COMPARISON OF DIFFERENT AIR TIGHTNESS AND AIR EXCHANGE RATE MEASUREMENTS IN A VERY SMALL TEST BUILDINGS

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ABSTRACT

The airtightness of the building envelope was studied in field measurements in recently constructed experimental small test buildings. Two types of research studies were carried out: the effect of special air tight sealing and the experimental determination of air exchange rate (h^{-1}) under real operating conditions. In very small buildings with many joints between materials and construction the role of the air tight sealing is very important; the experiments show changes in measured air tightness. Another parameter – air exchange rate has been studied in different test buildings using tracer gas equipment. Results obtained from this research show the real amount of exchanged air and it is very important to evaluate ventilation heat losses for low energy buildings.

KEYWORDS

Air tightness, airtight sealing, air exchange, tracer gas, test buildings.

1 INTRODUCTION

In frame of scientific project “Development of composite building walls constructive solution from the local materials by using multiphysical modelling according to the EU energy efficiency and optimal indoor climate requirements” (UL, 2013) five similar test buildings with internal dimensions 3×3×3 m were built in Riga, Latvia (Fig. 1). The main aim of the project is to compare constructions of different materials (wood, aerated concrete, ceramics, plywood, filled ceramics) with the same or very close heat transmittance ($U \approx 0.16\ Wm^{-2}K^{-1}$) in order to get the experimentally measurable effect of construction’s heat capacity and compare different annual moisture balance (Dimdiņa et al, 2013). Buildings are equipped with *Daikin Ururu Sarara* air-air heat pumps (Daikin, 3013), which provides heating, cooling and ventilation regime by adding amount of fresh outside air into the building.

First of all, the role of air tight sealing for all indoor joints was evaluated by using *Retrotec* blower door equipment at different construction stages for most critical log house. As the internal volume of those buildings is extremely small, using of standard fan may produce results with great uncertainty; therefore also small fan was used for standard air tightness measurements and obtained results compared.

In order to determine the real value of air exchange in room, which is an important factor to model the heat balance of a building and understand the ratio of conduction and convection heat losses, air exchange measurements using special *Lumasense* tracer gas measuring system are made. The obtained air exchange rates from long-term monitoring for different buildings were analysed.

Figure 1: Experimental test buildings

2 APPROACH

2.1 Air Tightness

To measure the air tightness of the test buildings, standard pressurization and depressurization tests at 50 Pa pressure difference were carried out using *Retrotec* blower door standard testing system (Retrotec, 2013) with 2 different fans (Fig. 2(a,b)):

- model 3000 with 56 cm fan, maximum flow 14440 m^3/h,
- model 200 with 38 cm duct tester fan, maximum flow 1155 m^3/h.

Two different fans were used to compare results obtained from fans with quite different workings flows. Due to very small building volume the biggest fan (model 3000) worked very close to the accuracy limits at very low flow rate, while the flow rate for model 200 was in the middle range. To exclude all possible small air leakages around the cloth door panel, which can be very important for so small buildings, an additional special air-tight membrane has been attached for system with fan model 200 (Fig. 2(c)) for some experiments.

(a) (b) (c)

Figure 2: Different *Retrotec* fans used for air tightness measurements: (a) – model 3000, (b) – model 200, (c) – models 200 with an additional air-tight membrane

As results of pressurization/depressurization two parameters are calculated:

- n_{50} – the air exchange rate at 50 Pa pressure difference (h^{-1}),
- q_{50} – the air permeability at 50 Pa pressure difference ($m\ h^{-1}$).

To visually detect typical air leakage locations and their distribution in the buildings at different construction stages infrared image camera *Flir P620* (FLIR, 2013) was used together with blower door system. Thermography surveys were conducted twice to determine the main air leakage locations and intensity: first, before inside finishing is done, and then after air tight sealing is completed.

2.2 Air Exchange Rate

The main aim of ongoing project is to determine and analyse energy consumption for all test buildings, therefore it is very important to evaluate all the heal losses. One of them is convection heat losses through ventilation opening, which can be characterized by knowing air exchange rate in the room. Tracer gas method (Laussmann and Helm, 2011; ISO 12569, 2012) and special measuring system *Lumasense* (Lumasense, 2013) including multipoint sampler/doser *Innova 1303* and photoacoustic gas monitor *Innova 1412* are used for this purpose (Fig. 3).

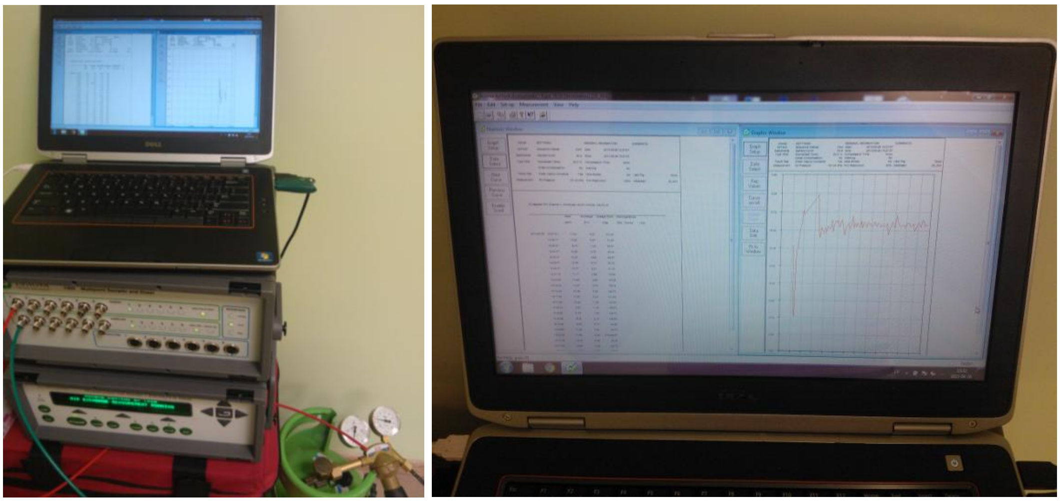

Figure 3: System and software used for tracer gas air exchange measurements

As the air volume in the room is only 27 m^3 and the expected air exchange value is small, a constant concentration method (ISO 12569, 2012) is used for long-term, continuous air change rate measurements. The principle of this method is to track the amount of tracer gas $F($ required to maintain it at a constant concentration $n($ at a constant level. To ensure better tracer gas mixing, an additional small-sized fan is used near the used doser nozzle.

3 RESULTS

3.1 Air Tightness

To control the air tightness at different construction stages, log test building is chosen with many wood construction joints, which are filled with a rubber spacer. Primarily, the air tightness measurements were carried out at the first stage of build-up process, when some places in building structures were not air-tight, e.g. window-sill is not fixed (Fig. 4(a)). After the interior finishing (Fig. 4(b)), the next air tightness measurements were carried out. Finally, the last experiments were made after all joints between materials and constructions are tightened with permanent airtight sealing (Fig. 4(c)). All the measurements are made using small fan with diameter of 38 cm and maximum flow 1155 m^3/h. Ventilation opening was hermetically sealed too.

Results from all three mentioned construction stages are summarized in Table 1 – as one can see, air exchange rate for this building is reduced twice after interior finishing is done, but sealing of material joint reduces air exchange very slightly. This can be explained by the fact that sealed joints around walls and ceiling/floor and around biggest pipe connections (Fig. 4(c)) are only small part of leakages; the most important part of air filtration is log interconnections, what is characteristic of this type of buildings. Experimental results from other test buildings after sealing (see below) confirms this assumption.

(a) (b) (c)

Figure 4: Different construction stages in log building: (a) unfinished interior, (b) finished, not sealed, (c) sealed

Table 1: Air tightness measurement results for log building at different construction stages

	Air exchange rate n_{50} (h^{-1})	**Air permeability q_{50} (m h^{-1})**
Stage 1. Unfinished interior	4.26	2.13
Stage 2. Finished interior, not sealed joints	1.97	0.98
Stage 3. All joints are sealed.	1.91	0.94

To analyse the influence of used experimental equipment, 2 additional measurement series were made for log building at stage 2 (interior finishing is done, but joints are not sealed): with a standard fan (diameter of 56 cm, maximum flow 14440 m^3/h) and with an additional air-tight membrane, which is hermetically fitted around the blower door cloth (Fig. 2(c)).

Results get from this investigation are shown in Table 2 – there is no difference between measurements with and without the additional membrane, but the results get from system with bigger fan differ by almost 20%. The main reason of this is the accuracy of parameters' reading in the range of very low flows, which means higher uncertainty for the measurements.

Table 2: Air tightness measurement results for log building with different fan configurations

Fan model (maximum flow)	**Additional membrane**	**Air exchange rate n_{50} (h^{-1})**	**Air permeability q_{50} (m h^{-1})**
Model 200 (1155 m^3/h)	No	1.97	0.98
Model 200 (1155 m^3/h)	Yes	1.97	0.98
Model 3000 (14440 m^3/h)	No	2.36	1.18

The next series of measurements were carried out after special airtight sealing that was made in every test building. *SIGA* (SIGA, 2013) high-performance adhesives are used for the sealing of vapour control layers, wood-based panels and different junctions of pipes/cables. Examples of sealing are shown in Fig. 5.

As the main material and the type of building construction differs, the results of air tightness measurements also vary in a quite large range (Table 3) – from n_{50}=0.67 h^{-1} for building with polystyrene filled ceramics as wall material to n_{50}=1.91 h^{-1} for log building. All possible material and construction joints in every building, as well as window and door are professionally sealed; therefore the only reason for different air tightness is air filtration through building structures (aerated concrete, wood etc.).

(a) (b) (c)

Figure 5: Sealing examples in different test buildings: (a) – vapour layer, wall and cable, (b) – plywood flooring, wall and pipes, (c) – plywood ceiling panels and ventilation opening

Table 3: Air tightness measurement results for different test buildings after sealing

Test building	**Air exchange rate n_{50} (h^{-1})**	**Air permeability q_{50} ($m\ h^{-1}$)**
LOG (log house with internal insulation)	1.91	0.94
EXP (polystyrene filled ceramic blocks)	0.67	0.34
AER (aerated concrete with external insulation)	1.12	0.56
CER (ceramic blocks with external insulation)	1.47	0.70
PLY (plywood boards filled with mineral wool)	0.93	0.46

A thermographic survey is also carried out together with blower door tests in all buildings after sealing. Is shows that the thermal bridges along the doors and windows are excluded (Fig. 6) and air infiltration/exfiltration does not exist. The zones with slightly lower temperature (from the inside) are found between walls and floor/ceiling (Fig. 7), but the temperature difference there even in case of 50 Pa pressure difference is relatively small and do not exceed 3°C, thermal bridges there are small.

The difference in air tightness parameters at 50 Pa pressure difference get from experiments (Table 3) describes mainly the variable properties of boundary materials and structures, but it does not describes the real convective heat losses from buildings. To evaluate actual air exchange under given climatic conditions, a completely different approach should be used.

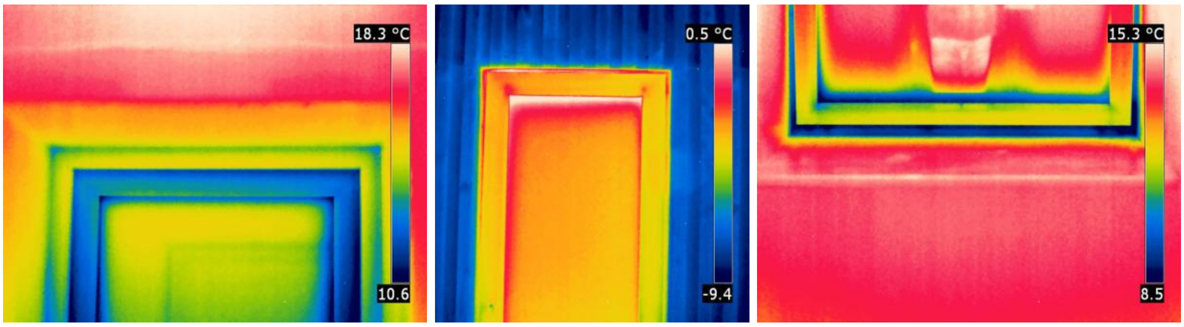

Figure 6: No thermal bridges or other defects are found for windows and doors at 50 Pa pressure difference

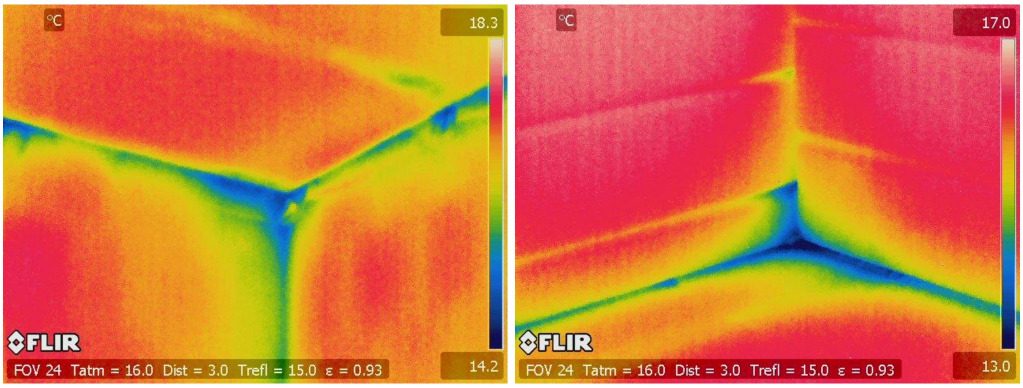

Figure 7: Ceiling/wall and floor/wall joints with decreased temperature at 50 Pa pressure difference

3.2 Air Exchange Rate

Actual air exchange rate at given climatic conditions (wind speed and direction, temperature difference etc.) and in set mechanical ventilation mode is very important factor; it describes not only the fresh air supply intensity, but also heat amount lost due to convective heat losses (air mass transfer). As the heat balance and heating/cooling energy needs in the test building are key factors, it is very important to measure the actual air exchange, which can be done by using tracer gas method.

Experimental studies of actual air change were made in all the test buildings after airtight sealing and with ventilation system running in standard mode (fresh air is added by heat pump from the outside, air exhaust is provided through the opening above the window). To ensure the air change results describing long-term building operation, measurements were carried out at least for 24 hours for every building. Obtained results (Table 4) show that the actual air change with switched on ventilation system in all test buildings is within the range of $0.43 \ldots 0.50\ h^{-1}$. Graphical representation of calculated air exchange values for long-term monitoring period is shown on Fig. 8; it is seen, that fluctuations of the instantaneous n values depending on wind speed/direction for different measurement series vary.

One additional measurement was carried out in log house with switched off ventilation system and sealed ventilation opening; this study shows that air change in sealed building without operating ventilation system is very close to zero (Table 4). As blower door experiments indicated (Table 3), log building has the highest air exchange rate n_{50}; therefore it may be concluded, that all other buildings will have even lower actual air exchange rate n. Thus, the general finding of this experiment is that all buildings are very air-tight and the actual air exchange rates n with switched on ventilation system are very close, which means that more than 90% of actual air exchange is a result of mechanical ventilation system operation.

Table 4: Air exchange rate n for test building under actual operating conditions

Test building	**Ventilation system**	**Ventilation opening**	**Air exchange rate n (h^{-1})**
LOG (log house with internal insulation)	On	Open	0.45±0.03
LOG (log house with internal insulation)	Off	Sealed	0.03±0.01
EXP (polystyrene filled ceramic blocks)	On	Open	0.48±0.02
AER (aerated concrete with external insulation)	On	Open	0.5±0.03
CER (ceramic blocks with external insulation)	On	Open	0.43±0.04
PLY (plywood boards filled with mineral wool)	On	Open	0.44±0.01

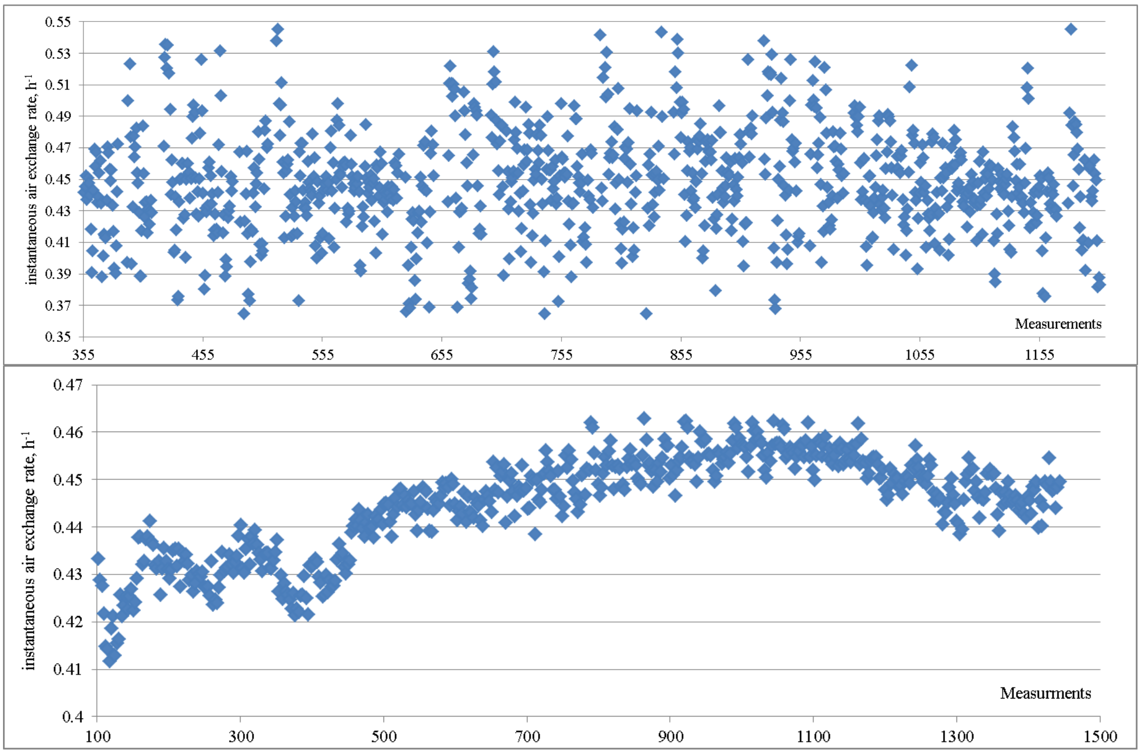

Figure 8: Examples of instantaneous air exchange rates estimated with tracer gas method

It is possible to use relationship between measured air exchange rate at 50 Pa pressure difference n_{50} and natural (actual) air exchange n, which was firstly investigated in the 80’s by (Kronvall, 1978) and (Persily and Linteris, 1983):

$$n = \frac{n_{50}}{20} \tag{1}$$

Using this equation, we can calculate the actual air exchange rate for LOG building without ventilation (Table 3), $n=1.91/20=0.10\ h^{-1}$. Comparing it with value $n=0.03\ h^{-1}$ measured by using tracer gas dilution method (Table 4), it is seen, that the difference is three times. Very simple equation (1) does not take into account neither effective average climatic conditions nor the building characteristics (shape, height etc.). Other studies (Dubrul, 1998) show that empirical correction factor between n and n_{50} changes from 10 to 30. Experiment in LOG buildings gives a result of 64; thus it can be concluded that use of blower door tests to correctly describe the real air exchange may produce very inaccurate results.

4 CONCLUSIONS

Air tightness measurements is test buildings with different structures showed that even in case when all possible joints and air gaps are perfectly sealed, there exist a small air flow, which cannot be completely excluded; one of possible explanation of this fact is air filtration through the building construction (especially for wooden materials). The use of standard blower door fan for air tightness experiments in small-sized buildings may cause serous measurement errors due to poor accuracy of equipment at very small flows; the fan with lowest airflows is recommended. Studies of actual air exchange rate using tracer gas dilution method demonstrated the dominant role of mechanical ventilation (more than 90%) in overall air exchange process in good airtightened test buildings. Comparing the results get from blower door tests and evaluated actual air exchange from tracer gas experiments, it has been established that correlation between those parameters can be fixed very approximately.

5 ACKNOWLEDGEMENTS

This research is done with financial support of ERAF, project realized by University of Latvia, No. 2011/0003/2DP/2.1.1.1.0/10/APIA/VIAA/041.

6 REFERENCES

Dimdiņa, I., Jakovičs, A., Gendelis, S., Kļaviņš J. (2013). *Testing of Energy-Efficient Building Envelope Materials in Natural Conditions.* In: Proceedings of World Sustainable Energy Days 2013, 27th February – 1st March, Wels, Austria.

Daikin (2013). Wall-mounted type Inverter Ururu Sarara [online] *www.daikin.com/global_ac/products/residential/urusara_series/outline.html* (accessed 25.08.2013).

Durbul C. (1998). *Inhabitants behaviour with respect to ventilation.* Technical note 23. Air Infiltration and Ventilation Centre (AIVC); 1988.

FLIR (2013). FLIR P620 Technical Data [online] *http://support.flir.com/DsDownload/Assets/40402-3403_en_50.pdf* (accessed 25.08.2013).

ISO 12569 (2012). *Thermal performance of buildings and materials -- Determination of specific airflow rate in buildings -- Tracer gas dilution method*. ISO Standard 12569:2012. Geneva: International Organization for Standardization.

Kronvall J. (1978). *Testing of houses for air leakage using a pressure method*. ASHRAE Trans 1978:84(1):72-9.

Laussmann D. and Helm D. (2011). *Air Change Measurements Using Tracer Gases: Methods and Results. Significance of air change for indoor air quality, Chemistry, Emission Control, Radioactive Pollution and Indoor Air Quality*, Dr. Nicolas Mazzeo (Ed.), ISBN: 978-953-307-316-3, InTech, DOI: 10.5772/18600.

Lumasense (2013). Ventilation and Air-exchange Measurements [online] *www.lumasenseinc.com /EN/products/gas-monitoring/ventilation-measurement* (accessed 25.08.2013).

Persily A., Linteris G. (1983). *A comparison of measured and predicted infiltration rates*. ASHRAE Trans 1983:89(2B):183-200.

Retrotec (2013). Air Leakage Test Systems [online] *www.retrotec.com* (accessed 25.08.2013)

SIGA (2013). Protection for House. Health. Climate [online] *www.siga.ch/en/product-overview.html* (accessed 25.08.2013).

UL (2013). University of Latvia. Project's "Development of composite building walls constructive solution from the local materials by using multiphysical modelling according to the EU energy efficiency and optimal indoor climate requirements" website [online] *www.eem.lv* (accessed 25.08.2013) (in Latvian).