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Paper 14

AIR LEAKAGE BETWEEN APARTMENTS

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1. SYNOPSIS

Air leakage through the building envelope is of great importance for the energy use of a building. However, from an indoor air quality standpoint, the size of interior leaks in e.g. multifamily buildings could be important as e.g. a source of pollution.

Using the standardised Fan Pressurization test method, it is not possible to separate interior leaks from leaks in the building envelope. One way to separate these leaks is to simultaneously depressurise (or pressurise) adjacent apartments to the same pressure and thereby eliminating interior leakage. The difference from the standardised measurement then represents the interior leakage. By adding one adjacent apartment at a time, leakage curves for the different building components could be established.

Results from measurements in three apartments show interior leaks to be between 12 and 36 % of total leakage at 50 Pa. Because the apartments are airtight to begin with, 0.45 to 0.90 airchanges per hour at 50 Pa, the interior leakages in absolute numbers are very small and sensitive to inaccuracies in the measurements. Only a few component leakages showed a meaningful curvefit. Vertical leaks were found to be bigger than horizontal, probably owing to more penetrations in floor structures for building services.

Pressure differences between apartments in a range of 5-15 Pa have been measured as an effect of operating the mechanical kitchen ventilation. At a 10 Pa pressure difference, air flow between apartments of 4-15 m^3/h could be seen from the measured leakage curves. If these comparatively small air flows during limited periods of time cause any problems with odours, pollutants etc. should depend on the conditions in the adjacent apartments.

Glazed courtyards are at the moment a popular feature in new and remodeled Scandinavian buildings. Very little data is available on airtightness and air infiltration regarding these courtyards. For design calculations only rough estimates are used. Air leakage of the glazed courtyard in the Suncourt building was found to be greater than expected, 4.2 airchanges per hour at 50 Pa or about 15 m^3/hm^2 leaking surface area. The average design air infiltration rate during operating conditions of 0.2 airchanges per hour might therefore be exceeded.

2. BACKGROUND

For energy use reasons, air leaks to the outside are important. Interior leaks do not normally affect the energy use but could be important from an indoor air quality standpoint.

New Swedish houses are generally made with comparatively low air infiltration levels and continuously operating mechanical ventilation. The level of airtightness in building envelopes is governed by requirements in the Swedish Building Code[1] and controlled by the Fan Pressurization Test method[1].

For multifamily buildings of three storeys or more, the present requirement (SBN 80[2]) on total air leakage is 1.0 airchanges per hour at a 50 Pa pressure difference. This value concerns only leaks to the outside and the average of depressurization and pressurization. Interior leaks e.g. between apartments are not governed by this code. Also, when performing a standardised Fan Pressurization test according to the Swedish Standard, no correction for interior leaks is made. The only conclusion that could be drawn from a measurement is if the result is fulfilling the requirements in the code. If the result is too high, it could not be stated whether a significant part of the leaks are to the inside. As Fan Pressurization tests are performed in practice, interior leaks are included in the result and the apartments are made to fulfil the requirement including interior leaks.

In the new edition of the Swedish Building Code, which hopefully will be released before the end of this year, the airtightness requirements will be given in the form of air leakage at 50 Pa per m^2 of envelope area. The envelope area is defined as area exposed to outside air. Thus the area of a crawlspace floor structure should be included but not the area of a slab on grade. The allowed leakage at 50 Pa will probably be 3 m^3/hm^2 for dwellings and 6 m^3/hm^2 for other buildings. This will be a more stringent requirement than in the previous code for most new dwellings.

There exist very limited data on interior leakage, which is a drawback when developing multicell infiltration models which attempts to calculate the airflow between rooms or apartments. This paper shows the results of an effort to measure interior leaks in new Swedish apartment buildings. Measurements of interior leaks have been performed in the Suncourt and Bodbetjanten buildings, which are included in the Stockholm Project[3]. The Suncourt building is also the

3. AIR LEAKAGE MEASUREMENT TECHNIQUE

The standardised airtightness measurements in Sweden with the Fan Pressurization method gives the total leakage of the measurement enclosure. There is no standard how to consider leaks between e.g. apartments. In order to separate interior leaks from exterior, additional measurements must be performed.

The method chosen for this study, was the multiple fan pressurization technique. Starting with a corner apartment, a standardised pressurization test was performed giving a value on total leakage. Measurements were made at 10 to 50 Pa in steps of 10 Pa and a curve fit to the power law equation, $q=C*dp^n$, was made. To eliminate the interior leakage through party walls and floors, the test was repeated together with one or more adjacent apartments. An extra manometer was used for each tested adjacent apartment to control that no pressure difference and thereby no air flow occured between the apartments. Up to three apartments were tested at the same time. In this study, only depressurization was used. The resulting flow curves between the apartments could be calculated as differences between the results of different measurement configurations.

With the presently used manual controls, the zero pressure difference between apartments could be maintained with a $\pm$ 1 Pa accuracy. The equipment used was calibrated to an accuracy of 5% in airflow measurements.

4. BRIEF HOUSE DESCRIPTION AND RESULTS

4.1 Suncourt building

The Suncourt building contains 71 apartments, of which 50 have entrances through a glazed courtyard, see Figure 1. Floors and party walls are of casted concrete and the exterior curtain walls are prefabricated elements with a wood frame and polyurethane foam insulation. The apartments have forced air heating system and mechanical supply and exhaust ventilation.

The apartments in the Suncourt building are very airtight, between 0.45 to 0.90 airchanges per hour at

50 Pa have been measured, which is well below the requirements in SBN 80. All the pressure test results are shown in Table 1, as well as the curve fit coefficients for the equation $q=C*dp^n$. The apartments measured simultaneously are located at the outer courtyard as shown in Figure 1.

The day of the multiple door measurements was cloudy with an outdoor temperature of 13.5 °C and an average wind speed of 1.7 m/s. No temperature corrections were made on the measured airflows.

	320	321
	220	221
		121

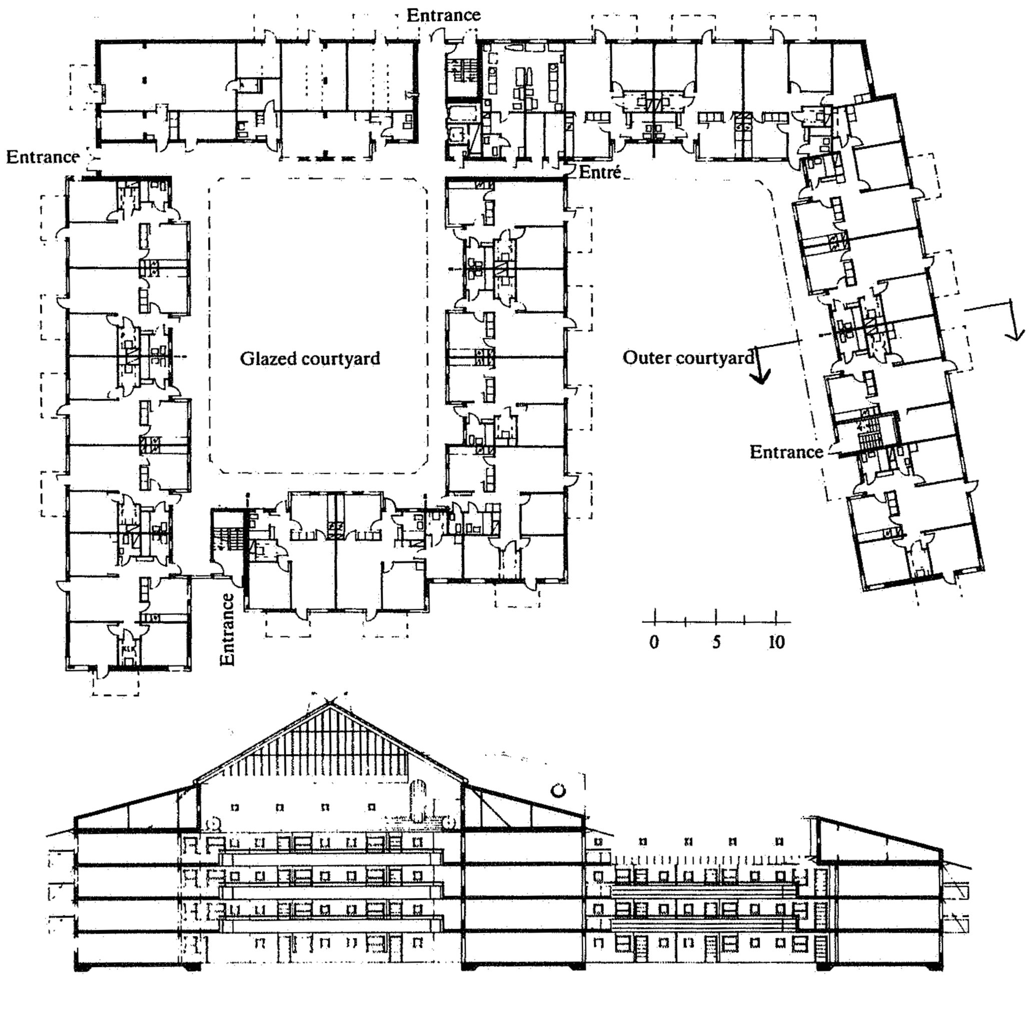

Figure 1. The Suncourt building with apartment location at the free end towards the outer courtyard.

Table 1. Depressurization test results from the Suncourt building. P after apartment No means pressurization results.

Principal+ supporting Apt No	Floor area m^2	V m^3	n_{50} airch/h	Curve fit C	n	r
321	94	225	0.69	10.36	.693	.9992
321p			0.68	7.88	.759	.9946
321+320			0.68	9.19	.721	.9974
321+320+221			0.61	10.50	.655	.9969
320	73	175	0.51	1.92	.983	.9991
320+321			0.53	2.98	.905	.9997
320+321+221			0.49	2.26	.931	.9953
221	94	225	0.45	1.81	1.03	.9992
221+321+320			0.38	2.53	.899	.9923
221+220			0.37	2.79	.868	.9932
221+220+121			0.36	1.78	.978	.9958
220	73	175	0.50	4.66	.748	.9971
220+221			0.50	3.89	.794	.9999
220+221+121			0.49	3.23	.837	.9988
121	94	225	0.57	3.99	.889	.9978
121+221+220			0.55	4.89	.824	.9990
105	73	175	0.78			
105p			1.03			
207	96	230	0.52			
207p			0.50			
309	61	145	0.81			
309p			0.77			
Glazed courtyard	560	8750	4.2	1148	.884	.985

Figure 2 further illustrates depressurization results from the upper corner apartment (No 321). The total leakage was measured to 0.69 airchanges at 50 Pa. The curves show the same apartment tested at three different configurations, where the top line is the total leakage. The difference between the top and second lines is the interior leakage to the apartment on the side. The difference between the second and third lines is the vertical leakage to the neighbour below. The interior leaks are, in this apartment, small compared to the leaks to the outside, about 13% at 50 Pa. The major internal leaks are in the floors.

This is not surprising, because the major part of the penetrations for building services are in the floor structures. The leaks to the side falls within the measurement scatter.

For the apartment below (No 221), the interior leaks was 36% of the total at 50 Pa. A higher proportion of internal leaks is expected for this apartment because of its higher proportion of internal surface area. In this case, the sum of two measurements had to be used to obtain the total interior leakage.

The component leakage through the floor structure between apartments 321 and 221, showed good agreement from both directions, 0.19 and 0.17 m^3/hm^2, respectively. For the side walls to apartments 320 and 220, respectively, the agreement was not good at all.

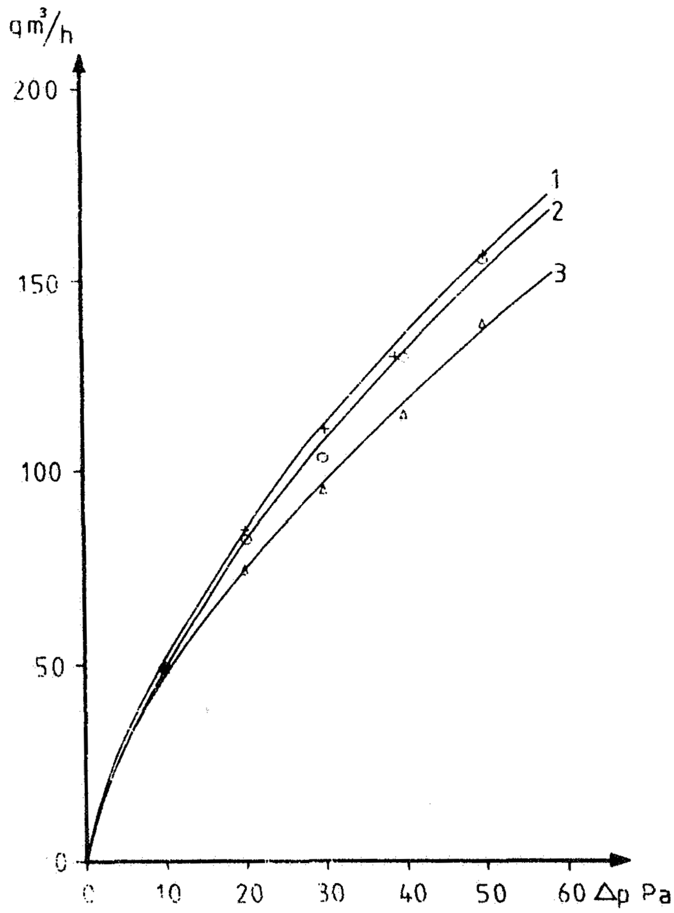

Fig. 2. Measured leakage curves for an upper corner apartment in the Suncourt building (No 321). Curve No 1 is measured total leakage of the apartment. Curve 2 shows simultaneous depressurization of the apartment to the side and curve 3 when the apartments to the side and below are simultaneously depressurized.

In order to measure the leakage of the glazed courtyard, two equipments were used in parallell. The result at 50 Pa is extrapolated from 22 Pa, which was the highest pressure reached. The leakage was higher than expected, about 4.2 airchanges/h at 50 Pa. If the 50 Pa leakage is divided by surface area, the result is about 15 m^3/hm^2, which is very high compared to the new building code. The wind speed was between 2-5 m/s, outdoor temperature 15 °C and courtyard temperature 23 °C at the day of the measurements.

4.2 Bodbetjanten building

The Bodbetjanten building is made with a different concept. The apartments have mechanical exhaust ventilation and a hydronic heating system. The party walls and floors are made of prefabricated concrete elements. The exterior walls are also made by prefabricated concrete elements with outside mineral wool insulation and a brick facade.

The depressurization test results for a bottom corner apartment are shown in Table 2, as well as curve fit coefficients for the equation $q=C*dp^n$. The interior leaks were measured to about 16% of the total airflow at 50 Pa. Also in this house, vertical leaks seems to be bigger than the horizontal leaks.

The weather was sunny with an outdoor temperature of about 20 °C and almost no wind.

Table 2. Depressurization test results from the bottom corner apartment in the Bodbetjanten building (Floor area 83 m^2, Volume 199 m^3)

Principal+ supporting apartments	n_{50} airch/h	Curve fit C	n	r
Bottom corner	0.90	6.41	.85	.9979
+side apt	0.87	5.75	.87	.9985
+side and above apts	0.79	2.58	1.05	.9952

5. DISCUSSION

Interior leaks between apartments has been found to be between 12 and 36% of the total leakage for three apartments in Suncourt and Bodbetjanten buildings. The used techniques for building construction and building services systems are common in new Swedish multifamily buildings.

Absolute numbers on component leakage was found in the order of 0.02-1.6 m^3/hm^2 at 50 Pa. These numbers are small compared to the building code value for external walls.

The measurements in the apartments have, with a few exceptions, given reasonable results and curve fits. However, when using differences in the measurements trying to obtain leakage curves, most results show meaningless correlations. The interior leaks in this buildings are comparatively small and thus sensitive to measurement errors. These measurements were performed in occupied apartments, which limited the apartment configuration and the access time to one day.

This type of multiple fan pressurization equipment measurements are not easy to perform in practice. The zero pressure difference between apartments is often difficult and time consuming to obtain. The interior leaks could be small compared to the flow to the outside and sensitive to small pressure differences and changes in windspeed and wind direction. One other potential error in the measurements could be caused by that a pressure drop develops from adjacent apartments to the outside when measuring the total leakage and thereby underestimating the interior leakage.

Future work with interior leakage should include repeated measurements at different outdoor conditions with different strategies in order to find the optimal method and a reliable error analysis.

The pressure difference between inside and outside during operating conditions in new Swedish apartment buildings depends on the type and adjustment of the mechanical ventilation system, envelope airtightness and outdoor conditions. For a so called "balanced" system with mechanical exhaust and supply ventilation (ES), the pressure difference is small. Buildings with exhaust ventilation system (E) normally operates with a greater negative pressure inside. Internal overpressure should be avoided in cold climates to prevent condensation damages in the building structure. Therefore, the ES ventilation systems are normally designed with the exhaust fan flows 10-30% bigger than the supply fan air flows.

Measured pressure differences on a calm day with about 22 °C temperature difference between in- and outdoors in a sample of apartments in the Suncourt building (ES system) varied between internal overpressure of about 2 Pa to internal underpressure of 5 Pa. However, if the kitchen exhaust flow was set to full speed, it resulted in a depressurization of the apartments ranging between 4-15 Pa. For the Bodbetjanten building apartment (E system), the normal operating negative pressure was about 15-20 Pa. With the kitchen ventilation on full speed, the pressure difference was 30-35 Pa.

A pressure difference between apartments of about 5-15 Pa could be caused by turning the kitchen ventilation on full speed in one apartment, when adjacent apartments operates in normal conditions. A 10 Pa pressure difference between apartments corresponds to an internal air flow in the range of 4-15 m^3/h, according to the leakage curves.

An airflow of 15 m^3/h is about the same size as the total supply air to many bedrooms. Interior leakage could possibly explain some odour problems experienced in new apartment buildings. If an apartment is next to a garage, pollutants of a more severe kind might enter the apartment. On the other hand, the airchange rate is higher and the time periods comparatively short when the kitchen fan operates in full speed.

6. CONCLUSIONS

Results from measurements in three apartments show interior leaks to be between 12 and 36 % of total leakage at 50 Pa. Because the apartments are airtight to begin with, 0.45 to 0.90 airchanges per hour at 50 Pa, the interior leakages in absolute numbers are very small and sensitive to inaccuracies in the measurements. Only a few component leakages showed a meaningful curvefit. Vertical air leakage was found to be bigger than horizontal, probably owing to the penetrations in floor structures for building services.

Pressure differences between apartments in a range of 5-20 Pa have been measured as an effect of operating the mechanical kitchen ventilation. At a 10 Pa pressure difference, airflow between apartments of 4-15 m^3/h could be seen from the measured leakage curves. If these comparatively small air flows during limited periods of time cause any problems with odours, pollutants etc. should depend on the conditions in the adjacent apartments.

Air leakage of the glazed courtyard in the Suncourt building was found to be greater than expected, 4.2 airchanges per hour at 50 Pa or about 15 m^3/hm^2. The design average air infiltration rate during operating conditions of 0.2 airchanges per hour might therefore be exceeded.

7. REFERENCES

(1) Thermal insulation - Determination of airtightness of buildings. Swedish Standard SS 02 15 51, Stockholm 1980.

(2) Swedish Building Code, SBN 1980, The National Swedish Board for Physical Planning and Building, Stockholm 1980.

(3) Elmroth, A., et. al., The Stockholm project. New Energy Efficient Multi-Unit Buildings, A Full Scale Development Project. CLIMA 2000 - conference, August 25-30, Copenhagen 1985.

Discussion

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P. Hartmann (EMPA Duebendorf, Switzerland) You talk about the changes in the Swedish building code from n5Ø values to leakage values per m2 of shell area: (a) What are the reasons? (b) Are there any new requirements for local leakage values and/or inter-apartment leakage?

P. Levin (Royal Institute of Technology, Stockholm, Sweden) (a) The reason is to make the airtightness requirement the same for exposed building envelopes. The n5Ø value gives different requirements depending on location, foundation type and shape, so that apartments and single family houses would have different requirements. (b) No, and no methods have yet been proposed, although some handbooks are under preparation which may clarify this issue.

W. De Gids (TNO Division of Technology for Society, Holland) How is the building envelope area defined in the new Swedish building regulations? For example in the case of atria. Is the internal wall to the atrium part of the building envelope?

P. Levin (Royal Institute of Technology, Stockholm, Sweden) It will depend on whether the atrium is heated or not.

D. Harrje (Princeton University, USA) You have mentioned the odour problem, which is related to internal leakage. Can you prove a correlation between odour transfer and location (of sources of odours and occupants) in the building?

P. Levin (Royal Institute of Technology, Stockholm, Sweden) We may learn more on this matter when we evaluate further the occupant interviews.

P. Charlesworth (AIVC, Warwick Science Park, UK) All the apartments tested met the Swedish air leakage standard. Have any "leaky" apartments (which do not meet the code) been tested?

P. Levin (Royal Institute of Technology, Stockholm, Sweden) Not with this multiple-equipment technique.