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Blower door tests of a group of identical flats in a new student accommodation in the Arctic

Martin Kotol^{*1}, Carsten Rode², Jan Vahala³

*1 Technical University of Denmark
Brovej 118
2800 Kgs.Lyngby, Denmark*

*2 Technical University of Denmark
Brovej 118
2800 Kgs.Lyngby, Denmark
Corresponding author: mrko@byg.dtu.dk

*3 Brno University of Technology
Veveří 95
60200 Brno, Czech Republic*

ABSTRACT

A new student accommodation for engineering students “Apisseq” was built in the town of Sisimiut, Greenland in 2010. Its purpose is not only to provide accommodation for students. Thanks to its complex monitoring system it enables researchers to evaluate the building’s energy performance and indoor air quality (IAQ) as well as performance of some single components. In summer 2012 a blower door test was performed on all 37 living units out of which 33 are identical single room flats and 4 are larger double room flats. The purpose was to evaluate the air tightness of the envelope and to find out how much the flats differ from each other in terms of air tightness. The overall average specific leakage measured was $w_{50} = 2.05 \text{ l}/(\text{s}\cdot\text{m}^2)$ of heated floor area corresponding to an air change n_{50} of 2.96 h^{-1} . Furthermore, the results showed that the difference between the most and the least tight flat is as high as 400%. This result is without consideration of one particular flat which had the extreme result of being 940% as leaky as the unit with the highest air tightness. The reasons for such poor air tightness are lack of the installation gap between the vapour barrier and the inner wall, and insufficient connections of the vapour barrier to the interior walls as explained in the paper. The large variation in results can be attributed to insufficient consideration of the importance of airtightness during construction of some parts of the building – despite of an intent to make a rather air tight building.

KEYWORDS

Blower Door Test, Air Tightness, Cold Climates, Residential Buildings

INTRODUCTION

In summer 2010 the new student accommodation for engineering students ‘Apisseq’ was finished in the town of Sisimiut, Greenland. The intention was to build an energy efficient building in which modern technologies, not yet commonly used in the Arctic, would be installed and which would provide its occupants with a healthy and comfortable indoor environment. Since balanced mechanical ventilation with heat recovery was installed, natural ventilation due to infiltration was no longer needed. In order to minimize infiltration heat losses, special attention was paid to the air tightness of the envelope.

There are no standard requirements on air tightness in the current Greenlandic building code, however the intention was to meet the current Danish requirement [1] which is that air changes through leakage in the building envelope must not exceed $1.5 \text{ l}/(\text{s}\cdot\text{m}^2)$ of the heated floor area when tested at the pressure of 50 Pa.

The aim of this study was not only to test the actual air tightness of the student accommodation, but also to study the distribution of the air tightness over a large number of identical flats by using statistical analysis.

Building key data

The floor plan of the building has the shape of an open circle, and has a partially heated ground floor and two upper floors. A main technical room and janitor's office are in the heated part of the ground floor and small storage compartments for each flat are in the unheated part together with small technical rooms with ventilation units. The 1st and 2nd floor consist of 33 identical single room flats, and four double room flats at the gables of the building. In addition, there is a common room with a kitchen and a laundry room on the first floor (Figure 1 shows the floor plans). In the second floor, the common room and laundry is replaced with single room flats. There is also a glazed atrium with a staircase in the centre of the building. Each single room flat has a total floor area of 23 m^2 and consists of an entrance (3.3 m^2), a bathroom (2.8 m^2) and a living room with a kitchenette (16.8 m^2). The double room flats have a floor area of 50.2 m^2 . All living units have a small balcony.

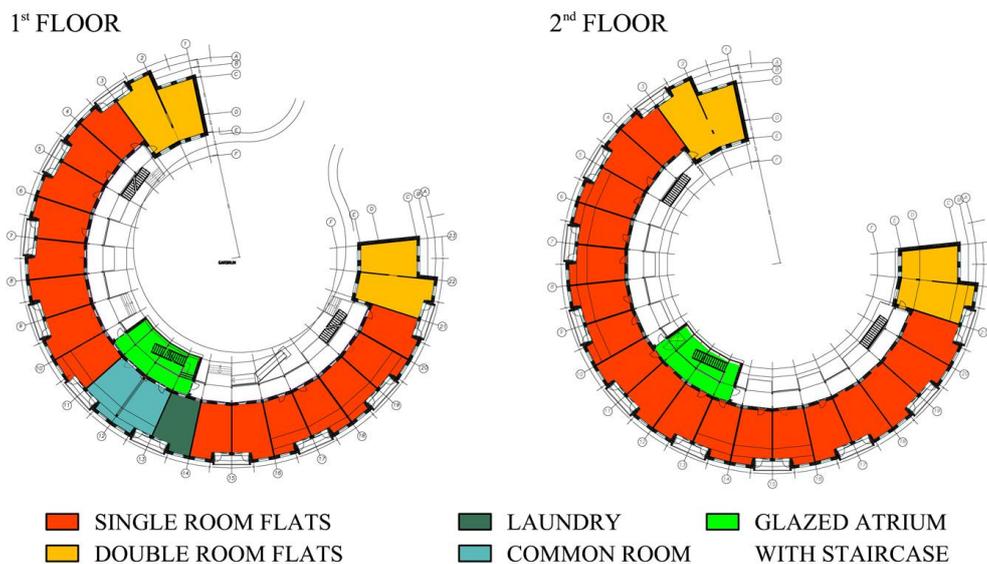


Figure 1. Floor plans of Apisseq

The aim to build an energy efficient building resulted in a well-insulated, air and vapour tight envelope supplemented by modern technology for space heating and mechanical ventilation of occupied spaces. The source for heating and domestic hot water (DHW) is district heating supported by evacuated tubular solar collectors connected to two accumulation tanks (2000 l each). The building is heated with radiators, floor heating is used in bathrooms and entrances. Ventilation is provided by two identical ventilation units. Fresh air is delivered into the living

rooms, and the polluted air is extracted through the kitchen hoods and exhausts in the bathrooms.

METHODS

Methodology of measurement

Standard procedure for measurements of air permeability of buildings and their parts in field specified in the standard [2] was followed. This standard offers two methods of air tightness measurement - method A where the air tightness of the object in use is measured and method B, when the air tightness of the building envelope is measured. Each of these methods requires a specific procedure of the object preparation before the measurement starts. Since the air exchange in all flats is ensured by means of mechanical ventilation there are not any ventilation elements or connections to the ambient, there is no difference between methods A and B in this case. All windows and doors to the ambient were closed, all air terminal devices were taped and internal doors were kept open to ensure equal pressure within the measured enclosure. The ventilation system was switched off.

Measuring equipment

The Retrotec Blower Door Test assembly was used to perform the tests. It consists of calibrated fan Retrotec 2200 Series, pressure gauge DM-2 and a cloth door panel. As the measuring and evaluation software was used the Retrotec FanTestic.

Measurement procedure

The fan was placed into the entrance door of an flat by using the cloth door panel. The measurement was automatically controlled by the software. The zero-flow pressure difference based on 10 baseline pressures taken for 10 sec each was taken at the beginning and at the end of every test. Subsequently the pressurization sequence was performed in 12 pressure steps by 5 Pa taken for 20 sec each from the initial level of 10 Pa to the final level of 65 Pa. After the pressurization sequence, the depressurization sequence was done. The results are the averages of these two measurements. The consistency of the measurements is given by correlation factor. The data are considered consistent when the correlation factor is 95% or higher.

In accordance with the standard, outdoor and indoor temperatures and the wind speed were monitored at the beginning and end of each test.

There have been changes of indoor and outdoor temperatures throughout the measurements. Calculation of airflow into the room through the fan is calculated can be affected by temperature fluctuations as they have effect on air density. However since the maximum difference between the temperatures had not been higher than 5K, the impact of these fluctuations is negligible.

In the case of flat 2.05 the blower door test was carried out on the balcony door after the first set of measurements. The second measurement was done through the balcony door. The intention was to compare the air tightness of the front door with the balcony door.

Some results were considered too far from normal. To enhance the preciseness of the measurements and to eliminate errors, the blower door test was repeated in flats 2.05, 2.12, and 2.20.

The characteristics of measured flats

The drawings of typical single and double room flats are shown in figure Figure 2 and the values used for the calculations are summarized in Table 1.

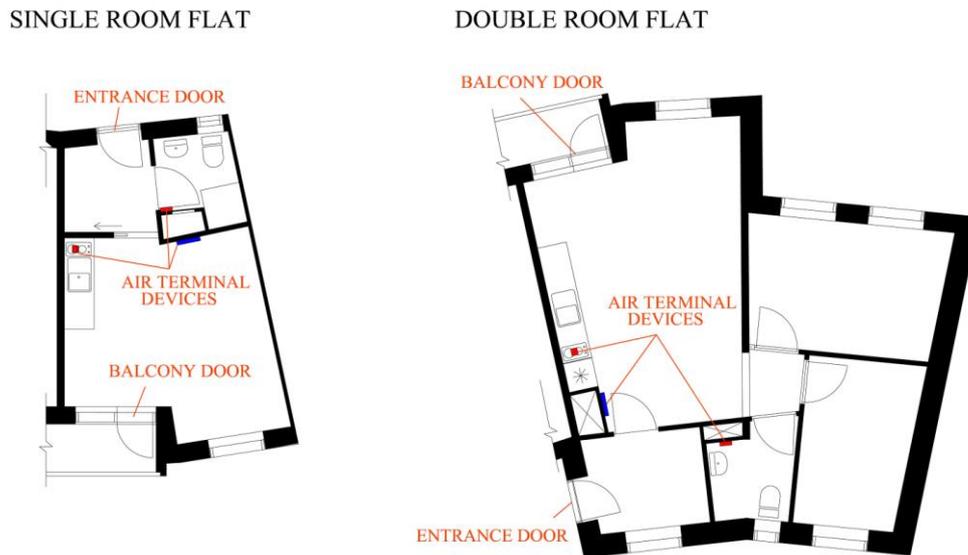


Figure 2. Drawings of the flats

| | Single room flat | Double room flat |
|---------------------------------------|------------------|------------------|
| Volume [m ³] | 57,5 | 131,8 |
| Total Envelope area [m ²] | 96 | 183,4 |
| Floor area [m ²] | 23 | 52,7 |

Table 1. Specification of flats

Evaluation of the measured data

Descriptive statistical analysis was performed on the results of specific air leakage. The possible relations in specific leakage between neighbouring flats in certain part of the building were tested by means of the t-test and Pearson's correlation test. P-values of 0,05 were used to determine statistical significance. Statistical software R and MS Excel were used for the statistical analyses.

RESULTS

Overall results

The correlation factor is, except for three measurements, always higher than 95%. Only depressurization of flats 1.07 and 1.12 and pressurization of flat 1.10 is between 92% and 95%. The differences between pressurization and depressurization tests (see Figure 3) are on average 9.1%. When comparing the positive and negative differences, a two sample t-test

yields a P-value of 0.95 which indicates that there is no prevalent trend of one of the tests (pressurisation or depressurisation) giving constantly higher or lower result.

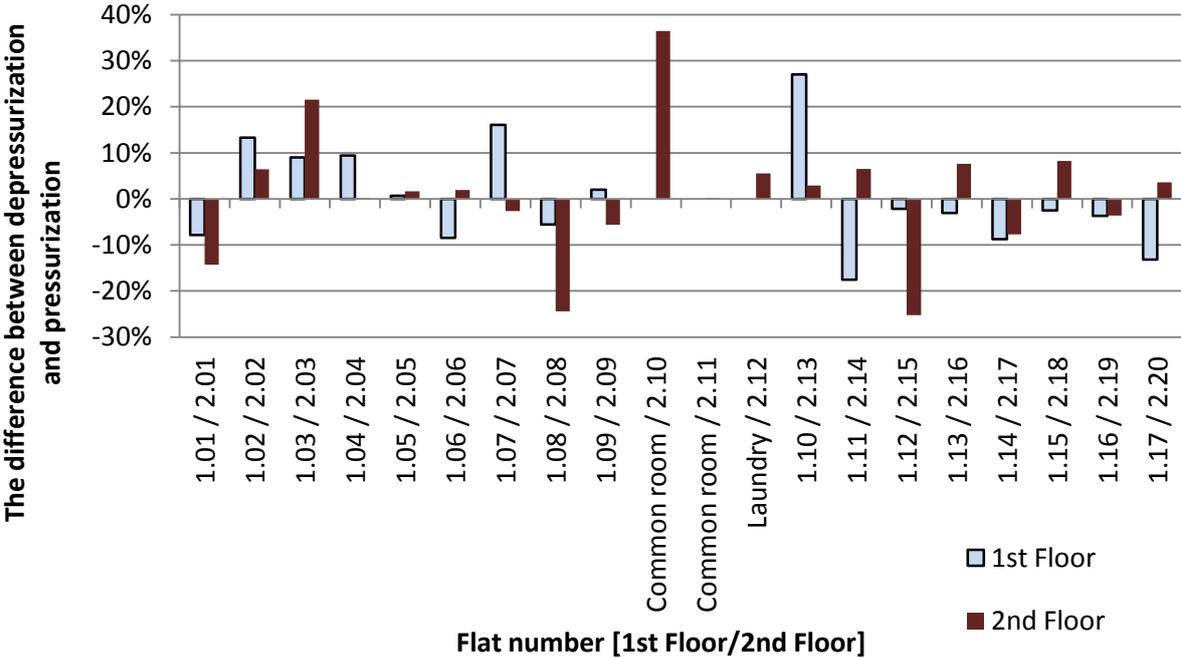


Figure 3. Negative values mean that the result from pressurization was larger than from depressurization

The mean value of specific leakages obtained from Apisseq is 2.05 l/(s·m²) with standard deviation of 0.96 l/(s·m²) corresponding to an air change n₅₀ of 2.96 h⁻¹ with standard deviation of 1.38 h⁻¹. The distribution can be seen from the box plot in Figure 4. It can be observed that the maximum value, which is the test result of flat 2.20, lies significantly above the 3rd quartile. To eliminate the measurement error we repeated the test next day. The result was only 3% different from the first test. This may indicate an abnormality due to construction problems in this flat. More discussion follows in the Discussion section.

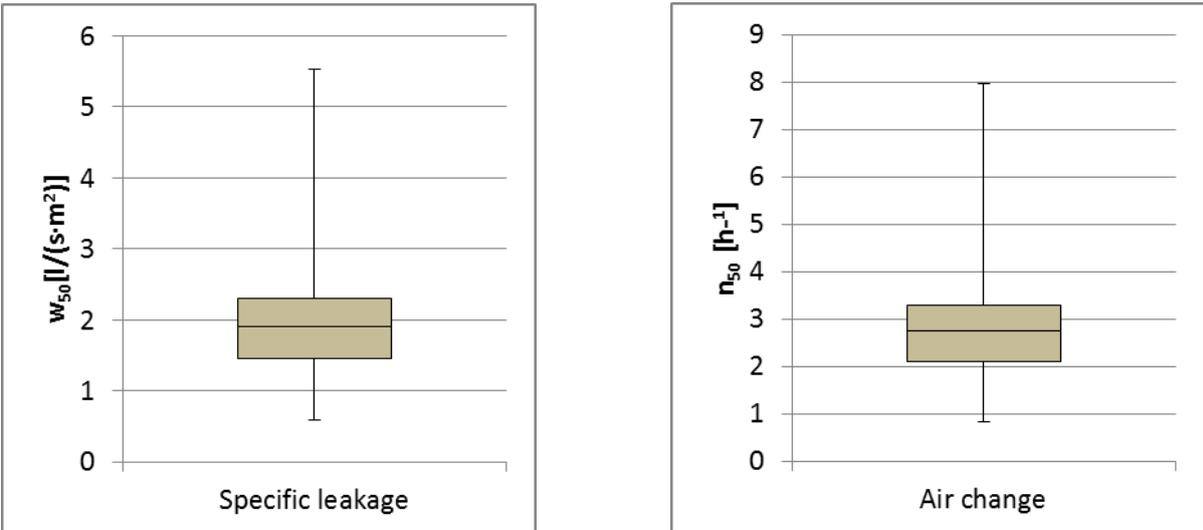


Figure 4. Distribution of overall results of blower door test

The combined specific leakage in all the tested units is presented in Figure 5. When testing the correlation between the first and second floor by means of Pearson’s correlation test, we found a positive correlation of 0.53 at 5% level of significance between the single room flats which are above each other.

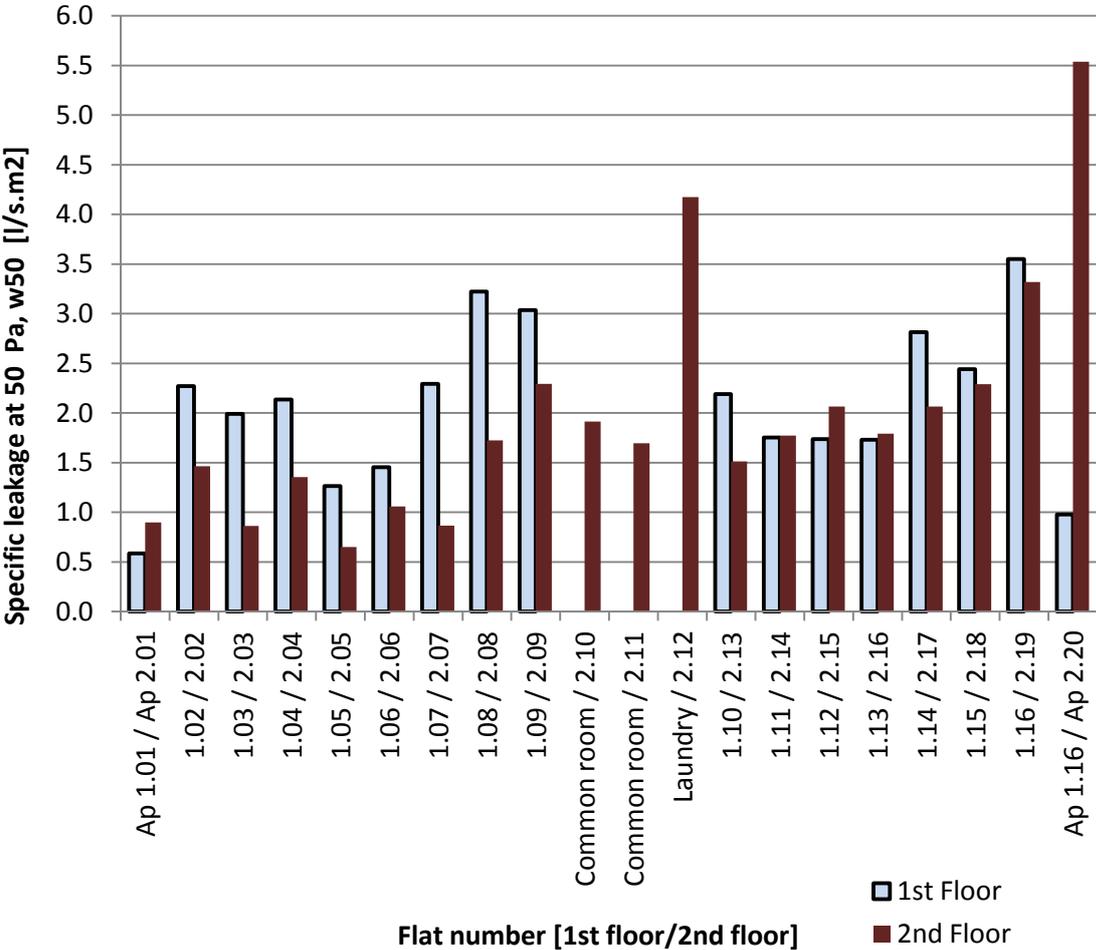


Figure 5. Combined results of testing all the units within the student accommodation

Comparison between flats inside and outside the atrium

The two sample t-test yields a P-value of 0.17 based on what the null hypothesis that there is no difference in air tightness between flats inside and outside the atrium cannot be rejected.

| Flats outside of the glazed atrium | | Flats behind the glazed atrium | |
|------------------------------------|------|--------------------------------|------|
| Mean | 1.98 | Mean | 2.51 |
| Median | 1.89 | Median | 2.29 |
| Standard Deviation | 0.68 | Standard Deviation | 0.81 |
| Variance | 0.47 | Variance | 0.65 |

Table 2. The statistics of w₅₀ [l/(s·m²)] measured in flats inside and outside the glazed atrium

Single room vs. double room flats

The mean specific leakage of the four double room flats is $2.00 \text{ l}/(\text{s}\cdot\text{m}^2)$, which is not different from the mean specific leakage of the single room flats: $2.06 \text{ l}/(\text{s}\cdot\text{m}^2)$ (Table 3). However, excluding the abnormally high specific leakage of the double room flat no. 2.20, gives a mean leakage of $0.82 \text{ l}/(\text{s}\cdot\text{m}^2)$, which is significantly smaller than the mean specific leakage of the single room flats (P-value of one tailed t-test < 0.01).

| | Single room flats | Double room flats | Double room flats without no. 2.20 |
|--------------------|-------------------|-------------------|------------------------------------|
| Mean | 2.06 | 2.00 | 0.82 |
| Median | 1.99 | 0.94 | 0.90 |
| Standard Deviation | 0.72 | 2.37 | 0.21 |
| Variance | 0.51 | 5.59 | 0.04 |

Table 3. The statistics of $w_{50} [\text{l}/(\text{s}\cdot\text{m}^2)]$ measured in single and double room flats

1st vs 2nd floor

There is no significant difference in air tightness between the units in the first and second floor (two sample t-test P-value = 0.82) even when the worst flat (2.20) is excluded (P-value = 0.33).

| | 1 st floor | 2 nd floor | 2 nd floor without 2.20 |
|--------------------|-----------------------|-----------------------|------------------------------------|
| Mean | 2.09 | 2.02 | 1.84 |
| Median | 2.14 | 1.78 | 1.77 |
| Standard Deviation | 0.79 | 1.10 | 0.75 |
| Variance | 0.63 | 1.22 | 0.56 |

Table 4. The statistics of $w_{50} [\text{l}/(\text{s}\cdot\text{m}^2)]$ measured in all units in 1st and 2nd floor

Flats that were tested twice

| | Flat 2.05 | Flat 2.12 | Flat 2.20 |
|-----------------------------|-----------|-----------|-----------|
| 1 st measurement | 0.65 | 4.18 | 5.36 |
| 2 nd measurement | 1.99 | 3.63 | 5.54 |
| Difference | 206% | 13% | 3% |

Table 5. The results of $w_{50} [\text{l}/(\text{s}\cdot\text{m}^2)]$ in units which were measured twice

Test on balcony door

| | Flat 2.05 | | |
|-------------------------|------------|--------------|------------|
| Blower door sitting in: | Front door | Balcony door | Difference |
| Specific Leakage | 1.99 | 0.85 | 57% |
| Uncertainty | 0.03 | 0.09 | |

Table 6. Comparison of main entrance door and balcony door

DISCUSSION

Overall results

The tests have shown, that the average specific leakage of the building is $2.05 \text{ l}/(\text{s}\cdot\text{m}^2)$ which would not fulfill the Danish requirement of $1.50 \text{ l}/(\text{s}\cdot\text{m}^2)$. Nevertheless 27% of all flats in the building had specific leakage lower than the requirement. This enhances the importance of large portion of flats in one building (even when they are identical) being tested when relevant results are sought.

The positive correlation between the single room flats above each other could be explained by the horizontal direction of the construction. The degree of dependence is however very low.

The reasons for poor air tightness are several. The lack of the installation gap between vapour barrier and inner surface plays a large role since all the installations have to penetrate the vapour barrier when entering the flats. Another reason is lack of overlapping flaps in corners where the vapour barrier connects to the concrete walls and floors/ceilings (see Figure 6).



Figure 6. Left: Correct connection with overlap; Right: Missing overlap

Additionally an extra focus on air tightness had not been a part of the building tradition in Greenland until very recent years. Which can explain the insufficient consideration of its importance during construction and design phase.

We assume that if the blower door test was done during the construction phase, many errors would be explored and fixed which would have positive effect on the final air tightness.

Comparison between flats inside and outside the atrium

We have not found any evidence that the air tightness of flats inside the glazed atrium is significantly different from the rest of the building.

Single vs. double room flats

The reason why the double room flats have better air tightness than the single room flats (with one notable exception) is the vapor barrier area/total area ratio which in single room flats is 2x higher than in double room flats which gives higher risk of leakages.

There is probably some larger penetration of the vapour barrier in the flat number 2.20 which causes that high specific leakage. It is suggested to repeat the test together with smoke generating device in order to detect the leakage.

Flats that were tested twice

The 206% difference between first and second test of the flat number 2.05 can only be explained by a procedural mistake whereas the other two differences (13% and 3% in flats 2.12 and 2.20 respectively) are probably caused by combination of systematic and random errors.

Test on balcony door

The results show that the specific leakage when tested with the blower door equipment in the balcony door is smaller than the leakage obtained from the test in the front door by 57%. It may imply that there is significantly higher air leakage through the balcony door than through the front door. To justify this hypothesis, repeated measurements and also measurements in other flats need to be done.

CONCLUSION

The air tightness of all 37 flats in the building was measured with the result which does not meet the current Danish requirements. There is however no such requirement in Greenland. Bringing awareness of the necessity of air tightness to all parties involved in construction process is of very large importance.

Performing the blower door test during the construction phase is a way to avoid errors as well as shoddy work.

When the actual air tightness of buildings is to be determined, large portion of the whole building rather than just small sample needs to be tested.

In order to test the validity of measurement procedure multiple measurements of specific leakage of randomly selected flat should be carried out.

During the experiment period (03 - 13 Aug.2012), the weather varied from day to day (sunny, cloudy, rainy). For further studies, these factors should be considered.

More tests should be carried out to compare the specific leakage when tested both on the balcony door and on the front door.

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