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Pressure difference in buildings with good air-tightness: control measurements after IAQ renovations

Katariina Laine[1*]

[1]Vahanen Rakennusfysiikka Oy, 02600 Espoo, Finland

Abstract. Improving air tightness of structures prevents uncontrolled air leaks and it can be used to solve IAQ problems in buildings, usually in combination with other renovation methods. When improving air tightness, the airflow rates of mechanical ventilation usually need to be readjusted to correspond to the changed airtightness of the envelope. In optimal situation the supply- and exhaust air volumes are balanced and the pressure differential is close to zero Pascal. The article presents several buildings (n=7, built 1986-2005, renovated 2012-2019), where air tightness has been improved and the mechanical ventilation / pressure ratio has been adjusted as a part of other IAQ renovations. The pressure difference measurements (duration 7…14 days) have been done three times after renovation: right after the renovation, after 2 years and after 5 years. In addition, the long-term functionality of the air tightness renovation has been tested at the age of 5 years both with visual survey and with a tracer-gas leak test. After 5 years, the structures had remained airtight and the sealing materials were found to be durable. Pressure ratio needed some fine adjustment in 30 % of the renovated areas, where monitoring was made right after the renovation. At the age of 5 years the pressure ratio range was acceptable (-5…+5 Pa) and stable in approximately 85 % of the renovated areas. In these airtight buildings, the major effect to the pressure difference was caused by the mechanical ventilation system. Pressure difference adjustment and stability was possible to reach in all studied buildings with careful maintenance.

1 Introduction

A typical implementation of a building envelope is not completely airtight. A good air tightness q_{50} value does not directly indicate efficient air tightness of single structures or rooms. There can be several air leakages in a building envelope and in other structures even with a good q_{50} value. A q_{50} value implements average airtightness of a building. The aging and use of the building further impair the airtightness. Common air leakage sites are found in e.g. the joint of ground slab and external wall and various inlets and seams of the building envelope. Typically, the airflow is from outside to inside the building caused by the building's pressure ratio. The building's pressure difference is determined by the combinatory interaction of wind, chimney effect and ventilation as well as the usage of the premises. The pressure difference will vary and can change very fast and strongly. As a result, the airflow conveys heat, moisture and impurities. In the external envelope structures and in the soil under building's ground slab there are commonly building material, outdoor and soil borne contaminants such as various types of dusts, microbes and their metabolites and radon, which can affect negatively to the indoor air quality when transported with the air flux into the room.

The aim of improving air tightness of structures is to prevent uncontrolled air leakages through structures. Several techniques have been implemented in order to prevent uncontrolled air flux through the structures since 1980's. When improving air tightness, the airflow rates of the ventilation system usually need to be adjusted to correspond to the changed pressure conditions. The target pressure ratio over the external envelope after the IAQ renovation is typically close to 0 Pa. The success of the IAQ renovation can be evaluated with control measurements. [1]

In the past, the national recommendation in Finland was to design ventilation systems that create a light underpressure in the premises to prevent moisture damages of external envelope due to condensation. Since 2017, the regulations guide to design new buildings with no harmful over- or underpressure. [2] However the underpressure should not exceed -15 Pa. [3] The target pressure ratio over the external envelope after the IAQ renovation in buildings with mechanical ventilation system is close to -2…0 Pa. [4]

There are no exact guidelines about pressure ratio target values or stability for existing buildings. Nevertheless, pressure ratio measurements are an established part and routine of indoor air quality condition surveys already for several decades.

* Corresponding author: katariina.laine@vahanen.com

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2 Methods

2.1 Background and IAQ renovations

The study material consists of seven 2-4 storey public school and office buildings built in 1986-2005. The prefabricated concrete buildings have external walls with brick facade, mineral wool insulation and concrete interior surface. Intermediate floorings are prefabricated concrete slabs and slabs on ground are concrete as well. Buildings have modern mechanical ventilation system. There were detected some IAQ related problems in the condition surveys implemented in 2011-2013. Inadequate airflow rates, mineral wool fibres, few local moisture and microbial damages in the structures and poor airtightness of the envelope structures were the most significant IAQ impairing factors. The aim of the renovations was to improve indoor air quality. The renovations were executed in 2012-2019 (22 440 m^2, 38 renovated areas). By 2019, the renovations were completed in 6 of the 7 buildings. [5]

The air tightness of the envelope structures was improved carefully as a part of the renovations. The air tightness of the envelope, as well as the partitioning walls and intermediate floors was improved. The airtightness was improved as well in separate storeys and even single spaces. The materials and methods were determined in the design documentation and the airtightening was implemented to cleaned, robust surfaces mostly with certified cement based waterproofing membrane. The life span expectation for the used materials is 25 years. The technical implementation was inspected in every room, including visual survey and tracer-gas leak test in a constant underpressure of -10…-15 Pa caused by mechanical ventilator (BlowerDoor). [6] All detected leak points were fixed. Minor leak was allowed only from the wooden window frame joints, which tightness changes with moisture differences.

Considerable changes to the mechanical ventilation system was made: fans were renewed, mineral wool based insulation materials were replaced and airflow rates as well the air distribution in the rooms was improved. Finally, the ventilation airflow rates were adjusted to correspond to the changed air tightness, aiming at pressure balance, ie. 0 Pa over the building envelope.

The buildings and the renovated areas are relatively comparable because of their similar structures, usage of the premises and the renovation methods and materials. In addition, the contractors, the project organisation, and the quality control methods were the same. The indoor air quality class was set as S2 for the projects. The quality class S2 assets target values e.g. temperature, CO_2 concentration and volatile organic compounds in the indoor air. [7]

2.2 Control measurements

All measurements were done according to the guidelines presented in Environment Guide 2016 [4]. Control measurements were performed after commissioning stage 6… 12 months, 2 years and 5 years after the renovation (Table 1). By the end of year 2019 there were 13 renovated areas, which were over 5 year old (A= 6918 m^2). In the table 1 are presented the used controlling methods and time. The aim of the control measurements was to evaluate the success of the IAQ renovations. The measurements verified the achievement of the set target values. In this article are presented only the pressure ratio measurements.

The control measurements included constant monitoring of temperature, relative humidity, CO_2 concentration and pressure differential ratio for 7…14 days period at 5 or 10 min data collection interval. Measurements were executed mostly during spring and autumn. The pressure ratio measuring devices were installed mostly through a window, or in some cases to the wall insulation layer through a borehole. Each of the renovated area (typically one storey of a building) had 2-4 devices installed to different facades.

Table 1. Control measurement methods and timeline.

Method	< 1 year	2 years	5 years
sensory survey (visual inspection)	x	x	x
dust samples (if mineral wool before renovation)	x		
indoor air temperature, moisture, CO_2 (measurement 7…14 days)	x		
pressure difference over envelope (measurement 7…14 days)	x	(x)	x
tracer-gas leak test (same method as on the construction site, random sample)			x
VOC, indoor air (if harmful values before renovation)		x	
radon (if harmful values before renovation)	x		
indoor air microbes (if microbe damages before renovation)	x		
structural moisture measurement (slab on ground)			x
user inquiry (when a building was completely renovated)			x

3 Results

3.1 Air tightness of the structures

The airtightness of the structures was tested 5 years after the renovation. Tracer-gas leak test was executed in five buildings (12 renovated areas), in randomly chosen 10 spaces. The tests were repeated exactly as at the commissioning stage. [6]

In the tracer-gas leak test the concrete ground slab in one large space (n=1, 75,5 m^2) was found to have remained airtight. A water pipe leakage accident had damaged the wooden flooring, which had to be removed and replaced, so it was possible to survey all the structures and materials beneath. The air tightening materials were in good shape and traction to the concrete was robust (fig. 1).

Fig. 1. Air tightening renovation made to concrete surfaces with cement based waterproofing at the age of five to six years.

In the external wall surveys (n=9, 77,5 m^2) the tracer-gas was supplied into the insulation layer. The inner surface of external walls was airtight except for wooden window joints. Three minor air leakages were detected. These were found from the elastic mass, which traction to the surface had impaired.

3.2 Pressure difference measurements

The main purpose of the pressure difference measurements was to evaluate the balance and the stability of the adjusted airflow rates. The results of the measurements done during the first year after the renovation and five years after the renovation are presented in figures 2-4. The data includes measurements from different floors, mechanical ventilation systems and cardinal directions. One bar-segment paragraph includes all measurement points during the measurement period.

The measurements presented in figures 5-8 were implemented in 2019 in one building (B). The renovations in different floors of the building were implemented in 2013-2019: part of basement 2013, 1st floor 2014, 2nd floor 2016, basement 2018 and 3rd floor 2019. In august 2019, the renovations in all floors, rooms and mechanical

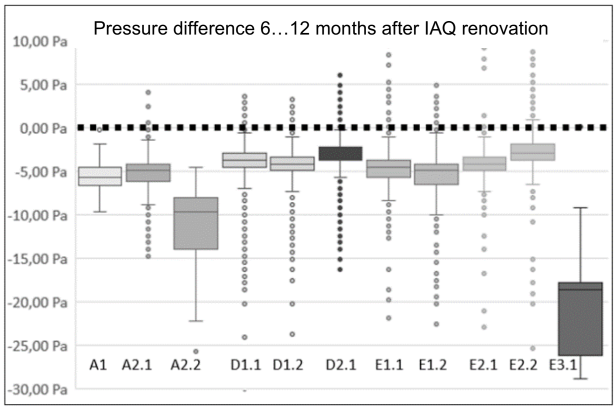

Fig. 2. Seven renovation areas measured during the first year after the IAQ renovation. Some areas had one measuring point, others two or more (e.g. A2.1, A2.2 are from same area).

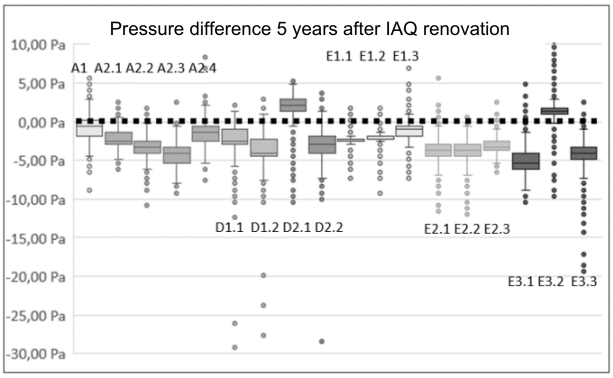

Fig. 3. Seven premises (same as in fig. 3) measured after five years from the IAQ renovation. Some areas have one measuring point, others two or more (e.g. E1.1, E1.2, E1.3 are from the same area).

ventilation were completed. The pressure difference measurements from floors 1-3 and basement were done at the same time. In addition, average wind speed and outdoor air temperature data was applied from Finnish meteorological institution. During the measurement periods, the rooms were used as usual (office usage) except for basement (storage) and the third floor, where the building users were moving back to the premises after the IAQ renovation.

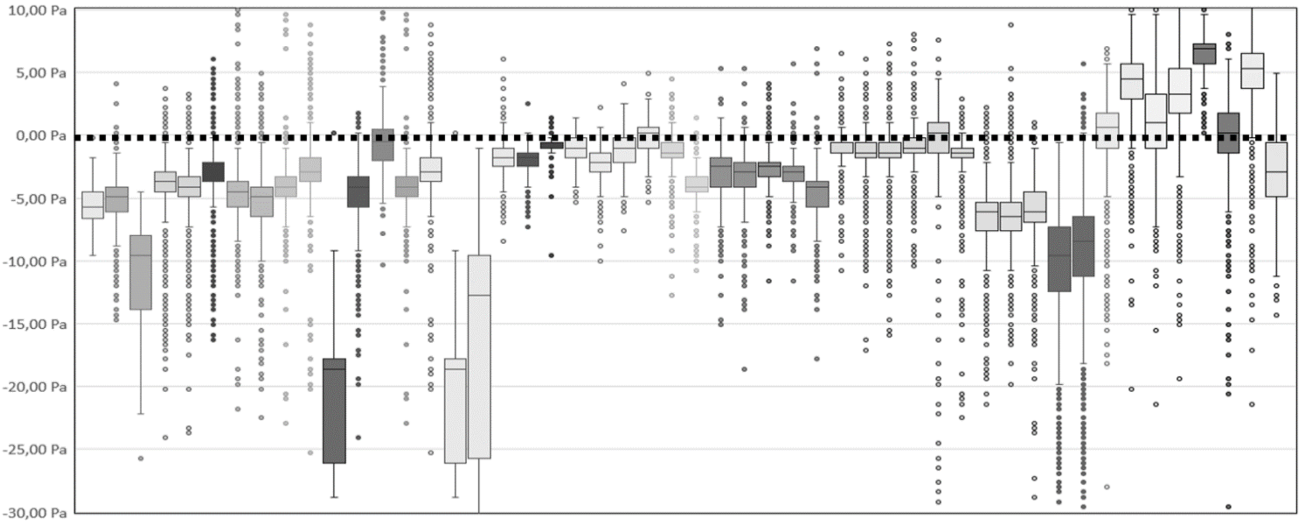

Fig. 4. Pressure ratio in 22 renovated premises measured 6-12 months after the IAQ renovation. There were 50 measurement points.

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In building B, the same mechanical ventilation unit serves the floors 1, 2 and basement. The third floor has its own unit. At the time of the measurement, both units were set to run with a 100 % power 24 hours, 7 days in a week. The toilets had a separate exhaust fans, which did run daytime 06.00-21.00 with 47 % power and at nights 21.00-06.00 with 30 % power. The aim of the increased ventilation on the third floor was to ventilate the spaces effectively during the first ~6 months after the renovation.

During 5.8-10.8 there was a weak north wind 2-3 m/s. It was rainy and east to northeast wind was blowing app. 4-5 m/s on the 11.-12.8. Weak east or northeast wind (app. 2-3 m/s) was blowing on the 13.-14.8.

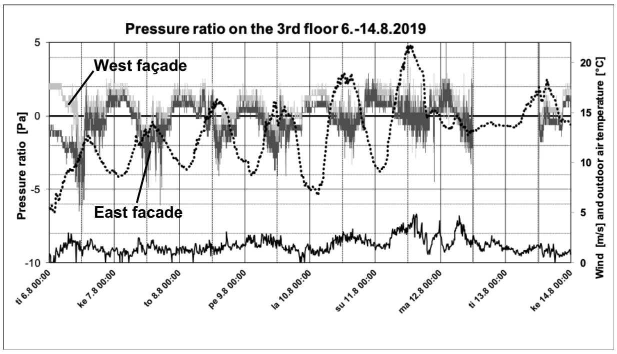

Fig. 5. Building B, floor 3. Pressure difference ratio, wind speed and outdoor air temperature on the 6.-14.8.2019. Wind speed is the thick black line and outdoor temperature is the black dot line.

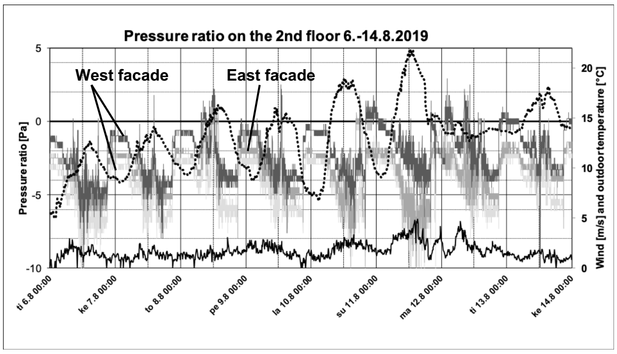

Fig. 6. Building B, floor 2. Pressure difference ratio, wind speed and outdoor air temperature on the 6.-14.8.2019. Wind speed is the thick black line and outdoor temperature is the black dot line.

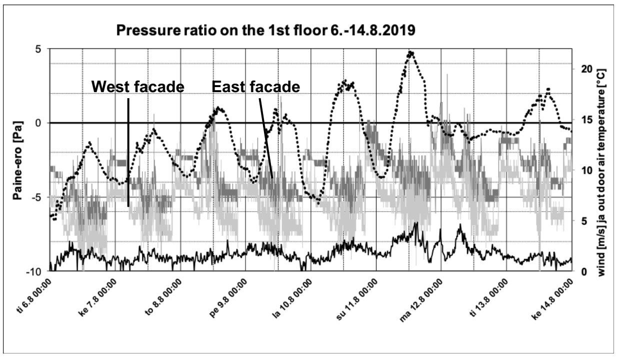

Fig. 7. Building B, floor 1. Pressure difference ratio, wind speed and outdoor air temperature on the 6.-14.8.2019. Wind speed is the thick black line and outdoor temperature is the black dot line.

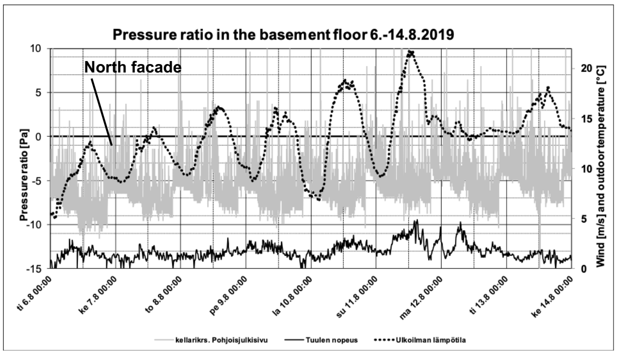

Fig. 8. Building B, basement. Pressure difference ratio, wind speed and outdoor air temperature on the 6.-14.8.2019. Wind speed is the thick black line and outdoor temperature is the black dot line. The constant change of the pressure ratio indicates of a technical fault condition in the ventilation system.

4 Discussion

The tracer-gas leak test revealed that the airtightness of the structures was good after a five-year period. The structures had remained airtight and the waterproofing materials were found to be durable. The observed airtightness and the impeccable condition of materials indicate durability, which lasts several years. The 25-year life span expectation is plausible.

In the figures 2 and 4 (pressure difference at the age of <1 year) unfavourable pressure differences can be seen in approximately 30 % of the measured spaces. There was a need for fine adjustment of the airflow rates. The figure 8 reveals a technical fault condition and a need for an inspection of the ventilation unit in the building B.

After five years, the pressure ratio range was smaller and more stable (figure 3). The pressure ratio remained between -5…+5 Pa approximately 85 % of the measured time. There was seen no need for further adjustments.

All measured data include periods of overpressure or underpressure caused by the constant influence of wind, usage of the spaces and the chimney effect. The weak wind (less than 5 m/s) during the measurements in 2019 did not disrupt the pressure ratio but stronger windiness creates more variation. Continuous large underpressure was not observed.

There was no significant difference in the pressure ratio measured from different facades or cardinal directions. The airtight external envelope impairs pressure effect of the wind effectively in separate rooms.

In the building B the time program changes of the mechanical ventilation unit had the most significant effect to the pressure ratio. A 17 % change of the exhaust fans airflow created app. 5 Pa difference to the pressure ratio. It is typical for airtight buildings that even a small imbalance in the supply or exhaust airflow can have a significant impact to the pressure ratio. It is not energy efficient to let the mechanical ventilation unit run with the 100 % power, but in building B it enables the stability of the pressure ratio. In this case, ensuring a good indoor air quality is a compromise on energy efficiency. It is obvious that the pressure differences change, when the ~6 months increased ventilation period is over and the time program of the mechanical ventilation unit and the percentages are changed. There will be need to repeat the measurements in future. However, in the studied buildings the developed automation system should allow stable and balanced pressure ratio also in the changed circumstances.

In general, the stability of the pressure ratio is more difficult to control in high buildings and in high spaces, like in stairways. This is caused by chimney effect, which is clearly seen in the measurements, especially in building B (fig.5 versus fig.7). It is not possible to compensate chimney effect with the existing ventilation systems in high spaces. Nevertheless, it seems that adjusting pressure difference close to 0 Pa is easier on the upper floor than on the ground floor or in the basement. All measurements from the upper floor indicate a better stability. This is a result of the chimney effect and more airtight building envelope. The airtight storeys and some airtight separate rooms make it possible to adjust pressure ratio with airflow rates. Stability of the pressure ratio can be easier to implement in an airtight building, because the windiness does not have as strong effect to the pressure ratio as in a building with poor airtightness. On the other hand, relatively small changes of the airflow rate or the usage of the premises can quickly create a strong under- or over pressure in an airtight building. In addition, technical failures of the mechanical ventilation can have a fast and strong influence to the pressure ratio.

It is known, that the pressure ratio varies also with the outdoor temperature changes. This usually occurs in the spring, when the temperature change is over 10 degrees during a day. This phenomenon was not verified in the measured buildings, mostly because of the timing and the shortness of the measurement period.

Stability of the pressure ratio has a major impact to the indoor air quality, when there are impurities in the structures. Therefore, balanced airflow rates and stable pressure ratio should be a target in every IAQ renovation. Separate target values of pressure ratio should be set for different types of buildings and spaces, because of different requirements and boundary conditions. There should also be guideline, when pressure ratio adjustment is successful and pressure ratio is stable enough. Because there is inevitable variation caused by various factors, tolerance should be allowed in the target values. Allowed measurement error and tolerance for the stability of the pressure ratio should both be defined.

Besides ventilation systems, outdoor air temperature, windiness, chimney effect and the usage of the premises, for example the cleanliness of the filters may have an impact on the pressure ratio. Uncontrolled measuring condition can provide limited information. Longer, at least 7-14 day constant, a couple of times in a year repeated measurement period would be more informative. The measurement period should include both weekdays and weekends. For a reliable measurement, measurement should be done during a moderate outdoor air temperature and the windiness should be less than 5 m/s.

The control measurements are important for verifying the set target values. Because the pressure ratio is sensitive to distraction in an airtight building, a control measurement is recommendable occasionally in premises, where the stability of pressure differences is important. In the studied buildings the airtight external envelope prevents the harmful air leaks, hence the stability of the pressure ratio in not that essential to ensure good indoor air quality.

5 Conclusion

The pressure difference measurements were useful in verifying the achievement of the target pressure ratio. In the measurements performed right after the renovations a more significant under- or overpressure was detected, which was mainly caused by the inadequately adjusted ventilation system. In general, after five years the range and stability of the pressure difference were adequate and close enough to the set target 0 Pa. A slight underpressure or periodic, harmless slight overpressure was seen in several spaces. More airtight envelope structures put greater demand on the performance of the ventilation. Even minor changes in air flow rates or fault condition can create significant instability to the pressure differences. Guidelines are inadequate at the moment.

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