LARGE BUILDINGS AIRTIGHTNESS MEASUREMENTS USING VENTILATION SYSTEMS

Szymański Michał*[1], Górka Andrzej[1], Górzeński Radosław[1]

[1] Poznan University of Technology
Pl. Sklodowskiej – Curie 5
60-965 Poznan, Poland
**Corresponding author: michal.szymanski@put.poznan.pl*

ABSTRACT

The airtightness test of the building is one of a few building envelope measurements used in practice, which is quantitative, not just qualitative as e.g. infrared thermography. The so-called blower-door test result may be a measure of the building design and construction quality and could also be used for the energy demand for heating and cooling analyses.
With the development of energy-efficient buildings, the awareness of the airtightness importance increases, which results in a growing number of measurements of small and mid-size structures. Due to the high cost and limitations in availability of measurement equipment, tests of large buildings are relatively uncommon. Sometimes in the existing buildings the leakage measurements could be conducted with the use of ventilation systems, which is allowed by the (EN 13829) standard. For this kind of tests one can use the measurement of the air flow rate at fans (fan nozzles), at variable air volume terminals (VAV) or in the duct system. The accuracy of the air flow measurement is crucial in these cases.
Attention should be paid to a number of aspects related to the building preparation and the test procedure. The problems of large buildings leakage tests are discussed in this paper, as well as typical design and workmanship mistakes. This paper presents the methodology and results of airtightness measurements of the selected facilities envelopes using a ventilation system in comparison to blower-door set.
In the case of multi-zone airtightness measurements, the ventilation system is suitable to generate an appropriate pressure in the adjacent zones. Another application is the coarse testing of the airtightness of the building, when the result of the measurement can be approximate. In the case of final measurement of the airtightness of the building with the use of ventilation system, the biggest problem is the reliable measurement of the air flow rate with the accuracy required by the standards. Measurement of airtightness of large buildings with use of existing ventilation system can be completed correctly in some cases, however, to obtain accurate results more expertise and effort are required than in the case of measurement with a set of typical blower-door fans.

KEYWORDS

large building airtightness, envelope air permeability, air leakage, blower door, air handling unit (AHU)

1 INTRODUCTION

Measurements of airtightness of large buildings usually require huge air streams during the test. In the case of standard blower door fans (BD) use for testing of a large building, a set of multiple devices must be built. Large fans (100.000 – 300.000 m³/h pro unit), powered by combustion engine and mounted on truck or trailer, are rarely used.
In the case of multi-zone buildings, each zone can be tested separately. Thereby the necessary number of fans is reduced, but air pressure in all adjacent zones must be equal to the tested zone, to eliminate the air flows between zones. Existing ventilation system can be effectively applied for this task, the air flow does not need to be measured, however, the possibility of

individual control of dampers and fans in the air handling units (AHU) is necessary, which often requires the cooperation with the facility technical staff.
Reduction of the test cost leads to a use of ventilation systems also directly to the measurements. Here, however, arises the question of air flow measurement accuracy. According to the European Standard (EN 13829), the accuracy of the device for measuring of air flow rate should be ± 7% of the measured value or better. In practice, the airflow can be determined, e.g. as a function of differential pressure measured at the inlet nozzle of the fan, but this applies almost exclusively to diagonal fans (axial-radial fans). Manufacturers of this type of fans declare the measurement accuracy worse than required by the standard (EN 13829) and the declared measurement accuracy is achieved only if the manufacturer of air handling unit (AHU) follows the guidelines for the clearances from other elements of AHU (Ziehl-Abegg, 2013). Another problem is the lack of continuous reading and recording of the measured air flow rate.
When using air handling unit fans to pressurize/depressurize the building, a problem regarding continuous reading and recording of the measured air flow may occur. In the case of AHU integrated in a Building Management System (BMS), recording of the variables with use of BMS is usually possible, but mainly with some constraints – e.g. low refresh rate and discretization of the measured values.

2 LARGE BUILDINGS AIRTIGHTNESS MEASUREMENTS

Large buildings are often much more complicated than single-family houses and equipped with lots of installations (except of warehouse buildings).
Compared to measurement of small buildings, testing of large buildings - especially in the case of public buildings – require:

a) more equipment and
b) higher labor input,

but also

c) better familiarity with a building and its technical equipment and
d) deeper understanding of the laws governing the air flows in the building.

To avoid the costs associated with the use of a large number of fans (BD), some measuring teams try to perform an air leakage test using the existing ventilation systems in the building, which is permitted by the standard (EN 13829). Sometimes, even with an adequate amount of equipment, one can forget about the points b) ÷ d) and this could be a source of measurement errors many times larger than the result of allowable measurement errors of air flow and differential pressure.

2.1 Preparation of the building

The influence of building preparation on the result of measurement is high. In the case of large buildings, the provisions of the standard (EN 13829) raise objections concerning the sealing of mechanical ventilation systems. Recommendation of diffusers and exhaust terminals sealing is sometimes very difficult to perform or practically impossible.
In the case of method A (testing of an operated building), most commonly the installation is cut off by closing the dampers on the side of the air intake and extract. This corresponds to the period of standstill of the building ventilation system (e.g. during the night), and do not introduces an error resulting from the ducts leakages, which in the case of ducts within the enclosure of the building, does not affect the air infiltration at normal operation.
Comprehensive preparation of the large building consumes in most cases much more time than just testing and leakage detection.

In practice, due to the lack of education in the area of building construction and installations, you can meet the contractors, who underestimate the role of this stage and concentrate only on achieving of appropriate levels of positive and negative pressure during the measurement.
Effect of this approach is getting results differing from the real airtightness of the object, an example of which is described in Section 4.

2.2 Location of air leakages

Large buildings are often characterized by a large number and variety of air leakages, also located in difficult to reach or inaccessible places. This requires leakage detection techniques different than for small buildings. Instead of smoke tubes and hot-wire anemometers, rather infrared cameras, as well as powerful smoke generators are mainly used.
Appropriate lifting equipment and permissions required by legal regulations to work at heights are also often necessary.

3 SPECIFIC NATURE OF AIRTIGHTNESS MEASUREMENT USING EXISTING VENTILATION SYSTEM

3.1 Introduction

Measurements of the building airtightness using air handling unit fans are rarely reported in the literature. There is a dedicated Canadian standard on this issue (CGSB-149.15) and some of the literature, of which the most important may be considered (Jeong, 2008) and (Kim, 2013).
The airtightness test performed with use of the ventilation system differs from standard measurement using BD fans mainly by the method of movement of the air (AHU fans instead of BD fans) and by the method of the air flow rate measurement. The measurement of the pressure inside the building envelope can be carried out in a standard way. In large or complex, low-energy commercial/educational buildings, the maximum air flow rate of the existing mechanical ventilation is more than enough for the realization of airtightness test. In the cases described below, the air change rate induced by the ventilation system were 2.8 h^{-1} and 2.1 h^{-1}, and the results of the airtightness test n_{50} were 0.6 h^{-1} and 0.3 h^{-1}. This means that the performance of the ventilation system was 4 ÷ 7 times higher than the performance needed to conduct an airtightness test of the building, what is opposite to *Kim* (Kim, 2013).
The remaining problem is the precise measurement air flow rate supplied to the building. This measurement can be performed in the following locations:

a) on the air intake or air outlet,
b) on the elements of the air handling unit,
c) on the ventilation ducts upstream or downstream of the air handling unit,
d) on the supply or exhaust grilles (terminals of the ventilation system).

In the cases b) ÷ d) one should bear in mind the impact of airtightness of ventilation components and properly to take into account/ in the results.

3.2 Measurement of the air flow inside the air handling units (AHU)

The air flow passing through the air handling unit can be determined on the basis of e.g.:

a) measurement of the dynamic pressure at the inlet to the fan,
b) measurement of the differential pressure between the static pressures in front of the inlet ring and the static pressure in the inlet ring of the narrowest point (Fig. 1) (Ziehl-Abegg, 2013),

c) measurement of the average dynamic pressure at the place of the air filter replaced temporarily by measuring element (Fig. 3) (The Energy Conservatory, 2014).

Case b) has occurred in the building analyzed in section 5. The accuracy of the air flow measurement, declared by the manufacturer of the fan is 8%, and does not meet requirements of the standard (EN 13829). Moreover the declared accuracy of 8% is achieved only when the air velocity at the inlet to the fan is more than 9 m/s and when required clearances between the fan and other elements of the air handling unit are preserved (Fig. 1).
Case c) is a solution of one of the companies operating in the field of measurement of airtightness of buildings (Fig. 3) (The Energy Conservatory, 2014). The declared accuracy is 7% of the measured value, which meets the requirements of (EN 13829). This measurement can be useful also in other locations of the ventilation system, because of very small required clearances: 15 cm upstream and 5 cm downstream.

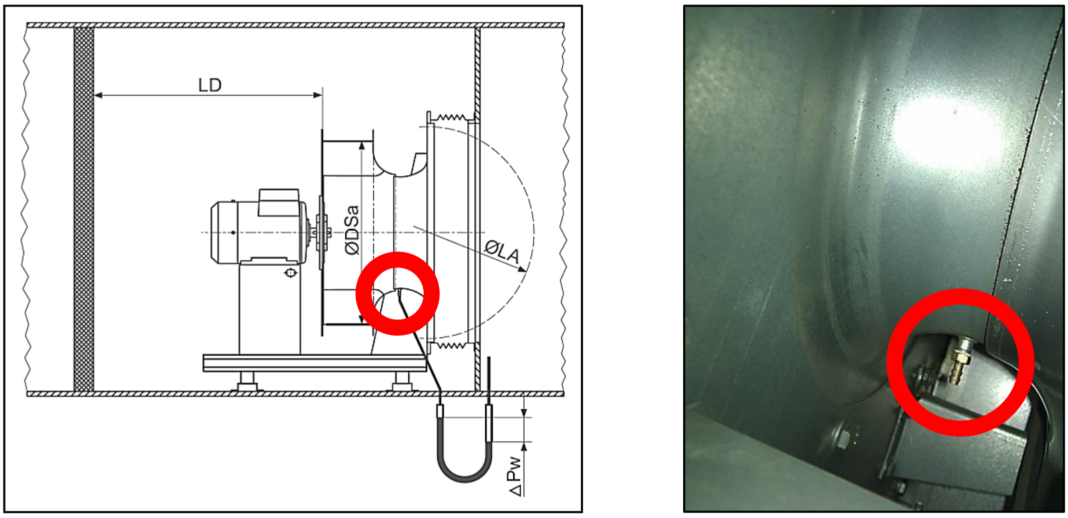
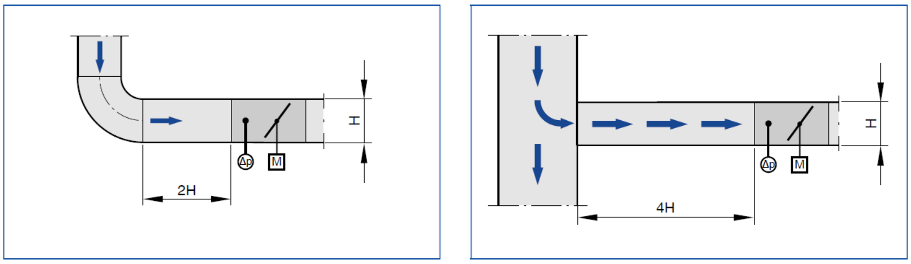


Fig. 1. Method of the air flow measurement inside AHU and location of the measuring connector (Ziehl-Abegg, 2013)



V/Vnom	Accuracy
20%	14%
40%	8%
70%	5%
100%	5%

Fig. 2. Mounting conditions of VAV controller for correct air flow measurement and its accuracy (Trox)

Fig. 3. Air handler flowmeter temporarily mounted in the place of air filter (The Energy Conservatory, 2014)

3.3 Measurement of the air flow using VAV terminals

The measurement of the air flow on the VAV controllers is attractive because these devices are factory-equipped with a sensing element that generates an analog output signal proportional to air flow. However, the accuracy is variable and satisfies the requirements of (EN 13829) only when the elements are correctly mounted and when the flow is higher than 70% of the nominal flow (Fig. 2). Additionally, the measurement of the air flow using the terminal devices of ventilation system should take into account the possible leakage of air in the ventilation system – it was estimated for the case described in Section 5.

3.4 Application of the Building Management System (BMS)

In a modern public building, equipped with mechanical ventilation and appropriately designed control system and BMS, it is theoretically possible to perform the airtightness test even remotely. The only task to do on site is to close external doors and windows, and open the inner door, which does not require skilled staff. With the use of BMS, appropriate dampers have to be closed and selected fans should be operated at variable speed to reach the desired pressure in the building envelope. The results of the measurement is obtained from BMS as a record of key parameters: air flow rates, differential pressures etc. Such a measurement would be performed according to the method A of (EN 13829) and would correspond to the actual state of unused building, which takes place at night or on weekends. In practice, such a method of measurement encounters serious problems, examples of which are described in Section 5. Nevertheless BMS system in a building can be an effective support when carrying out airtightness test using AHU fans.

4 AQUAPARK - POZNAŃ

The tested building is a new, large waterpark, with an internal volume of about 200.000 m³ and the A/V ratio of 0.20 m^{-1} – see Figure 4.

Fig. 4. Aquapark (sports and leisure complex) – Poznań, 2011

The initial air leakage test was ordered by the investor in 2012 to measurement company, which used the existing mechanical ventilation system. The contractor declared the flow measurement accuracy at AHUs of ± 2÷5%, despite no such a data from the manufacturer. During the building preparation and the airtightness test, several mistakes were made. The most important measurement mistakes were as follows:

- three-zone test with no simultaneous pressurization of adjacent zones (uncontrolled flows),
- airflow measurement was performed with unknown accuracy and several ventilation systems (not involved in the test) operating,
- building not prepared properly for the test: conducted with no control on inter-zonal opening positions (doors), some windows were opened.

The final, control measurement with use of BD set-up was carried out in 2013, as a part of the research of Institute of Environmental Engineering, Poznań University of Technology (IEE PUT). The facility was divided for this purpose into two zones: A – recreation area, B – sports pool hall and office area (Fig. 5).The pressurization in the tested zone was made by seven blower door fans set. In the adjacent zone the pressure was maintained at the same level (±3,0 Pa) with use of AHUs. Measurement of the flow rates on the fans (registered by the central BMS), gave the opportunity to compare the results for both zones, using concurrently Blower Door units and air handling units of unknown accuracy.

Table 1 presents the results of the primary and control measurements.

Table 1. The zone measurements results of the aquapark building V≈200.000 m^3

Year of measurement	Method of measurement	Accuracy of measurement	Adjacent zone pressurized?	Measuring team	n_{50} (h^{-1})	q_{50} ($m^3/(h \cdot m^2)$)
2012	AHU	unknown	No	External, 2 pers.	1,30	6,46
2013	BD	5%	Yes	IEE PUT*), 10 pers.	**0,64**	3,17
2013	AHU	unknown	Yes	IEE PUT*), 10 pers.	0,83	4,11

*) IEE PUT = Institute of Environmental Engineering, Poznań University of Technology

Considering the measurement with use of BD devices as a reference, for the entire facility the following indicators were obtained: n_{50} = 0,64 h^{-1} and q_{50} = 3,17 $m^3/(h \cdot m^2)$.

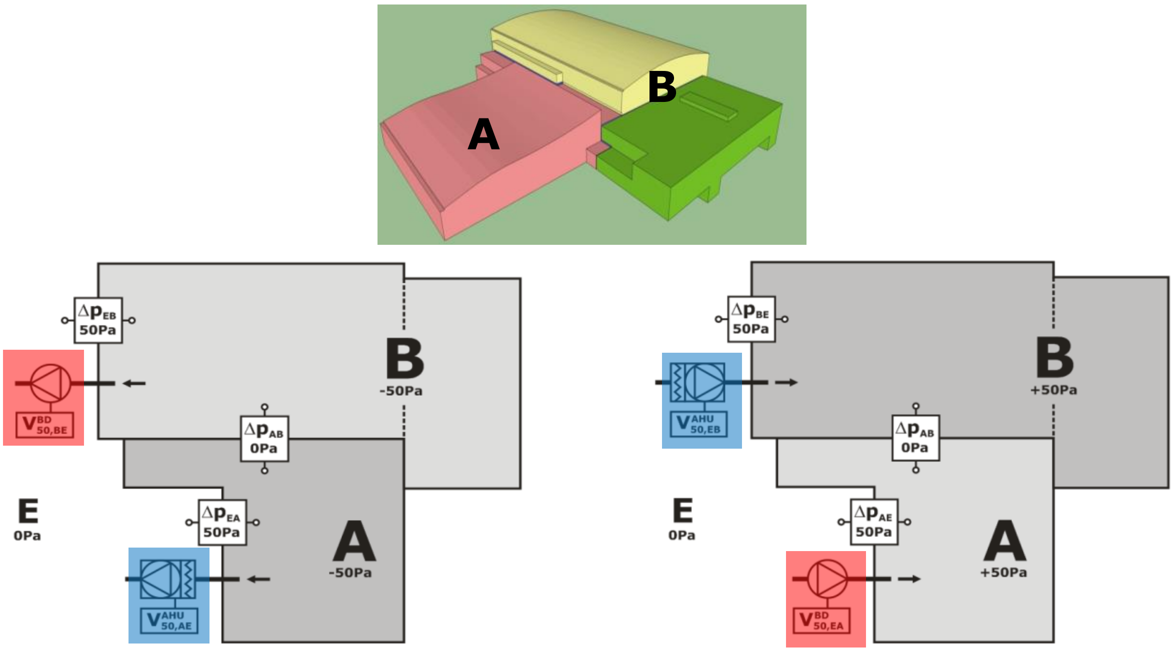


Fig. 5. Air tightness measurement with pressurization of adjacent zones (description: A, B - building zones, E - environment, AHU - Air Handling Units, BD - Blower Door); 3D model (middle); Sample measurements using a Blower Door for underpressure in zone B (left) and the overpressure in zone A (right)

The results obtained with the ventilation system use, with adjacent zones pressurized, are about 30% higher (n_{50} = 0,83 h^{-1}). It should be noted however, that the accuracy of airflow measurement in air handling units was not determined.

The primary measurement, performed in 2012 by the external test company, with the mistakes listed above, gave the result (n_{50} = 1,30 h^{-1}) of more than twice higher than reference one.

5 EDUCATIONAL AND RESEARCH BUILDING - POZNAŃ

The Mechatronics, Biomechanics and Nanoengineering Centre (MB&N) is a facility used for educational and scientific (research and development) purposes, with an internal volume of about 50 000 m^3 and the A/V ratio of 0.20 m^{-1} – see Fig. 6.

Fig. 6. Educational and research building – Poznań, 2011

The building is equipped with 36 supply-exhaust ventilation lines and 40 exhaust lines, the total supply air flow is approximately 118.000 m³/h (2,3 h^{-1}). During the building commissioning process, the airtightness test with use of BD devices was properly carried out. After three years, in 2014, as part of research conducted by IEE PUT, the airtightness of the building was re-tested in two ways:

a) with use of BD set-up,
b) with use of ventilation system and BMS (air flow readings from VAV terminals).

The summary of measurements results is presented in Table 2.

Table 2. The measurements results of the educational building V≈50.000 m^3

Year of measurement	Method of measurement	n_{50} (h^{-1})	q_{50} ($m^3/(h \cdot m^2)$)
2011	BD	**0,30**	1,18
2014	BD	**0,44**	1,70
2014	VAV	0,54	2,07

Leakages in the building, during the first three years of operation increased by almost 50%. Major leaks were caused by ventilation dampers and their actuators damages as well as windows and doors damages.
The accuracy of VAV controllers installed in the building, according to the manufacturer's declaration, is 5-14% when properly assembled - Figure 2.
The measurement error resulting from the ventilation ducts leakages was estimated, based on the surface of ventilation ducts and their air tightness class, for about 2%. Possible leakages of the duct system would cause an underestimation of the test results in both cases, pressurization and depressurization.
The measurement with VAVs was more labor-intensive than using the BD, because of the need to manually adjust the ventilation system components. It was not possible to use the full capabilities of the BMS according to the approach described in section 3.4, mostly because of:

a) air intake and extract dampers are controlled by a common signal from the BMS - it is not possible e.g. remotely open intake damper and while closing the extract,
b) air handling units have safeguards to ensure equal supply and exhaust air flows - for example, it is not possible remotely turn on a supply fan with exhaust fan turned off.

Accordingly, dampers and fans control was carried out mainly in manual mode, and the BMS system was used primarily for data acquisition, on the air flow and pressure in the building – Figure 7.

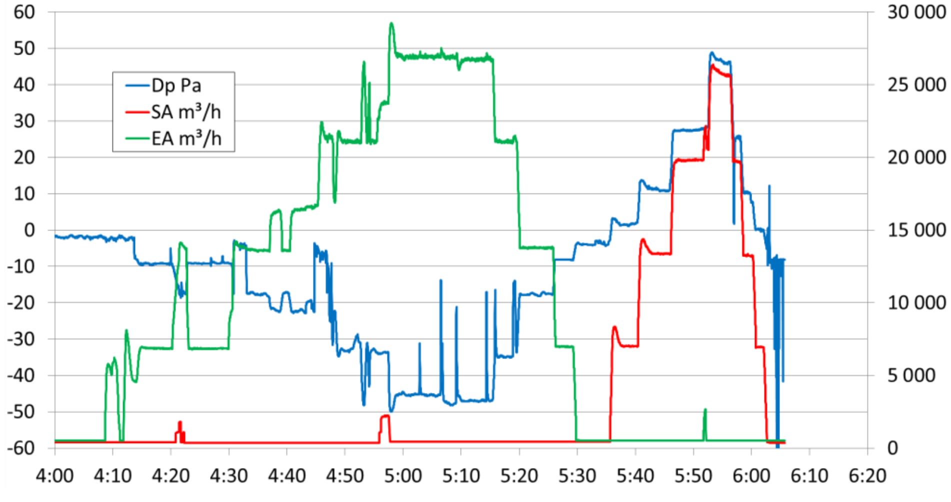


Fig. 7. Example data: air flows (SA – supply air, EA – exhaust air) and pressure difference (Dp) recorded by the BMS during the airtightness test.

6 CONCLUSIONS

Large buildings airtightness measurements using ventilation systems is a method acceptable by the (EN 13829) standard. It allows to conduct the airtightness test of a large building without application of blower-door fan set-ups, which can reduce the cost of the test. The accuracy of the air flow measurement is crucial in these cases. For this kind of tests the air flow rate can be measured at air intake, at fans (fan nozzles), at variable air volume terminals (VAV) or in the duct system. Standard equipment of the air handling units and of the ventilation system is often insufficient to achieve the desired accuracy of the measurement.

In the case of multi-zone airtightness measurements, the ventilation system is very suitable to generate a corresponding pressure in the adjacent zones. Another application is the coarse testing of the airtightness of the building, when the result of the measurement can be approximate. Measurement of airtightness of large buildings with the use of the existing ventilation system can be completed correctly in some cases, however, to obtain accurate results more expertise and effort are required than in the case of measurement with a set of typical Blower Door fans.

Lack of knowledge of airtightness testing procedures on the side of clients results in accepting the measurements which are conducted in the wrong way and whose results are incorrect. Establishment of an association of persons or companies, carrying out airtightness measurements could ensure a proper quality of services provided on the market.

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