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Air tightness measurements in older Danish single-family houses

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Abstract

This paper reports and discusses the air tightness of the building envelope in existing single-family houses in Denmark. The air tightness of the building envelope depends in particular on the performance of specific construction details. There is a lack of knowledge about the air tightness of the building envelope of older buildings despite the fact that the air tightness has a major influence on the energy use. In connection with renovation of the Danish building stock, the coming years will see increased focus on the air tightness of the building envelope like in other countries.

This paper presents the results of measurements in 16 single-family houses built between 1880 and 2007. The air tightness of the building envelope was measured according to EN ISO 9972 using the blower-door technique. The results are compared with measurement results of the average air-change rate in the same houses measured over a period of 1-3 weeks when the houses were in normal use.

The measurement results of the air tightness of the building envelope range from 1.1 to 5.8 l/(s·m²) at 50 Pa. The investigated houses are all naturally ventilated. The results of the ventilation measurements showed an outdoor air supply ranging from 0.09 to 0.28 l/(s·m²) per heated floor area, which is below the requirement stipulated in the Danish Building Regulations of 0.3 l/(s·m²).

Typically, leaks are observed in connection with penetrations of the envelope, e.g. for electrical installations, exhaust ducts and chimneys. In addition, leaks are observed around older windows and doors and in connection with wooden ceilings and attic hatches. The findings should be taken into account when renovating older single-family houses.

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Keywords: Field measurements; air tightness; blower-door; leakage; ventilation rate

1. Introduction

Denmark is known for having a dedicated focus on energy use in buildings. Over 30% of Denmark's energy consumption is attributable to private households [1]. The majority of single-family houses built 30 years ago or more are naturally ventilated. Energy upgrading of such houses together with focus on providing a satisfactory indoor air quality could result in implementation of mechanical ventilation in an increasing number of existing single-family houses. In Denmark privately owned single-family houses represent a significant energy saving potential as they account for approximately 60% of the heated residential floor area [2].

The energy use in buildings is influenced not only by the amount of thermal insulation in the building envelope (heat loss) but also by the ventilation and air tightness of the envelope (ventilation loss). In particular, the efficiency of the heat exchanger in a

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mechanical ventilation system depends on the air tightness of the envelope as uncontrolled air flow through unintentional openings will slip by the heat exchanger.

In Denmark the first regulative demands for air tightness in new buildings was enrolled in 2006 as an extension to the Danish Building Regulations [3], which imposes a maximum level of acceptable leakage for the building envelope at 50 Pa of 1.5 l/(s·m²) (5.4 m³/h·m²) but it does not include mandatory testing but there is a demand for random checks of new buildings. Since then the demand is tightened for new buildings in 2015 to 1.0 l/(s·m²) (3.6 m³/(h·m²)) whereas air tightness requirements do not apply for older buildings. When a building undergo refurbishment or renovation there is no demands for the air tightness of the building envelope for existing buildings.

In Denmark a default airtightness value of 1.5 l/(s·m²) can be used in the energy performance calculation without testing but if better airtightness if proven by measurements the measured value can be used.

There is a lack of knowledge on the air tightness of the building envelope of older buildings despite the fact that the air tightness has a major influence on the energy use. Anticipation would be that new buildings have better air tightness than older dwellings. However, Sinnott & Dyer [4] found that this was not the case for 28 measurements performed in Ireland and other investigations [4,5] have shown that workmanship and supervision during the construction phase has a major impact on air tightness. Further it could be anticipated that there is a relation between the air tightness of a house and the average ventilation rate of the same house, so that houses with high leakage rates also would have high average ventilation rates and therefore this is compared in the current investigation. In UK there is a rule-of-thumb that gives the relation between air tightness and natural ventilation rates but this may also overestimate the ventilation rates [6]. The Danish Building Regulations stipulate a ventilation requirement of 0.3 l/(s·m²) for new buildings and the measured average ventilation rates in the 16 single-family houses will be compared to this value.

This paper presents the results of measurements in 16 single-family houses built between 1880 and 2007. The air tightness of the building envelope was measured according to EN ISO 9972 [7] using the blower-door technique. The results are compared with measurement results of the average air-change rate in the same houses measured over a period of 1-3 weeks when the houses were in normal use. The investigation also focused on locating leaks. This information could be used to improve the airtightness when older single-family houses undergo renovation.

2. Potential of existing single-family houses

The measured single-family houses included in this investigation were built between 1880 and 2007 covering a wide range of building periods. In Tab. 1 the total number of single-family houses from the investigated periods is shown.

In the 1960es and 1970es there was a boom in the number of newly constructed single-family houses in Demark. During that period many owners helped construct their own home. The general impression is that single-family houses from that period have lower quality than older houses. The older houses are known to be fine craftsmanship of good quality, and typically they are brick wall houses with either brick wall or plaster finish on the internal side, which could imply good air tightness. Opposite, the 1960-1970es houses often have partly lightweight facades and wooden ceilings, which can course leakage. Therefore it is anticipated that it may be possible to see a connection between the building period and the actual air tightness of the houses.

Table 1. Number of single-family houses in Denmark by building period [8]

Building period	1851 - 1930	1931 - 1950	1951 - 1960	1961 - 1972	1973 - 1978	1979 - 1998	1999 - 2006	After 2007
Number of built Single-family houses by period	297.832	134.001	108.299	273.139	147.183	127.005	48.836	31.525
Average size, heated external area [m²]	120	125	125	143	156	143	160	233
Single-family houses, total heated external area [m²]	35.706.073	16.793.524	13.548.064	39.052.489	22.999.832	18.215.274	7.809.797	7.342.484
Measured houses, year of construction	1880/ 1913	1935/ 1949	1956/ 1959	1963	1974/ 1975/ 1976	1981/ 1985/ 1996	1999/ 2005	2007

The number of single-family houses built in each of the periods in Tab. 1 signal the renovation potential for single-family houses in Denmark but of these some may already have been renovated or refurbished. The investigated 16 single-family houses cover a wide span of building periods, which should make it possible to investigate if older brick wall houses are more air tight than houses from the 1960es and 1970es. Furthermore, the newest investigated house was built in a period where the air tightness requirement was in force.

3. Methods

The measurements reported in this paper are performed as a combination of measurements of the air tightness of building envelope by use of blower-door tests and measurements of the average ventilation rate based on the use of a passive tracer gas technique, the so-called PFT-method.

3.1. Blower-door tests

The air tightness of the building envelope was measured using the blower-door technique. The procedure used was largely compliant with EN ISO 9972, Method 3. External doors and windows, intentional vents, attic hatches, letterbox and extract fans were closed but not sealed; open fireplaces were sealed.

Testing was carried out using an automated blower-door. The tests were performed using a Retrotec Door Fan 3.1 or a Minneapolis Door, Model 4.0. The systems are similar regarding functionality, practical use and measurement accuracy. The test procedure is that an outer door is temporarily replaced with a fan, which is capable of inducing a pressure difference across the building envelope and through logging a series of values of pressure difference – pressurization as well as depressurization – and induced airflow the air leakage can be derived. The result of a test is the average airflow rate [l/s] at a pressure difference of ±50 Pa divided by the heated area of the building tested [m²], thus [l/s] per [m^2] ~ q_{F50}.

3.2. Measurements of the average ventilation rate

The average ventilation rate was measured using a passive tracer gas technique, the so-called PFT-method (PFT: PerFluorocarbon Tracer). Tracer gas is emitted passively at a constant and known rate from miniature tracer gas sources and the average tracer gas concentration in the room air is determined using passive adsorption tube samplers. The samplers are analyzed in the laboratory using thermal desorption and gas chromatography. Measurements using the PFT-method are performed over a period and the result of a measurement is the average ventilation rate during the measurement period. In this study the measurement period in each house was about 10 days. The result of a measurement using the PFT-method is expressed in [l/s] per m2 heated area in accordance with the Danish building regulations. The uncertainty of such measurements, typically stated in percentage terms of the standard deviation, is about 20 %SD.

4. Results

The measurements were performed during autumn 2015. The blower door tests showed results of the specific leakage rate ranging from 1.1 to 5.8 l/(s·m²) at 50 Pa, see Fig. 1.

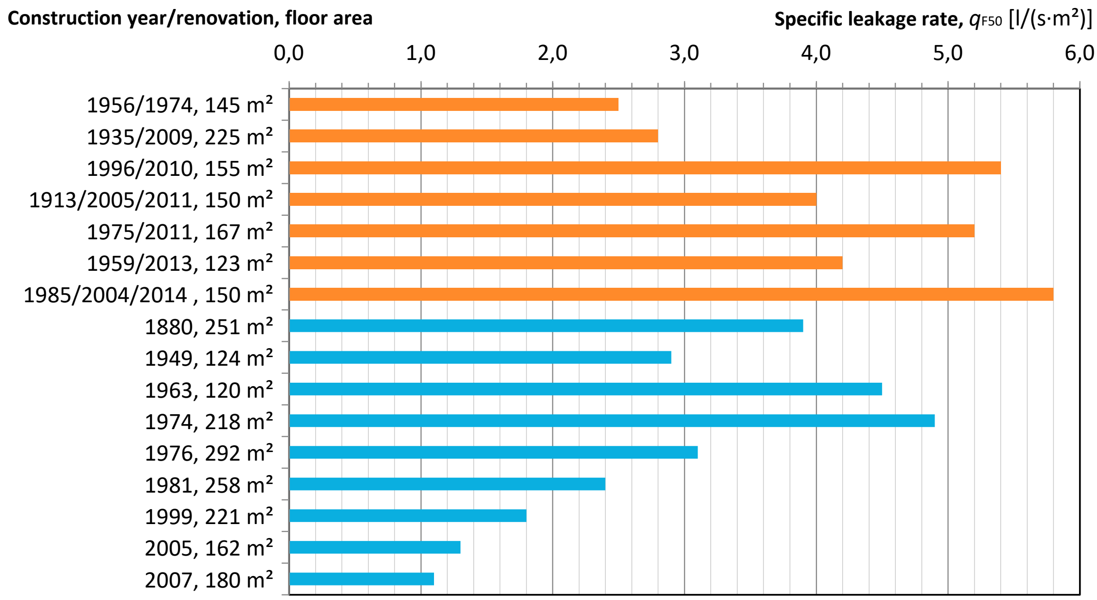

Fig. 1. Specific leakage rate in 16 single-family houses, orange = refurbished/renovated houses, blue = original houses.

The houses from 2005 and 2007 with q_{F50} of 1.3 and 1.1 l/(s·m²) meet the air tightness requirement, q_{F50} of 1.5 l/(s·m²) for new buildings from 2006 until 2015. All other houses have higher leakage rates. 7 houses have undergone refurbishment or renovation and have q_{F50} of 2.5 to 5.8 l/(s·m²), while the 7 original houses from 1880 to 1999 have q_{F50} of 1.8 to 4.9 l/(s·m²).

Thermography in connection with the blower-door tests showed that many of the leaks occur in connection with penetrations of the building envelope, e.g. for electrical installations, exhaust ducts and chimneys. In addition, leaks are observed around older windows and doors and in connection with wooden ceilings and attic hatches [9].

The specific leakage rates are compared with the measured average ventilation rates in the same houses, except one, during normal use. This is shown in Fig. 2. The results of the average ventilation rate were between 0.09 to 0.28 l/(s·m²) or between 0.15 to 0.45 h^{-1}. Fig. 2 illustrates both the average ventilation rate and the blower-door tests results. In one of the single-family houses the measurement of the average ventilation rate was not performed. This can be seen in Fig. 2 where one point is given the value 0,00 but this just mark that no measurement was performed. The average ventilation rates were measured in November and December 2015. None of the measured ventilation rate complies with the requirements of 0.3 l/(s·m²) for new buildings in Denmark.

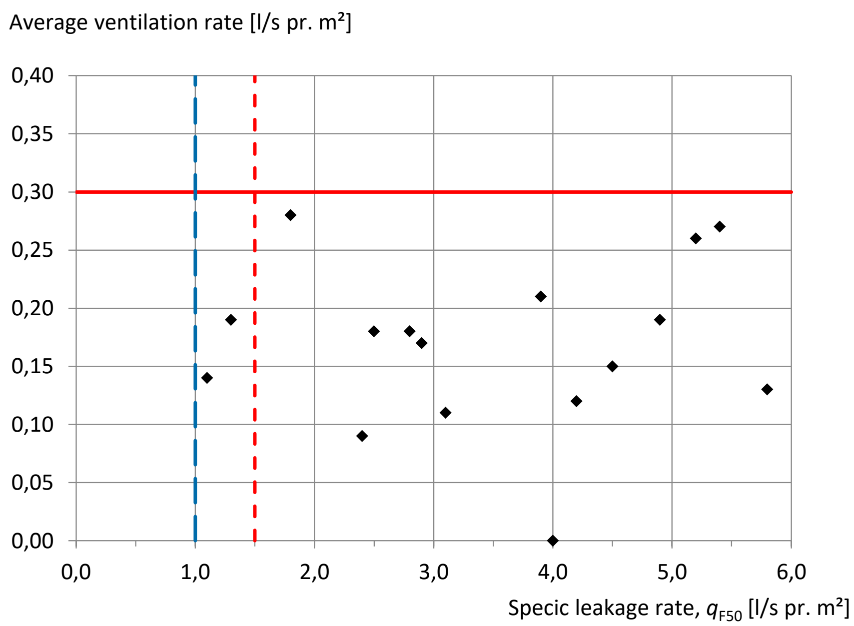

Fig. 2. Relation between the specific leakage rate at 50 Pa and the average ventilation rate. The horizontal red line shows the ventilation requirement for new DK buildings. The vertical lines give the requirements for air tightness in new buildings in DK; dotted red 2006 requirements, dotted blue 2015 requirements.

5. Discussion

There is a wide spread in results for the tested 16 single-family houses of 1.1 to 5.8 l/(s·m²) at 50 Pa.

The houses from 2005 and 2007, meets the Danish Building Regulations requirement for air tightness from 2006. The prospect of a future requirement seems to have had an influence on the craftsmanship. Based on this it can be anticipated that for buildings with even more focus on supervision and craftsmanship during construction it should be possible to achieve air tightness for new buildings that meets the Danish BR15 air tightness requirement, q_{F50} of 1.0 l/(s·m²).

As expected the older houses does not fulfill the requirements for new buildings but the results also indicate that renovated houses may have higher leakage rates than non-renovated buildings. This was an unexpected observation but more data is needed to investigate this further. A closer look at the renovated houses and the actual changes could not pinpoint the reasons e.g. some of the changes involved extension of the houses but these seemed to be quite air tight whereas the leaks were observed in the original parts of the houses. However, this may imply a high influence of the airtightness of the building envelope from the craftsmanship during construction which can be hard to improve in later by renovation of the house.

In the original single-family houses the two biggest leaks were measured for houses built in 1963 and 1974 with measured specific air tightness, q_{F50} of 4.5 and 4.9 l/(s·m²) respectively. In the 6 renovated houses the measured results were q_{F50} in the range of 2.5 to 5.8 l/(s·m²) and of those 4 houses had results between 4.0 and 5.8 l/(s·m²). Based on the results it is not possible to find a linear relation between the building period and the air tightness. Therefore, it is not possible to estimate the air tightness of a single-family house merely based on the period where it was built. This supports earlier findings that the quality of the houses and the craftsmanship has an influence on the air tightness [4,5].

Single-family houses from the 1960-1970es were expected to have less air tightness than older houses. Current measurement results may support this but this is only an indication that also needs further investigation due to the small number of houses. However, it is noticed that also the renovated houses from this construction period have a high leakage rate. Possible explanations could again be the quality of the houses and the craftsmanship during construction. When these houses undergo renovation there might be a lack of focus on the need for air tightening in order to achieve a better energy performance of the houses. Therefore, it is important to ensure more focus on airtightness of the building envelope during renovation projects in order to support at better energy performance of renovated single-family houses.

The measurements must follow the standard EN ISO 9972, but some of the guidelines for the pressure difference intervals were deviated. Introducing high pressure differentials could impose a risk of damage in older single-family houses. This investigation used different pressure intervals of 25-60 Pa, 30-70 Pa, 35- 70 Pa and 20-80 Pa, which all cover the spectrum around 50 Pa because according to the Danish Building Regulations, the specific air tightness must be reported at 50 Pa. In each of the tested pressure intervals 8 to 10 measuring points were achieved for both pressurization and depressurization. EN ISO 9972 prescribes that the lowest pressure difference should be approximately 10 Pa. The test intervals all user higher pressures as the lowest point, but as the uncertainty is reduced at higher pressures, and the intervals should be evenly distributed, this is a compromise which should ensure as accurate results as possible. There have been no tests with pressure differences near 100 Pa, as there may be risks associated with applying high pressure differentials in older single-family houses. The intervals used in the current investigation are commonly used in practice in Denmark. ASHRAE[10] suggests that a pressure interval of 10 – 75 Pa is used for both pressurization and depressurization tests, which seems to be well in line with the used pressure intervals.

All the measured single-family houses included in this investigation have natural ventilation. The results of the average ventilation rates were between 0.09 to 0.28 l/(s·m²), which do not comply with the requirements of 0.3 l/(s·m²) for new buildings in Denmark. By definition in the Danish Building Regulations homes are always in use. This requirement is specifically for housing, and the rationale behind this requirement is that the ventilation in homes should always be active, as there may be ventilation needs, even if there are no people present in the home. In practice the average ventilation rate in naturally ventilated single-family houses will depend on the occupant behavior, such as whether they dry clothes indoors and for that reason need short-term airing to reduce the moisture level, and general user habits for ventilation. In addition, the measuring periods also include periods when the houses are empty e.g. when occupants are at work.

The average ventilation rate measurements are in the same level as an earlier investigation with measurements of 24 newer Danish single-family houses built in the period 2006-2009 where the average ventilation rate on average was found to be 0,19 l/s·m²[11]. This support that the climatic conditions during the performed measurements are comparable as similar results is found in earlier investigations.

Fig. 2 illustrates both the average ventilation rate and the blower-door tests results and as there is no linear trend it is not possible to conclude that there is a connection between the measured air tightness and the average ventilation rate as expected which is in line with UK results [6].

Thermography in connection with the blower-door tests showed that many of the leaks in the older houses are associated with envelope penetrations for electrical systems, radiator pipes and chimneys. Leaks are also observed around windows and doors and especially near wooden ceilings and attic hatches. Therefore, it is suggested in relation to renovation that extra attention should be at these locations in order to improve the air tightness and thereby improve the energy performance of the older single-family houses. However in practice it may be difficult to improve the airtightness of older single-family houses if the quality of the craftsmanship during construction of the houses was poor combined with an earlier lack of focus on airtightness of the building envelope.

6. Conclusion

The paper concerned measurements of air tightness of 16 houses from 1880 to 2007 with natural ventilation. The measurement results of the air tightness of the building envelope ranged from 1.1 to 5.8 l/(s·m²) at 50 Pa. The results of the ventilation measurements showed an outdoor air supply ranging from 0.09 to 0.28 l/(s·m²) per heated floor area, which is below the requirement stipulated in the Danish Building Regulations of 0.3 l/(s·m²).

Typically, leaks are observed in connection with penetrations of the envelope, e.g. for electrical installations, exhaust ducts and chimneys. In addition, leaks are observed around older windows and doors and in connection with wooden ceilings and attic hatches. The findings should be taken into account when renovating older single-family houses, since this could help to improve the energy performance of the older single-family houses in Denmark. This is especially relevant if the renovation includes installation of a mechanical ventilation system, since the efficiency of the heat exchanger in mechanical ventilation systems depends on the air tightness of the envelope as uncontrolled air flow through unintentional openings will slip by the heat exchanger.

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