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Multifamily Buildings Air Tightness Testing

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Abstract

Large number of the airtightness tests for single family houses were conducted during last years, but only few results for multi-family residential buildings are available worldwide. Lack of measurement database makes it difficult to assess the energy impact of the infiltration and to formulate guidelines and requirements.
Multifamily buildings airtightness tests performing methods and results analysis is the subject of the paper. Literature review revealed that performing tests and interpreting results are much more complicated in multi-zone buildings.
Measurements of unoccupied two five-floors buildings were presented in the paper. Results were compared with results obtained with FLiB an ATTMA calculation methods developed for subsidies verification. It was concluded that whole building airtightness value cannot be easily calculated as weighted mean result for separate zones. The whole building, one zone testing is found to be the only one method resulting in real value for the building, but in parallel it is extremely difficult to measure occupied multifamily building as a whole.

Keywords - airtightness measurement; multi-zone measurement; multi-family building

Introduction

Large number of airtightness test for single family houses were conducted during last 40 years, but only few results for multi-family residential buildings are available worldwide. Lack of measurement database makes it difficult to assess the energy impact of the infiltration and to formulate guidelines. In Poland almost half population live in multi-family building and even small corrections in buildings' envelopes and ventilation systems may result in great scale IAQ improvements and energy consumption reduction.

It is extremely difficult to measure occupied multi-family buildings as a whole. As a result single dwellings measurement are conducted. With adjacent zones not pressurized equally the result is influenced with interzonal leakages. In addition the leakages of common spaces are often quite different than dwellings', which makes the estimated result unreliable.

First sections of this paper provides a review of multi-family buildings market and the presentation of the airtightness measuring methods. Next, two case study buildings characteristics, tests preparation and equipment are presented. It is followed by measurement methodology description and the results presentation. Conclusions are presented in the final section.

1. Multi-Family Buildings

The residential stock with 75% of floor space is the largest sector of EU building stock. Within the residential segment 64% of floor space are single family houses, 36 % are apartment buildings. In Poland multi-family houses segment is bigger with 44%, compared with 56% of single family houses [3]. IAQ are dependent on ventilation operation and the density of population. Matulska-Bachura [8] gives currently floor space per capita in Poland of 26,3 m^2/person, which is quite low in comparison with western Europe countries (Table 1).

Table 1. Floor space per capita, m^2/person [3]

Region	Multi-family houses	Single family houses
North & West EU	36	50
South EU	31	41
Central & East EU	20	26
Poland	average 26,3	

For the existing polish multi-family stock no reliable airtightness data exists. There are some reasons of such a state. Occupied multi-family residential buildings are extremely difficult or impossible to be measured as a whole. Access to apartments is limited and require cooperation with many building occupants. Testing prior to occupancy requires balancing the construction schedule, coordination with the owner and completion of the building (all leakage influencing components).

Few airtightness results for the multi-family residential buildings exist on European and North America market [4], [9]. Bailly [2] presents airtightness database consist of 31 000 measurements but few entire multi-family buildings are measured. Finch [4] gives the number of 100 000 single houses' measurements documented and less than 500 for multi-unit buildings worldwide. Building envelopes are often far different in construction and results from different countries are inadequate to compare.

2. Multi-Family Buildings Airtightness Measurement

As multi-family buildings are difficult to measure, a guarded zone test method (Figure 1, right), called also guarded zone pressurization technique or balanced fan pressurization, is used to measure specific single zone air leakages in multi-zone building. To reduce the influence of airflows between zones, both the specific zone (room, dwelling, floor, etc.) and any adjacent conditioned zones (beside, above, below) should be pressurized to the same equal test pressure [4], [7], [9], [10].

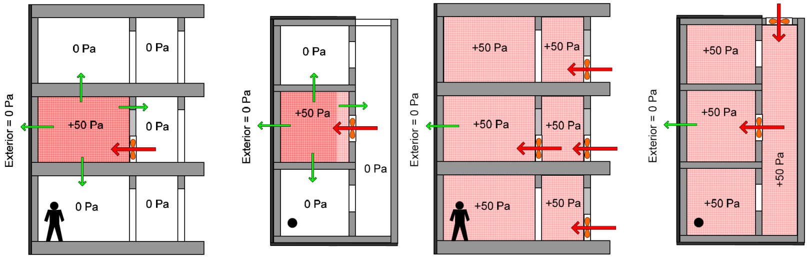

Fig. 1 Single zone test with adjacent zones open to exterior (two left figures: section and plan view of test floor) and guarded zone test with adjacent zones pressurised (right figures) [9]

It is essential that the larger and leakier zones have the strong influence of a whole building result. For multi-family building wrong results could be obtained when determining building airtightness with use of dwellings results (or even single dwelling result) neglecting the influence of common spaces (which are impossible to be measured separately).

Measuring a zone with adjacent zones not pressurized (Figure 1, left) gives the result which include air leakages to adjacent zones [5], [11]. These leakages have no influence on buildings heat losses and should be excluded from the result. Ricketts [9] find interior separators often less airtight than the exterior enclosure. Walther [10] describes the FLiB (Fachverband Luftdichtheit im Bauwesen e.V.) method developed for subsidies verification procedure of measuring at least 20% of dwellings in building separately. Apartments on different floors should be chosen, at least one on the top floor, one in-between floor and one on the ground floor. The adjacent zones should be open to outdoors, to minimize the airtight influence of these zones. Weighted average from the results of the separate zones can be calculated, based on the volume and is equivalent to the value that would be measured on the building as a whole. Particular zones can be up to 30% leakier than the limit value for the whole building. It is noted that the whole building measurement is more reliable, as the method is based on an assumption of zones' similar airtightness properties.

Due to difficulties in measuring the whole residential buildings the ATTMA standard [1] gives also the possibility of testing at least 20% zones, in this case of building's exterior walls area, but concludes that the leakages limit should be 10% smaller than that for the whole building.

As concluded above, the leakages of common spaces play very important role in these assumptions. With very leaky zone not selected for the test (usually common spaces) described methods could lead to wrong results. Walther [10] noticed that there is lack of feed-back from the use of mentioned method and it seems that these methods have been derived according to expert intuition but without solid argumentation.

Hult [7] examined uncertainty for multi-zone air measurements. Uncertainty in leakage to outside due to pressure fluctuation and calibration error in guarded test result is relatively small. If the interzonal leakage area is small relative to the leakage area to the outside then the uncertainty in the leakage measurement is 4%. If the interzonal leakage area is increased, the uncertainty in the measured leakage is 14%. But leakages in interconnected zones that are not pressurized during the test may have much more substantial impact on the order of 30÷100% of the leakage directly to the outdoors [7]. Gorzenski [6] presented large aquapark (volume of 200.000 m³) multi-zone airtightness test results doubled in case of no adjacent zones pressurized, compared with the guarded zone test results.

3. Case Studies Buildings

An unoccupied multi-family residential buildings located in Poznan, Poland were chosen for the research (Figure 2). They were under construction, but all envelope components which have the influence on airtightness were completed. Tests were performed during autumn 2013 (#1) and summer 2015 (#2).

Fig. 2 Case studies multi-family residential buildings (#1 left, #2 right)

Both objects are multi-family six stores residential buildings. Outer walls are made with silicate bricks and insulated with expanded polystyrene. Walls are finished with gypsum plaster layer from inside and with silicate thin-layer plaster on polystyrene from outside. Floors are made with beam-and-block concrete and covered with concrete topping.

Building #1 is equipped with natural ventilation system with 131 trickle vents mounted into triple pane window frames and with ceramic blocks extract ducts dedicated for each apartment. With high outdoor (~90%) and indoor (~75%) air relative humidity it was assumed and observed that during test trickle vents were fully open. Building #2 is equipped with mechanical exhaust ventilation system. Exhaust air is used for garage heating.

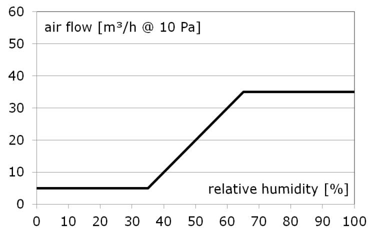

Fig. 3 Trickle vents air flow as a function of relative humidity characteristics by manufacturer

The buildings' floor areas are 3,100 m² (#1) and 8,300 m² (#2). Consequently the interior volumes are 7,850 m³ (#1) and 23,400 m³ (#2). There are 47 dwellings with floor area of 25.6÷81.7 m² (average 53.6 m²) in building #1 and 107 dwellings with 56.7m² average floor area in building #2.

Measurements were conducted with accordance to EN 13829. In building #1 for the whole building test all ventilation extract ducts were shut with use of 146 inflatable inner rubber bladder (Figure 4).

Fig. 4 Extract ducts closed with use of inflatable inner rubber bladder, building #1

Fig. 5 Chimneys top with gaps between chimney walls and ventilation duct (building #1, left) and large openings between dwellings and shafts (building #2, right)

During preparation huge gaps between chimney walls and garage ventilation duct (Figure 5, left) were observed at roof level in building #1. In building #2 lower attention was paid for internal tightness and as a result large openings between dwellings and shafts were observed (Figure 5, right).

A total of 3 Minneapolis Blower Door (BD) were used for the tests in both cases.

4. Measurements Results

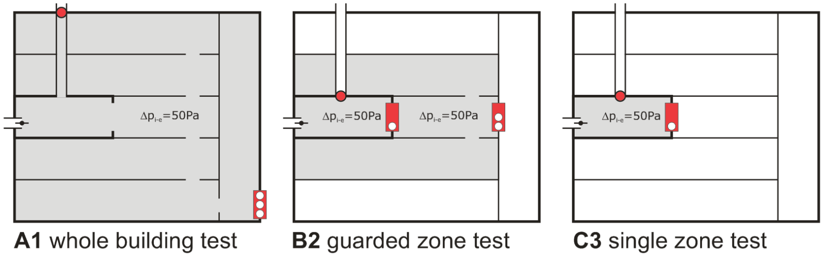

Fig. 6 Measurements configurations (pressurized zone marked with grey colour)

Several measurements (Figure 6) were conducted for building #1:

- A1 - whole building airtightness test with use of 3 BD units, extract ducts were sealed from the top on roof level, variants:
  - both pressurisation and under-pressurisation,
  - both closed and open all trickle vents,
- B2 - guarded zone test of selected 5 different dwellings located on third floor, extract ducts sealed at the dwelling level, trickle vents closed, under-pressurisation only, use of 1 BD for zone pressurising and 2 BD for three floors (above, current and below) pressurising,
- C3 - single zone test for all 47 apartments in building, no adjacent zones pressurization, extract ducts sealed at the dwelling level, trickle vents closed, under-pressurisation only, 1 BD used.

Whole building airtightness tests (A1) were conducted according to EN 13829 in two variants: first one with all trickle vents open and second one with all of them closed. n_{50} values were found to be 1,20 ACH for vents closed and 1,55 ACH for open. The difference in V_{50} airflow was only 2800 m³/h, which for 131 trickle vents gives the difference in airflow of 21,4 m³/h between closed and open vent at the pressure difference of 50 Pa. Based on Figure 3 the difference should be 30 m³/h at the pressure difference of 10 Pa and 88 m³/h at the pressure difference of 50 Pa, assuming flow exponent of ⅔. Obtained airflow is more than 4 times smaller than it should be, based on manufacturer data.

Building was found to be air tight, even with trickle vents open. One should keep in mind that extract ducts were sealed from the top on roof level during the test.

Results of guarded zone (B2) and single zone tests (C3) for selected 5 different apartments located on third floor are presented in Table 2. Extract ducts were sealed at the dwelling level, trickle vents were closed. In guarded zone test (B2) equal pressure in adjacent zones (three floors: above, current and below) was generated with 2 Blower Doors.

Table 2. Guarded (B2) and single (C3) zone test results

Dwelling	Floor area	Volume	B/C V_{50}	B/C n_{50}	C/B diff.
	m²	m³	m³/h	ACH	%
2.M8	75.4	190.8	130/146	0.68/0.77	12
2.M9	65.8	166.4	100/138	0.60/0.83	38
2.M7	36.2	91.6	60/72	0.65/0.79	20
2.M3	57.2	144.6	90/160	0.62/1.11	78
2.M2	60.5	152.9	100/127	0.65/0.83	27
average				0.64/0.86	35

Weighted (per volume) average air leakages are about 35% higher (C/B factor) in a case of single zone (n_{50} = 0.86 ACH) compared to guarded zone method (n_{50} = 0.64 ACH). It is due to taken interzonal airflows into account.

Single zone tests (C3) were conducted for all 47 dwellings in building. Adjacent zones were not pressurized. Extract ducts were sealed at the dwellings level, trickle vents were closed. Total floor area of all dwellings is 2520 m² and the inner volume is 6345 m³. Common spaces (staircases, lift shafts, corridors) floor area is 595 m² and the interior volume is 1505 m³. The weighted (per volume) building n_{50} average of C3 tests was 0,92 ACH, with the range between 0,46 ACH and 1,65 ACH for individual apartments.

Table 3. Results of single zone tests for 47 dwellings (C3) and other estimated (*) values

#	Area	Volume	Description	V_{50}	n_{50}
		m³		m³/h	ACH
1	47 dwellings	6345	measured, single zone (C3) - FLiB	5893	0,92
2	47 dwellings	6345	#1 reduced by C/B 35% factor	4365*	0,68*
3	whole building	7850	measured, whole building (A1)	9310	1,20
4	common spaces	1505	subtraction #3 - #2	4945*	3,28*
5	whole building	7850	ATTMA (#1 +10%)	8016*	1,02*

Summarized results for building #1 are presented in Table 3. If one assumes obtained result (#1) is 35% higher (C/B factor), due to internal leakages included in result (Table 2), the corrected V_{50} value for all dwellings is 4365 m³/h (n_{50} = 0,68 ACH). Estimated (weighted per volume average) n50 value for the whole building, with 100% dwellings tested (more reliable result than required 20%), would be:

- 0,92 ACH - FLiB method (#1),
- 1,02 ACH - ATTMA method (#5).

The most accurate result, for the whole building (A1, #3), was n_{50} = 1,20 ACH. Both methods would result in underestimation of n_{50} value: 15% for ATTMA and 23% for FLiB method. The common spaces n_{50} value was found to be 3,28 ACH.

For the building #2 A1 and C3 test were performed. C3 single zone tests were conducted for selected 14 dwellings, adjacent zones were not pressurized, extract ducts were sealed at the dwelling level. Selected dwellings were located on different floors: the top, the middle and the lowest. For building #2 investor was obliged to measure airtightness and the n_{50} value of less the <1 ACH was required. As a result quite good result of n_{50} = 0.68 ACH for the whole building (A1) was obtained. Results for C3 dwellings tests are presented in Table 4.

Table 4. Single zone tests results (C3) for building #2

dwelling	A_f	h	V	V_{50}	n_{50}	$\Delta(n_{50})$ [%]	
	m²	m	m³	m³/h	ACH	1.75	0.69
M-1.05	52.7	2.58	136.0	276	2.03	116	293
M-1.13	80.6	2.58	208.0	364	1.75	100	253
M-1.19	36.0	2.58	92.8	164	1.77	101	256
M-1.02	39.3	2.58	101.3	172	1.70	97	246
M-3.05	53.2	2.58	137.3	295	2.15	123	311
M-3.13	80.2	2.58	207.0	222	1.07	61	155
M-3.14	29.8	2.58	76.8	160	2.08	119	301
M-3.01	69.0	2.58	178.0	175	0.98	56	142
M-5.09	80.2	2.72	218.1	275	1.26	72	182
M-5.08	38.9	2.72	105.7	165	1.56	89	226
M-5.01	68.5	2.72	186.4	590	3.16	181	458
M-5.05	39.2	2.72	106.7	195	1.83	105	264
M-5.14	79.6	2.72	216.4	400	1.85	106	267
M-5.16	46.2	2.72	125.5	210	1.67	96	242
average			2096.1	3663	1.75	100	253

The leakiest dwelling (n_{50} = 3.16 ACH) was one equipped with two roof windows located on the highest floor. The tightest dwelling has the n_{50} of 1 ACH, and the weighted average was found to be 1.75 ACH. It means that averaging of single zone method results for selected dwellings in this case lead to 2.5 larger value than that obtained for the building as a whole.

5. Conclusions

Results of airtightness tests of two multi-family residential buildings and its dwellings were presented. Quite different results were observed in both cases. The whole building (A1) n_{50} value for building #1, with natural ventilation and no special investor interest in airtightness, was found to be

1.20 ACH. Building #2, with mechanical ventilation and investor attention to airtightness was found to be much more airtight with n_{50} of 0.68 ACH.

Interesting results were observed based on C3 single zones guarded test results. Building #1 had leaky common spaces and there were small leakages in between dwellings and common spaces. Building #2 had tight building envelope but leakages between dwellings and common spaces were huge.

Airtightness values based on C3 results weighted average (n_{50} = 0.92 ACH for building #1 and n_{50} = 1.75 ACH for building #2) were in contrary to the results obtained for the whole buildings (A1).

Table 5. Whole building (A1) and weighted average based on single zone tests results (C3) for the both buildings

n_{50}	ventilation	method A1	method C3	common spaces
#1	natural	1.20	0.92	leaky
#2	mechanical	0.68	1.75	tight

The whole building (one zone) testing (A) was found to be the only one method resulting in real value for the building. Single zone test (C3), with adjacent zones not pressurized, gives the result which contains outdoor and indoor leakages. Determination of zones' outdoor leakages is possible with guarded test method (B2). Weighted average based on single zone (C3) or guarded test (B2) results may lead to under- or overestimation - due to different leakages to outside of common spaces and dwellings and different leakages between them. It is practically impossible to measure the leakages of common spaces separately, that is why only whole building (one zone, A1) airtightness test only gives the reliable result. On the other hand, measurement of multi-family buildings as a whole (A1) is practically possible only if building is unoccupied.

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