Air tightness of Structural elements and internal air leakages in a multi-apartment building

Air tightness of structural elements and internal air leakages in a multi-apartment building

Anu Aaltonen, M.Sc.
Kimmo Lähdesmäki, M.Sc.
Juha Vinha, Associate Professor

Tampere University of Technology, Finland

KEYWORDS: *Air tightness, structural elements, internal, multi-apartment, depressurization method*

SUMMARY:
This presentation introduces a method development process, where the objective is to determine the proportional share of air leaks in the different structural elements of an apartment and their effect on the total air tightness. The proposed method consists of a series of depressurization measurements: each measurement reveals a different aspect of the leaking and together they give a comprehensive view of the air tightness in the different parts of the measured apartment.

1. Introduction

EVAKO *(Economical Decision-making in Suburban Renovation Projects)* is a Finnish project aiming to determine criteria for expedient, energy efficient and economical renovations in the suburbia. The project involves an experimental renovation venture in a quarter of tenement buildings, in which one aspect is the improvement of comfort and habitability in a single flat. To achieve this, a survey of the current problems was carried out by means of tenant interviews. A frequent complaint was infiltration of smells and noises from the neighbouring flats. As this is most probably inflicted by inadequate air tightness between the apartments, there arose a need to examine this issue further.

The Building Physics research group at the Tampere University of Technology set to find a reliable way to determine the proportions of leakage in the different structural elements. There are already measurement approaches such as the multiple fan pressurization technique (Levin 1988) or the balanced fan depressurization method (Reardon et al. 1987). The group wanted, however, to fit the technique to the available equipment – two sets of Minneapolis Blower Door measurements systems – and the circumstances at the actual measurement site.

The main target was to examine the internal air tightness, i. e. the air tightness of the structural elements separating the apartments in comparison with the air tightness of the building envelope. However, it was considered profitable to see into the leakage proportions of the different elements of the building envelope all at once.

2. Measurements

The air permeability of the building envelope or parts thereof can be measured by a fan pressurization method, by which the air flow through the construction can be calculated (SFS-EN 13829). There is a limitation to the method, though: the standard test will not recognize any individual air leak sources or indicate the proportions of different structural elements of the measured entity. Therefore, a series of measurements would be needed in order to eliminate potential air leak sources one by one and thus determine their share of the total air leakage.

2.1 Principles

The first set of measurements was planned to be as extensive as possible to take into account any possible variations in the leak routes and their elimination. It was anticipated that the inspection of the results would allow the exclusion of some variations without notable deterioration in the reliability of the method.

The fan pressurization test equipment is mounted to an outer doorway of the inspected entity. Measuring an apartment, the customary location would be the balcony door, but also the staircase door can be used. As the equipment fills up the whole doorway, there will not appear any air leakage through the door in question. Because of this, and also in order to get comparison material, the measurements were performed at both locations. The variations A – C were performed at the staircase door and D – G at the balcony door. All the variations were performed by both depressurization and pressurization methods.

TABLE 1. The measurement variations A – G.

Var.	Sealed openings	Objective
Equipment at the staircase door		
A	The intentional routes of ventilation system; standard test (SFS-EN 13829)	Determining the total air leakage of the apartment
B	Sealing A + window and balcony door seams	Determining the influence of windows and balcony door to the total air leakage
C	Sealing B + seams of the building envelope	Determining the influence of building envelope joints to the total air leakage
Equipment at the balcony door		
D	The intentional routes of ventilation system; standard test according to SFS-EN 13829	Comparison material to variation A, determining the balcony door influence
E	Sealing D + window seams	Comparison material to variation B
F	Sealing E + seams of the building envelope	Comparison material to variation C
G	Sealing F + staircase door	Determining the staircase door influence

The variations A – G are relatively simple measurements that can be performed in the apartments individually, one by one. Respectively, they can determine only the air leakage proportions of the elements of the outer building envelope.

To distinguish the internal leaks out of the residual leakage, another variation was devised. This technique is in principle similar to the guarded zone method used by Reardon et al. (1987), Levin (1988) and Fürbringer et al. (1988). The variation H performs the standard fan depressurization test in the measured apartment (guarded zone) as in the variation D. At the same time, another set of test equipment is used to create an equivalent pressure into all the spaces bordering the measured apartment (guarding zone). This counter-pressure inhibits air leakage through the boundary elements and so eliminates its proportion out of the total leakage. The pressure difference must be controlled at various points of the guarding zone to make sure that the zero pressure difference level between the zones is sustained.

2.2 Execution

The EVAKO project renovation venture takes place in two tenement buildings, which are owned and managed by Tampereen Vuokratalosäätiö VTS (Tenement Building Foundation of Tampere). Both buildings were built in 1978 of concrete and concrete sandwich elements. Each building has three storeys and three staircases; one has 21 apartments and another 27.

The objective set by the EVAKO survey was to determine the air tightness of the buildings and apartments, including the internal air tightness between apartments. The testing equipment was Minneapolis Blower Door system with APT test device and Techlog software. All the measurements were based on the standard SFS-EN 13829. By performing the set of measurements and the interviews both before and after the renovation, it would become possible to assess the success and quality of the repairs. The initial measurements were executed in May-June 2010, just before the beginning of the repair works. The reference measurements will be executed in June 2011.

The measurements were planned to take place in relatively empty buildings. Especially the guarded zone tests were to be performed by using the whole staircase as a counter-pressurized guarding zone, which would have required unlimited passage to all the apartments in a staircase. However, the time allowed for the measurement project was significantly cut out due to the tenants' relocating issues. During May 2010 12 apartments were able to be tested with the A – G variation series. Only four apartments underwent the whole set including also the counter-pressure test H, while in three apartments a combination of standard test D and counter-pressure test H could be performed.

The measurements were performed in each apartment in a partially inverted order of A-B-C-G-F-E-D, which allowed the smooth adding and removal of the sealing. In addition to the actual test procedure, some sequences of constant 50 Pa pressure were created to allow the searching and verifying of the air leaks in the apartments. The search was performed by sensory impression (feeling of draught), smoke pens and thermal camera. In some cases an anemometer was used to assess the leakage flow. One set of the variations A – G took approximately a whole working day per apartment.

Typical sources of perceptible air leakages in the apartments were windows, doors and especially the mail drop slits in the staircase doors. In many cases one could even state that the slit would be the principal fresh air inlet to the apartment. Concerning the internal air tightness, the duct through-holes between the apartments were notable leakage points.

3. Calculations

The air change rate or n_{50} [1/h] is a value that is generally used to express the air tightness of a building. It represents the air leakage rate per internal volume at the test reference pressure (50 Pa) differential across the building envelope. (SFS-EN 13829.) The value n_{50} is used also in this survey to represent air tightness.

3.1 Preparing the data

3.1.1 Variations A — G

The value n_{50} can be attained automatically from the BlowerDoor test equipment and software. Each variation was performed by both depressurization and pressurization methods and the mean value of those was calculated. This n_{50}-value was tabulated from each variation in each apartment.

3.1.2 Variation H

In the case of counter-pressure the automated process can not be used. The pressure steps required by the standard (in this case 20 … 70 Pa by steps of 10 Pa) were created manually simultaneous at both the measuring and the counter-pressure equipment. At each step the air leakage rate was noted down 5 times in both the depressurization and pressurization mode. The mean value of these 10 measurements gives the air leakage rate V in the measured apartment. As the V values are set into a Pa/V chart, a graph and its regression line can be determined. The equation of the regression line gives at the point 50 Pa the corresponding V_{50} value, and of this the n_{50}-value was calculated by dividing it by the apartment's internal volume.

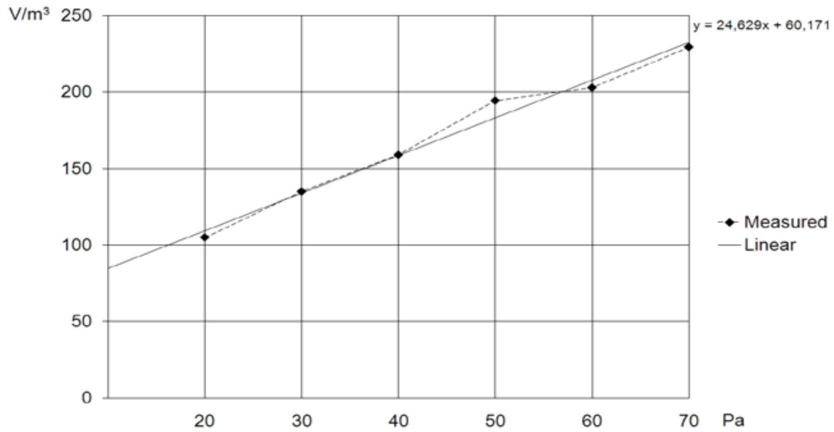

CHART 1. Determining the V_{50} value of apartment A1 in the variation H.

To determine the reliability of this manual procedure, the variation H included actually two sets of measurements. The first one (H_{ref}) was performed without the counter-pressure so that the conditions were similar to variation D, and the second set (H_{cp}) was the actual counter-pressure measurement.

The differences between the variations were extremely small, only ±0.02 on average, and thus the manual procedure can be accepted as an adequately reliable method of measurement.

3.2 Combining the variations A – G

The following calculations define the air leaks through different structural elements:

TABLE 3. Shares of air leakage rate in variations A – C and D – G.

Equipment at the staircase door	
A	The measured air leakage rate through the whole envelope (excluding the staircase door)
A–B	The share of windows and balcony door
B–C	The share of the building envelope joints
C	The residue leakage, incl. the leaks through the building envelope body and the internal leaks
Equipment at the balcony door	
D	The measured air leakage rate through the whole envelope (excluding the balcony door)
D–E	The share of windows
E–F	The share of the building envelope joints
F–G	The share of the staircase door
G	The residue leakage, incl. the leaks through the building envelope body and the internal leaks

As stated earlier in the section 2.1, the pressurization test equipment leaves its mounting location out of the measurement. Therefore a concept of “theoretical air leakage” may be introduced; it takes into account also the air leakage potential of the measurement point and it can be calculated here by *A + (F – G)*. All the shares are then calculated respective to this value.

At this point we should keep in mind one of the targets in developing the method: some variations should be able to be excluded without a definite deterioration of the overall reliability. Therefore the comparisons should give some support to these expectations.

The share of the balcony door can be determined in two different ways: either by *(A – B) – (D – E)* or by *A + (F – G) – D*. Again, if the two are compared, the differences are very small, only between 0.02 … 0.34, and thus either calculation method can be approved.

In some cases the balcony door share gets a negative value. In these cases the values are, however, extremely small and the occurrence may be due to inaccuracy of measurement and/or calculation. It may be interpreted so, that the share is zero, or there is no air leakage through the balcony door.

Shares of the building envelope joints are determined by *(B – C)* or *(E – F)*. Again, the differences between the results are extremely small; either calculation or even the mean value is acceptable.

The case of residue leakage *C* or *G* is a difficult one, because the values are not directly proportional; the share of the (different) measurement point is missing in both. As the stairway door typically leaks more than the balcony door, the variation C may give a too optimistic result compared to the variation G.

3.3 Choosing the variations

After the comparisons conducted in the previous section there are some conclusions to be made. One should consider not only the accuracy and reliability of the method, but also the efficiency and fluency of the measurement process. The previous section proved that there are not considerable differences between the different ways of share calculation, so the determining criterion might well be the measurement process. Based on this, the following calculations were used:

TABLE 4. The final calculation process.

Calculation	Result
A+(F–G)	The theoretical air leakage rate including the whole envelope of the apartment
D–E	The share of windows
A+(F–G)–D	The share of the balcony door
E–F	The share of the building envelope joints
F–G	The share of the staircase door
G	The residue leakage, incl. the leaks through the building envelope body and the internal leaks

This elimination leads to a set of five measurements: four with the measurement point at the balcony door and one at the staircase door. This should simplify the original scheme rather considerably and reduce the measurement time needed at each apartment.

3.4 Calculating the effect of counter-pressure

The share of the air leakage through the body of the building envelope (as the joints are already reckoned in) is calculated by the subtraction of the standard test and the counter-pressure test: $D - H_{cp} = H$. The result *H* consists of all the building envelope elements calculated before, so the final share of the building envelope body will be the remainder of the separation $H - (D - E) - (A + F + G - D) - (E - F)$. Finally, the amount of the internal leaks can be defined from the shares of the residue leakage *G* and the building envelope total leakage *H* and thus it will be $G - H$.

4. Results

4.1 Graphical presentations

As the calculations of the section 3 are performed, the results can be depicted in different manners, depending on the respective need and audience. Here are shown some basic graphical representations of the proportional shares of air leaks in the different structural elements. Due to the extremely small sample of the counter-pressure tests the results are not included here.

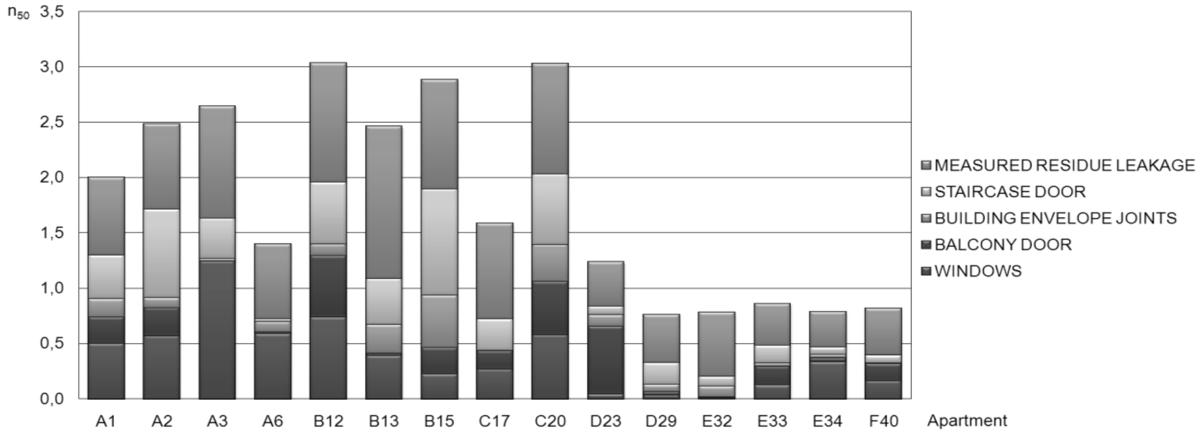

CHART 2. Shares of the structural elements compared to the total n_{50}-value.

During the measurements it was perceived that the building A apartments achieved notably better air tightness results than those in the building B. The difference between the buildings was evident also in the tenant interviews: the smell and noise problems were far more frequently mentioned by the building B inhabitants. In the chart the difference between the two measured buildings is evident: building A (apts D...E) performs decidedly better than the building B (apts A...C).

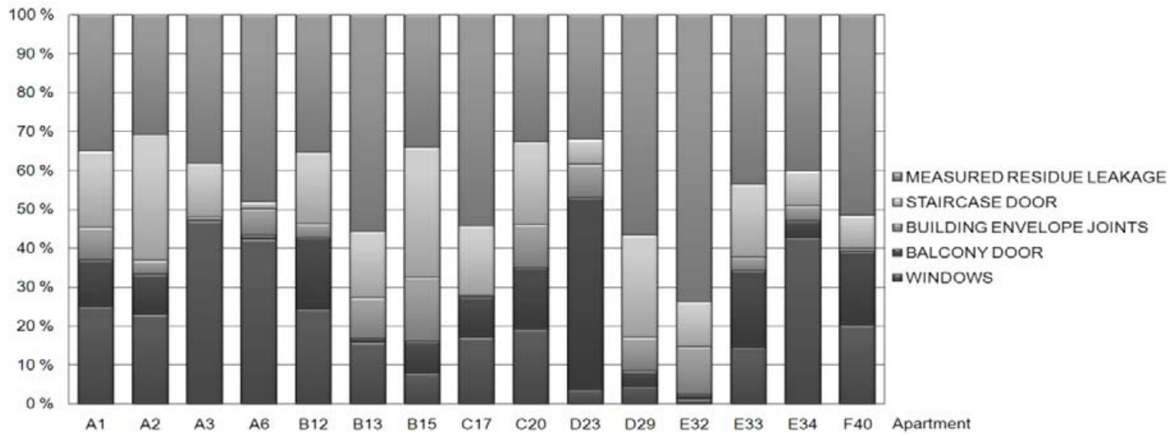

CHART 3. Shares of the structural elements by percent.

As the proportions are relative to the total of 100 %, it is easier to compare the relative shares. Combined, these two charts may give some clues to the reasons behind the good or bad performance of an individual apartment.

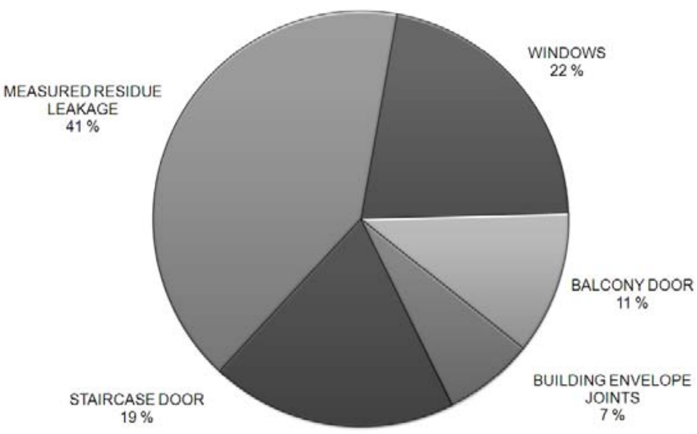

CHART 4. Shares of the structural elements, mean values.

This is probably the most informative representation of the results, if detailed information on the individual apartments is not required. It gives the overall idea of the typical air leakage distribution in the building and is a serviceable comparison tool to other targets and projects.

As the scope of this presentation is not a case study, but the development of the method, an in-depth analysis of the measurement results is not included.

4.2 Error evaluation

In the final stages of the calculation process some disturbing results began to emerge. It was well anticipated that, for the practically air tight concrete element structures, the share of the building envelope body would be very near to zero. However, for the 4 apartments that underwent the whole set of the measurement variations, the calculations gave even negative values. The final results left also the share of the internal leakages much smaller than expected. The unsatisfying results were anyhow explained by a look into the error prospects of the method.

TABLE 5. Share of the air leakage through the building envelope body.

Apt.	Residue leakage	The building envelope, total	Building envelope body	Internal leakages
	G	*H*	*H-(D-E)-(A+F+G-D)-(E-F)*	*G-H*
A1	0.70	0.70	-0.21	0.00
A3	1.01	0.93	-0.33	0.08
C17	0.86	0.66	0.23	0.20
D29	0.43	0.30	0.16	0.14

The standard states the uncertainty of the reference values to be typically 5 ... 10 %. In calm conditions the overall uncertainty of all quantities is in most cases less than ± 15 %, but can reach even ± 40 in windy conditions. (SFS-EN 13829.) The equipment accuracy is ± 3... 4 % (Energy Conservatory 2011). Further inaccuracies may have been inflicted by the changing weather and pressure conditions an even the changes in the measurement team personnel.

As the measured entities were small and their air tightness relatively good, it is obvious that even small uncertainties have great influence on the accuracy of the results. The calculation process of course accumulates the errors, too. Also the measurement sample was far too small to evaluate errors by any statistical methods. For the needs of more sophisticated approaches detailed error evaluation methods have been introduced (e.g. Fürbringer & Roulet, 1991), but they definitely fall out of the scope of this project. It might be enough to state that the uncertainty of this method is very high and the results should therefore be considered to be quite cursory.

4.3 Limitations and challenges

The greatest limitation to the original measurement plan proved to concern the concept of counter-pressure measurement. As stated in the section 2.1., the measurements can be executed properly only in an empty staircase. Even then, one can measure only apartments that do not have any boundary walls to the next staircase – this would require a third set of test equipment to create the counter-pressure behind the boundary wall.

As the requirements to the measurement site were this tight, measurements took a rather long time and the results were not quite as enlightening expected, the use of the counter-pressure method should be examined rather critically on each prospective project separately.

5. Conclusions

The original aim of the development project was to define the air leakage mechanisms and routes in a multi-apartment building. Thus, it was slightly disappointing that the share of unsolved residue – especially the internal leakages – remained quite large. To divide the proportion to smaller, well defined shares of air leakages may not be possible to undertake reasonably by this method. However, the results concerning the shares of structural elements are interesting and enriching. Their full value will certainly uncover only with the comparative analysis on the post-reparation measurements.

Problematic was also the fact that at this point the number of measured apartments was extremely small. To acquire statistically reliable results a considerably larger sample will be required. It would be interesting and challenging also to apply the method to different structures and types of housing; e. g. a timber-framed detached house would be an extremely intriguing research subject.

6. Acknowledgements

The research project was first proposed by M. Sc. Juhani Heljo of the Construction Management and Economics unit at Tampere University of Technology, who is also the EVAKO project manager. The other partners of EVAKO have also contributed to the execution of this project, including the Tenement Building Foundation of Tampere (VTS) and Ekokumppanit Oy (Eco Partners), a sustainable development actions and projects coordinator in the Tampere region.

References

The Energy Conservatory: Products, Automated Blower Door Systems and Accessories. http://www.energyconservatory.com/products/products1.htm. Accessed 28.2.2011.

Fürbringer, J.M., Roecker, C., and Roulet, C.-A. 1988. The Use of a Guarded Zone Pressurization Technique to Measure Airflow Permeabilities of a Multizone Building. Proceedings of the 9th AIVC Conference, Gent, Belgium.

Fürbringer, J.M., and Roulet, C.-A. 1991. Study of the Errors Occurring in Measurement of Leakage Distribution in Buildings by Multifan Pressurization. Building and Environment (1991), vol 26.

Levin, P. 1988. Air leakage between apartments. Proceedings of the 9th AIVC Conference, Gent, Belgium.

Reardon, J. T., Kim A. K., and Shaw, C. Y. 1987. Balanced fan depressurization method for measuring component and overall air leakage in single-and multifamily dwellings. ASHRAE Transactions 1987, vol. 93 pt. 2.

SFS-EN 13829. 2000. Thermal performance of buildings. Determination of air permeability of buildings. Fan pressurization method (ISO 9972:1996, modified). Finnish Standards Association SFS.