# The impact of wind gusts on air infiltration in buildings

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## SUMMARY

Air infiltration holds a central role in building energy consumption and is associated to several building physics phenomena. Air infiltration in buildings due to wind-induced pressure is a complex process, strongly influenced by the turbulent nature of wind. This extended summary highlights the findings of a series of studies with focus on unsteady wind and its impact on air exchangesin buildings. The focus is on wind gustiness and its relation to air infiltration under natural conditions. Wind spectrum analysis shows that high-frequency wind gusts provide important information, while only considering mean wind speed and direction are not adequate to predict air exchanges in buildings. The impact of gustiness becomes greater for evenly distributed leakages between windward (upstream) and leeward (downstream) façade. Infiltration measurements under unsteady wind can vary significantly from results estimated based on pressurization measurements. In addition, wind gustiness is responsible for large pressure differences across leakages, thus it can affect the results of leakage numbers and the uncertainty of such measurements especially when the measurement point is low.

## KEYWORDS

wind-drivenair infiltration; unsteady wind; gustiness; spectrum analysis; air leakage

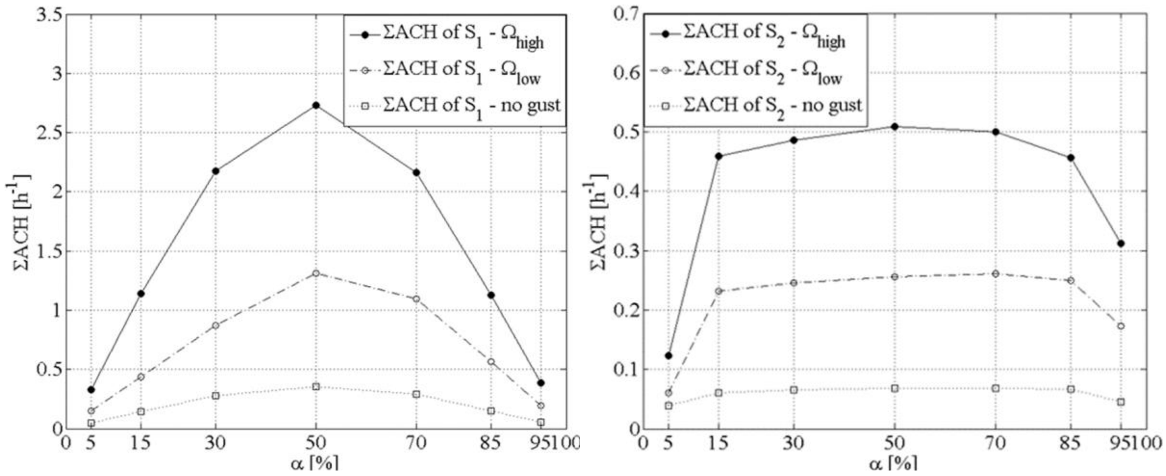
## 1 INTRODUCTION

Air infiltration is defined as the uncontrolled or unintentional flow of outside air tothe internal space of a building through leakages in the envelope, typically cracksand/or large leakage areas (e.g. Chan *et al.*, 2013). Wind-induced pressure, stack effect and mechanical ventilation are the direct forces causing airflow in buildings. The unintentional nature of air infiltration and the complex aerodynamic phenomena that may occur around buildings or may govern the flows across small cracks (e.g. Walker *et al.*, 1998) has led to assumptions employment. In steady-state models, all the three driving forces as well as the resultant air flow through openings/cracks are taken into account by their mean values. For simplicity reasons, it is usual that the wind characteristics are expressed by a typical mean value at a reference height (Orme et al., 1998), i.e. the height of the roof or the height of the meteorological instrumentation (10 m). In other words, the fluctuations of input parameter values, i.e. velocity, direction etc., are not considered. Air infiltration in buildings due to wind-induced pressure is a complex process, strongly influenced by the turbulent nature of wind (Haghighat et al., 2000). Mostof the models and studies exclude the dynamic nature of air infiltration, despite thefact that Hill and Kusuda (1975) have pointed it out decades ago.

This extended summary highlights the findings of a series of studies with focus on unsteady wind and its impact on actual air infiltration rates in buildings (Kraniotis, 2014a). Wind gustiness is under investigation and to this purpose both numerical (Computational Fluid Dynamics - CFD), experimental (tracer gas) and mathematical techniques (wind spectrum analysis) have been used. In particular, by employing the latter the aim to study the wind spectral density in different frequencies and moreover whether high-frequency wind gusts can relate to air infiltration rates.

## 2 RESULTS

The research conducted highlights the importance of dynamic characteristics of wind for a realistic estimation of air infiltration rates of buildings. Despite the value and the usefulness of artificial steady state techniques (pressurization methods) to evaluate the airtightness level of an envelope, the in-situ air exchanges can significantlyvary under natural conditions.
A CFD study (Kraniotis*et al.*, 2014b)that simulates a periodic wind gustiness, shows that by holding mean wind speed and wind fluctuations amplitude same in different cases, wind gust frequency significantly affects the infiltration rates (Fig. 1a and 1b). The impact is greater for evenly distributed leakages between windward (upstream) and leeward (downstream) façade. The total area of leakages in the building envelope is 128 $cm^2$ and the airtightness level has been estimated as $ACH_{50} = 1.5\ h^{-1}$. The results show that depending on the situation of the internal volume, wind gustiness can create high pressure differences of same magnitude as a pressurization test at 50 Pa. The latter implies that unsteady wind can strongly affect airtightness measurements when performed during a wind day, i.e. $\bar{U} = 5$ m/s, which is characterized by high-frequent gusts, i.e. f = 0.5 Hz (Fig. 1a). Fig.1b shows that even low-frequent gusts, i.e. f = 0.1 Hz can result in approximately 15% of ACH that a pressurization test would result.



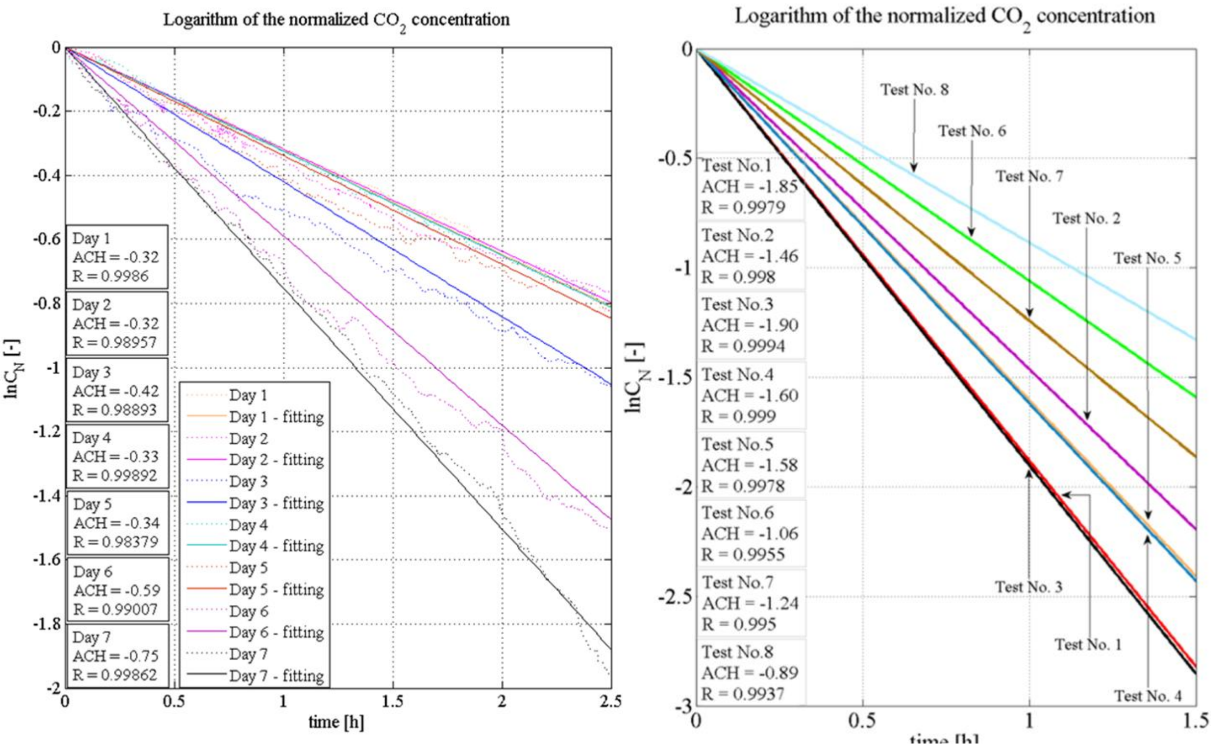

(a) (b)

Figure 1:Air exchange variation with leakage distribution under three different wind-gustiness scenarios (Kraniotis *et al.*, 2014b). a) single-compartment building. b) double-compartment building of same volume as (a), while internal leakages of 8 $cm^2$ have been considered in the partition walls.

Carbon dioxide as a tracer gas has been used in these studies in order to quantify air infiltration rates. The results of two building-cases are shown in Fig. 2. It is clear that there is a significant variation among rates in each case. With the help of an ultrasonic anemometer, the turbulent wind and in particular wind gustiness has been analysed. In ventilation studies, Fast Fourier Transform (FFT) is often employed in order to derive a spectral analysis of the data and consequently to gain additional information about the wind energy distribution with respect to frequency (Newland, 1975):

$$S(f) = |v'(f)|^2 = \left. \int_{-\infty}^{\infty} v'(t)e^{-ift}\,dt \right|^2 \quad (1)$$

where, i.e. for the current project, *S* is the wind energy, *f* the frequency, *v'* the fluctuations of the wind orthogonal velocity *v*, *t* the time and *i* the imaginary unit.




(a) (b)

Figure 2:Decay of logarithm of the normalized carbon dioxide concentration $C_N$with time. a) tracer gas measurements in an office room of a building (Kraniotis *et al.*, 2014c), b) tracer gas measurements in a cubic test box (Kraniotis, 2014a).

Fig. 3 shows the filtered wind spectral density $S_{yy}(f)$ for the case of the cubic test box. The results are linked to Fig. 2b. The findings of Fig.3 reveal that the wind spectral density in high-frequency region is important; wind events with high-frequency gusts have resulted in higher infiltration rates.

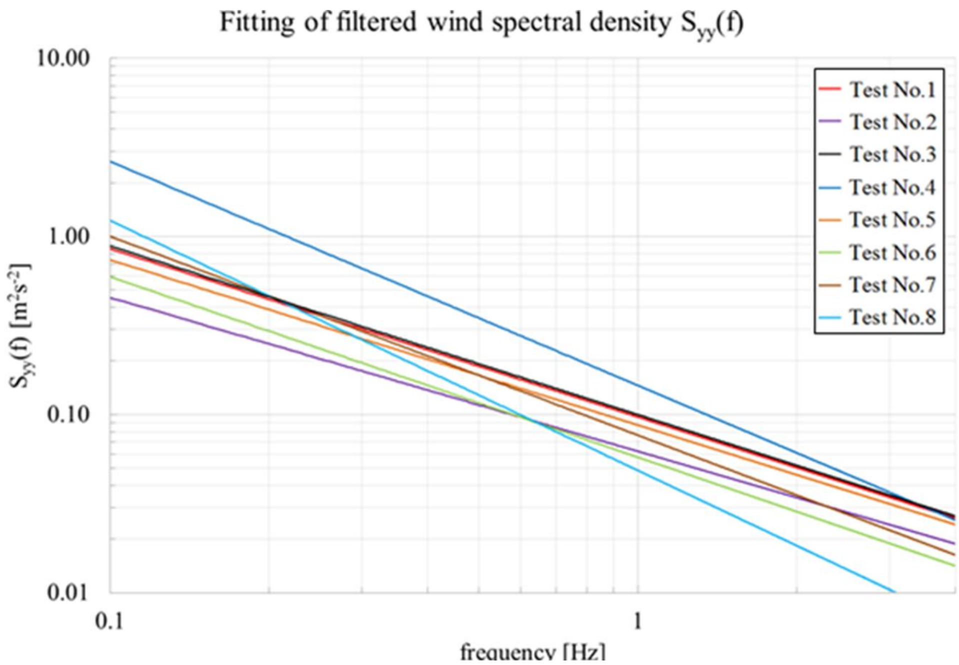


Figure 3: Filtered wind spectral density $S_{yy}(f)$ for the case of the cubic test box (Kraniotis, 2014a).

Despite the few samples, a multiple linear regression (MLR) that takes into account both gust frequency (gustiness) $G_c$ and gust strength $S_g$, along with wind direction $\theta_w$ and mean wind speed $\bar{U}$, has been tested (Eq. 2).

$$ACH = \alpha cos\theta_w + \beta\bar{U} + \gamma G_c + \delta S_g + c \quad (2)$$

High value of $G_c$ implies that high frequency fluctuations have occurred over a period of time. The second variable, $S_g$, gives the normalized cumulative strength of these events, providing a magnitude of the amplitude of the wind fluctuations that $G_c$ refers to.

Fig. 4 shows the prediction of air exchanges is more accurate when high-frequency wind gusts are taken into consideration. When the gust analysis and the dynamic phenomena were studied on a 1s time interval basis the agreement between the regression analysis and the experimental results was very good. Analyzing the wind data on a 2s-basis, it results in good agreement as well. However, when using 1min or 10min as intervals the predicted values of ACH show moderate agreement with the MLR. In particular, for the tests No.1 and No.3 with the highest ACH and the highest wind gust frequencies (Fig. 2b) the 1min- and 10min-models shows their worst performance. It is remarkable that when the prevailing wind direction angle is oblique and not normal to the crack, these two models provides fairly good predictions, but still worse compared to the 1s- and 2s-models.

It very likely that increasing the time interval causes lack of the high frequency dynamic wind phenomena. Especially when the dominant wind is flowing normal or in small oblique angles to leakage paths, small-interval gusts should be considered. Otherwise, less dynamic data i.e. 1min or 10min intervals for the wind gusts could be enough.

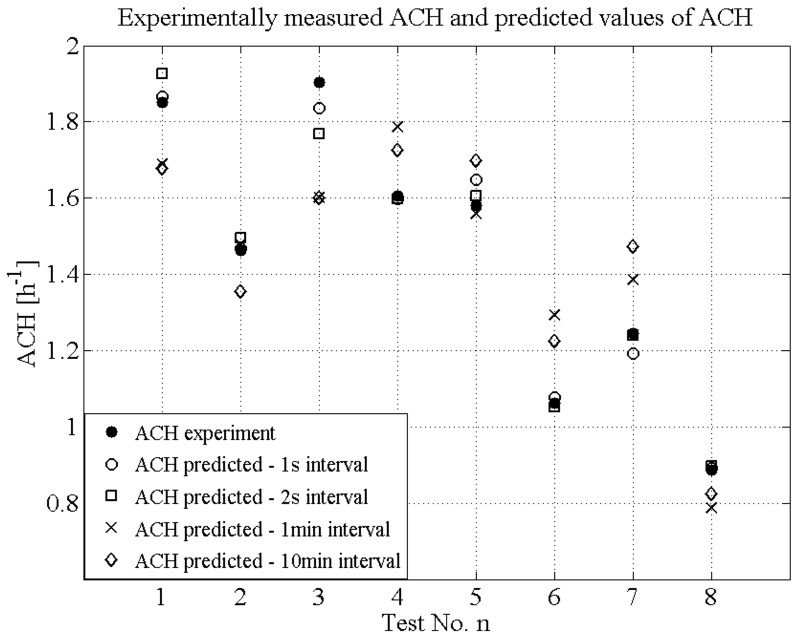



Figure 4: Experimentally measured infiltration rates and predicted values of ACH when 1s, 2s, 1min or 10min are used as time interval for depicting the wind gust phenomena (Kraniotis, 2014a).

## 3 REFERENCES

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