused by the wind. As expected the pressure difference (figure 4) increases with increasing wind speed (figure 5).
On the northwest side the average of the pressure differences in October 2016 is 0 Pa. The maximum wind pressure on the façade is 66 Pa; the highest wind suction is -62 Pa. The average wind pressure is 2 Pa and wind suction is -2 Pa.
The southeast façade shows an average of 1.5 Pa wind pressure on the façade. The maximum wind suction is -62 Pa and the maximum wind pressure is 121 Pa. The averages for wind pressure are 4.3 Pa and wind suction -2.6 Pa.

It is obvious that the average of the wind speed in figure 5 doesn't explain all pressure differences in the diagrams. What is the reason? In this study the maximum wind speeds are missing and smaller intervals than an average over one hour could be helpful, in order to understand the peaks in the pressure differences. Additionally it is necessary to record the wind direction, because the pressure differences are depending on the direction of the flow on the façade, too.

An unexpected observation is the high fluctuation in a very short time of the pressure differences around more or less 0 Pa. It seems to be no steady wind on a certain level. The next chapter will show this in detail.

6.2 Wind Fluctuation

Figure 6 shows the pressure differences of 14th October 2016 and figure 7 the wind.

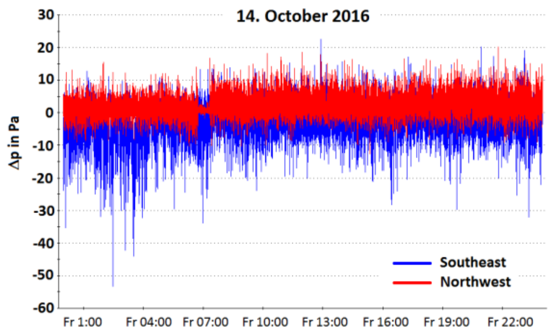


Figure 6: Pressure differences caused by wind 14th October 2016

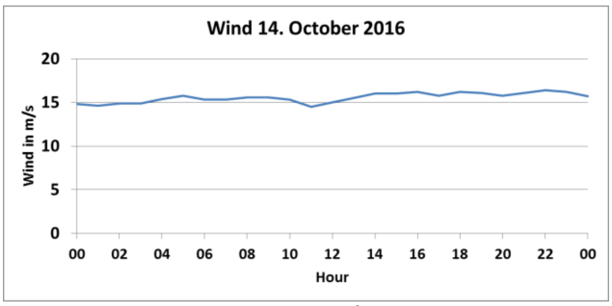


Figure 7: Wind on Helgoland 14th October 2016 (source: DWD)

The graph in figure 7 shows an almost steady wind of ca. 15 m/s (7 Beaufort) over the day. But the pressure differences in figure 6 (Northwest) vary over a range of 15 Pa between 5 Pa wind pressure on the façade and 10 Pa wind suction. The fluctuation on the Southeast side is even 30 Pa and higher. Also in this case it would be helpful to have a smaller resolution of the wind measurements.

Around 7 am the pressure differences on the Northwest side are much lower than on the Southwest Side. This is caused by an open window in the room on the Northwest side. It is interesting to see that this has more or less no effect on the other side of the apartment.

In figure 8 the graph shows the pressure differences over one hour between 3 pm and 4 pm of 14th October. Also here is the fluctuation visible.

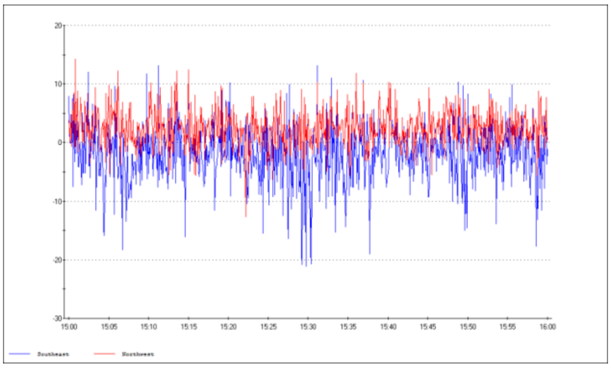


Figure 8: Pressure difference over one hour caused by wind of around 15 m/s

7 CONCLUSIONS

The recorded pressure differences show a great dependence on the wind speed and the direction of flow on the building. It is interesting that the pressure differences fluctuate strongly at very short intervals. A constant pressure over a certain time could not be observed. The temperature differences play a subordinate role or no role in these measurement objects.

The influence of the exhaust ventilation system on the measured differential pressure is visible at low wind speeds and is about 2 to 3 Pa. However, since a measurement of the exhaust airflow did not take place, it is not clear how high the exhaust airflow was at the measurement time point. Depending on the exhaust airflow, a differently high differential pressure in the dwelling will occur. However, this connection has not been included.

A reference of the measured differential pressure to the maximum wind speed is achievable, due to the measuring interval of the local wind speed measurement of 1 minute, not all wind peaks are recorded. Visible is only the greatest wind speed in the respective minute interval. The recording interval during the pressure measurement during those recordings is 1 or 5 seconds. A direct comparison between the differential pressure tip and the wind speed peak is thus not possible.

A difference in pressure between the positioning of the pressure receptacle on the window reveal and the window surface is not detectable.

On the facade of the park, higher differential pressures can be measured than on the courtyard side oriented towards neighboring buildings. However, since only the local wind speed has been recorded, the wind direction from is missing.

With a frequency consideration or averaging, the constantly occurring alternating wind loads, which reach significantly higher values, enter into the result only with a low value due to the lower frequency. The pressure fluctuations between the positive and the negative pressure also cancel one another in the mean value. Although strong fluctuations in the differential pressure are recorded, the average value is very low. In this respect, an average consideration without appreciation of the pressure peaks is not sufficient. In addition, a more detailed consideration of the effects of these pressure peaks on the volume flows over the building envelope is required.