Air leakage of defects in the vapour barrier of compact roofs

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ABSTRACT

The harsh Norwegian climate requires buildings designed according to high standards. The airtightness of the building envelope is crucial to attain an energy efficient building and to avoid moisture problems. A considerable part of building defects registered in the SINTEF Building defects archive are related to compact roofs.

Flat compact roofs with insulation of EPS or high-density mineral wool between the vapour barrier and the membrane roofing are a common solution particularly in large buildings. In order to retain the membrane roofing from wind forces, the membrane roofing is fastened to the load bearing construction beneath the insulation by use of long screws that penetrate the vapour barrier. Increased requirements related to the airtightness of buildings in the Norwegian building design codes has drawn the focus on airtightness also for compact roof constructions. In the recent years, it has become common to use adhesive tapes to ensure increased airtightness of joints and penetrations in the vapour barrier. However, practitioners have questioned the use of adhesive tape to ensure airtightness, as the vapour barrier at the same time is penetrated by screws. The presented study is trying to provide some answers to the matter.

A laboratory investigation using a special test rig has been conducted in order to measure the air leakage of screw holes and overlapping joints in the PE foil. Different screws and load bearing materials were investigated. Additionally, the air leakage of an overlapping joint was tested for different overlapping widths.

The results of the measurements are used to calculate the air leakage through compacts roofs of two model buildings of different size. The calculations show that air leakages through the screw holes and overlapping joints in the vapour barrier had a minor effect on the airtightness (n_{50}) of the model buildings.

The results from the study imply that a given a vapour barrier clamped between two plane materials it is unnecessary to use adhesive tapes in overlapping joints of the vapour barrier. However, the application of adhesive tape is advisable in order to avoid air leakages between the vapour barrier and other building components, e.g. transition between roof and cornice or penetrations in the vapour barrier such as ventilation channels.

KEYWORDS

Compact roofs, vapour barrier defects, air leakage, laboratory investigation

1 INTRODUCTION

The latest revision of the Norwegian building code (DIBK, 2016) as well as a growing number of passive houses increased the importance of energy savings of buildings. An energy efficient building requires high performance airtightness of both the wind and the vapour barrier of the construction. The harsh Norwegian climate demands buildings designed according to high standards. The airtightness of the building envelope is crucial to attain an energy efficient building and to avoid moisture problems. During the heating season, there is typically an overpressure in the upper parts of the building caused by the density differences of the indoor and outdoor air. Therefore, there is an increased chance for moisture transport by exfiltration through the roof construction. Previously (Hagentoft and Harderup, 1995) have shown that air leakages can carry moisture into the construction causing unacceptably large moisture levels even at moderate indoor moisture levels. A considerable part of building defects registered in the SINTEF building defects archive are related to compact roofs (Gullbrekken et al., 2016). Moisture problems related to air leakages in the joint between the roof and the wall are a known sources to building defect (Silseth et al., 2012).

Flat compact roofs with insulation of EPS or high-density mineral wool between the vapour barrier and the membrane roofing are a common solution particularly in large buildings. In order to retain the membrane roofing from wind forces, the membrane roofing is fixed to the load bearing construction beneath the insulation by use of long screws that penetrate the vapour barrier. Stricter demands related to airtightness of buildings in the Norwegian building design code has increased the focus on airtightness also for compact roof constructions. In the recent years, it has become common to use adhesive tapes to ensure increased airtightness of joints and penetrations in the vapour barrier. However, practitioners have questioned the use of adhesive tape to ensure airtightness, as the vapour barrier at the same time is penetrated by screws. The presented study is trying to provide some answers to the matter.

Typical leakage paths of Norwegian houses have previously been studied by (Brunsell and Uvsløkk, 1980) and (Relander et al., 2009). They found that junctions by walls and floors as well as joints around windows are typical air leakage paths. In detached houses (Kalamees et al 2008) found that the junction between the roof and wall was one of the most typical leakage paths (Kalamees et al., 2008).

This work is based on measurements performed by Askeland in 1992 (Askeland, 1992). The work was partly published previously in a Norwegian project report (Askeland 1992). However, the scope of (Askeland 1992) was limited to solely reporting the air leakages and not to evaluate their practical consequences. Raw data from the measurements have been used in the current work.

In order to address the effect of vapour barrier leakages of compact roofs, the following research questions are outlined:
1) How large is the air leakage caused by fasteners (screw penetration) through the vapour barrier (PE-foil)?
2) How large is the air leakage caused by loose clamped joints of the vapour barrier (PE-foil)?
3) How do the sum of local leakages in the vapour barrier layer influence the leakages on the air change rate of two model buildings.

2 METHOD

2.1 Laboratory measurements

The measurement device consists of a dividable airtight aluminium box with a metering area of 715 mm x 715 mm (approximately 0.5m²). The sample was fixed to the airtight measurement box by special clamps and gaskets to ensure an airtight joint.

The airflow was measured by use of a gas meter. It was coupled in series with a fan. A micromanometer was used to measure the pressure difference over the sample. Accuracy and measuring range of the applied measuring equipment are given in Table 1. A vapour barrier of PE foil with a thickness of 0.2 mm was used. A 100 mm thick layer of rock wool hard mineral wool insulation was included to provide underlayer for the installed penetrations, see Figure 1 and 2.

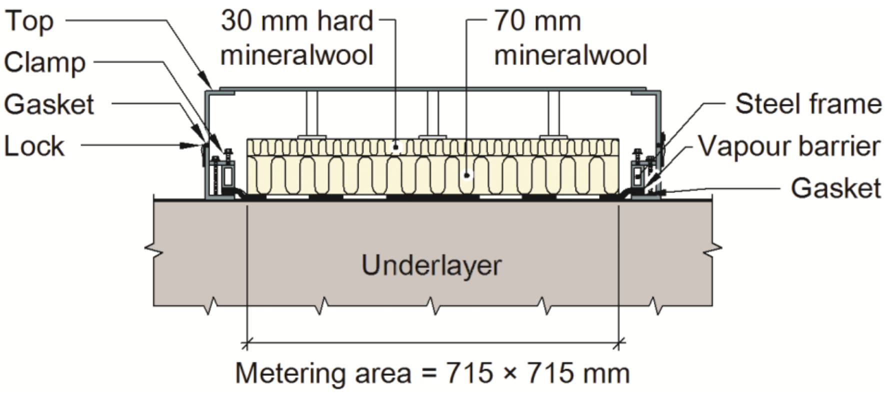

Figure 1. The measurement device for testing air leakage of vapour barrier joints.

Table 1. Accuracy and measuring range of applied sensors

Sensor	Manufacturer	Type	Resolution	Range
Pressure gauge	Furness	FCO 12	±1 Pa	±100 Pa
Gas meter	Elster	-	0.1 l	-

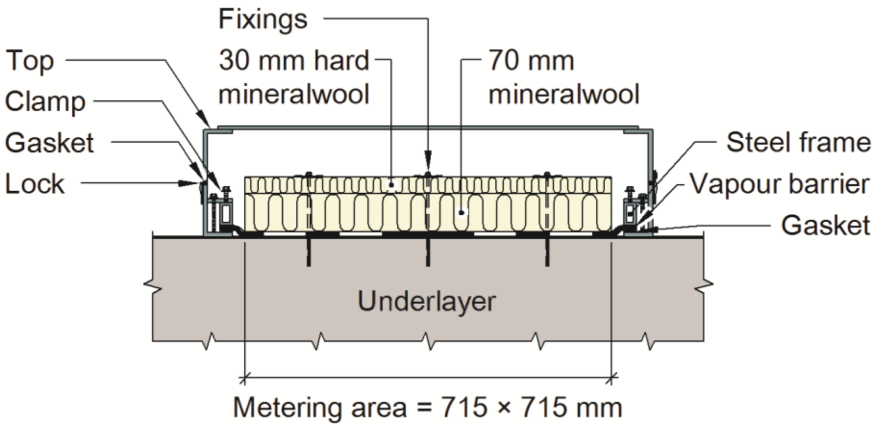

Figure 2. The measuring device for the testing of air leakage of fasteners.

The measuring procedure is given by 1) and 2).

1) Three pressure pulses of 500 Pa
2) Airtightness measurements at following the pressures: -10, -50, -400, -50, -10 Pa

In this paper the measurements of 50 Pa pressure difference is reported. An overview of the underlying materials and fasteners included in the measurements are shown in Table 2.

Table 2. The different underlying materials and fasteners included in the measurements

Underlay	Fastener	
0.65 mm steel plate	Self-drilling screws (4.5 mm)	
60 mm concrete	Telescope 4 (5.5 mm) (5.0 mm predrilled hole)	Bifit (4.8 mm) (6.5 mm predrilled hole) (37 mm long nylonpipe)

Air leakages through the loose clamped joints in the PE-foil were tested with an overlap of the PE-foils of 175 mm, 350 mm and 700 mm.

2.2 Study on different building models

Two different building models were analysed:

1) A dwelling with a base area of 100 m² (10 m x10 m), a total floor area of 200 m² and a building volume of 600 m³. The airtightness rate n_{50} was set to1.5 h^{-1}, the minimum requirement according to the current Norwegian building design rules.
2) A large shopping centre with a base area of 900 m² (30 m x 30 m), a total floor area of 1800 m² and a building volume of 7200 m³. The airtightness rate n_{50} was set to 1.5 h^{-1}.

The input for the calculations are given in Table 3. Incorrect fastener means that the screw or fastener is positioned in an incorrect manner causing an extraordinary air leakage. Different incorrect fasteners have been tested and reported as part of section 3.2. A compact roof with an underlayer of concrete and a fastener of type Telescope 4 was assumed for the calculations.

Table 3. Input data for the roof calculations.

Input for the calculations	
Number of fasteners	3 screws per m²
Joint length	4 meter width of the PE-foil
Number of incorrect fasteners	1 mistake per 10 m² roof area

3 RESULTS

3.1 Airtightness of the laboratory equipment

Air leakages through the measuring equipment were determined by installing an airtight metal- plate in the metering area. The air leakages of the measuring equipment was determined in advance of each of the measurement set-ups. In most of the set ups the measuring equipment was highly airtight.

3.2 Air leakages through the fastening screws

Figure 3 shows the air leakages through the different fastening screws and underlays.

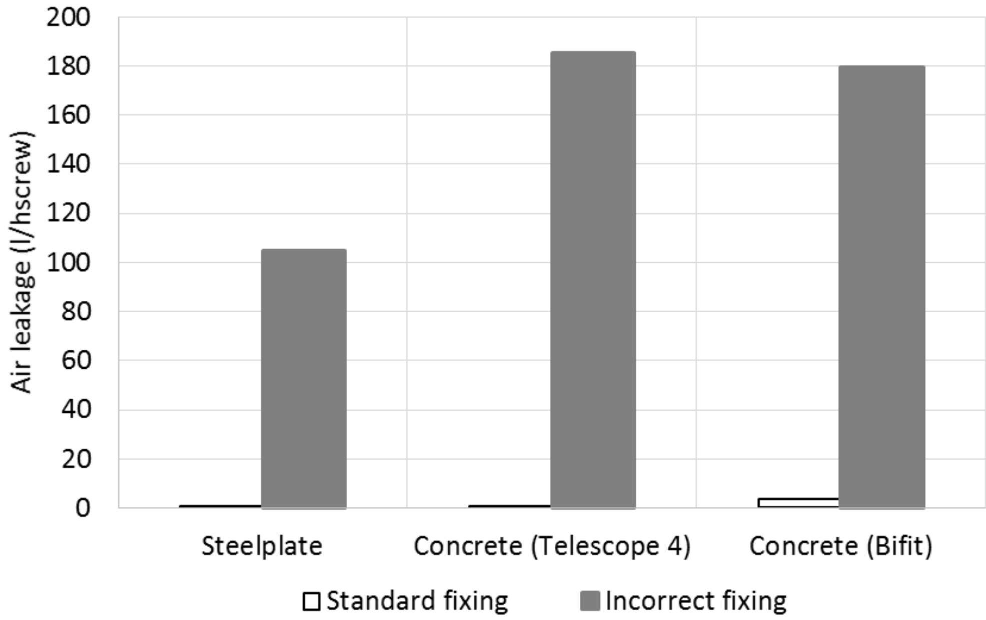

Figure 3. Air leakage of different fastening screws and underlays of 0.65 mm thick steel plate and 60 mm thick concrete.

3.3 Air leakages of loose joints in the PE-foil.

Figure 4 shows the air leakage through a clamped joint in the PE-foil.

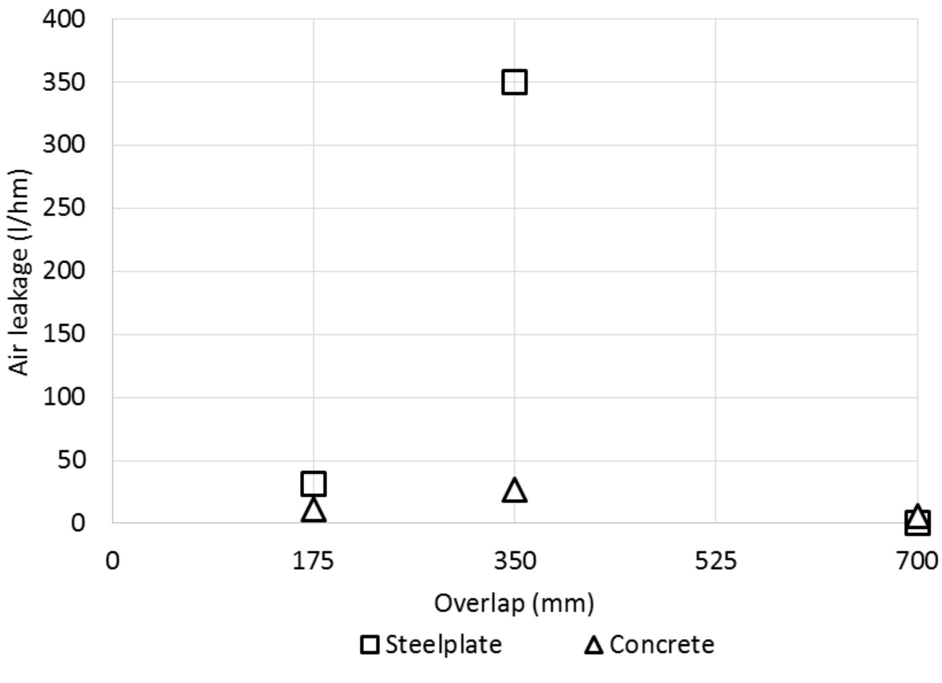

Figure 4. Air leakage of loose joints in the PE-foil.

3.4 Building model calculations

The joint length of the roof was calculated by assuming 4 m width of the PE-foil. A compact roof with an underlayer of concrete and a fastener of type Telescope 4 was assumed. The air leakages of the fasteners, the joints in the PE-foil and incorrectly applied fasteners were calculated using of the results from Table 3 and Figures 3 and 4.

Table 4. Results from the calculation of the two model buildings.

		Model 1	Model 2
Air leakage limit at 50 Pa	**m³/h**	**900**	**10800**
Air leaking through roof	**m³/h**	**3.2**	**29.4**
Air leakage joints	m³/h	0.38	3.99
Air leakage screws	m³/h	1.02	9.18
Air leakage incorrectness	m³/h	1.80	16.2

4 DISCUSSION

4.1 Airtightness of fastening screws

Regardless of the underlay the measurements show a small air leakage through a correctly fitted fastener. As expected, an incorrect fastener represents a considerable larger air leakage.

4.2 Loose clamped joints

The tests were performed under ideal conditions and on a limited sample size. Especially regarding the air leakages through the joints of the vapour barrier care should be taken when evaluating the results. As the results show, the underlayer below the PE-foil is influencing the results to a large extent. The steel plate measurements was performed with the PE-foil directly on top of the corrugated steel plate. The vapour barrier was oriented perpendicular to the corrugations. As the results show this design gives large uncertainties regarding the airtightness performance because the lacking continuous pressure between two plane materials. Therefore, the SINTEF Design Guidelines recommend that the vapour barrier is positioned between a mineral wool layer of 50 mm and the rest of the roof insulation. Compared to the steelplate underlay the concrete underlay gives considerable lower air leakages. An underlayer of concrete results in a rather even surface. Given an underlayer of concrete, there are small differences between the different overlap lengths. However, the lowest air leakage was measured for the 700 mm overlap.

4.3 Two building models

The calculations of both building models showed that air leakages through loose clamped joints and screws amounted to less than 0.5 % of the air leakage limit at 50 Pa pressure difference. Given ideal conditions, this indicates that air leakages through screw holes, both correct and incorrectly installed, and joints in the vapour barrier of compact roofs represent minor air leakages. The results indicate that, given ideal conditions where it is possible to ensure clamping of the joint between two plane materials, the use of adhesive sealing may be unnecessary.

However, adhesive sealing can be useful to ensure airtight joints in and between building parts. Previously (Brunsell and Uvsløkk 1980), (Relander et al. 2009) and (Kalamees et al. 2008) found that joints between the wall and roof are typical air leakage paths. Experience from e.g. building damages also show that it is challenging to ensure an airtight joint between the roof and the wall of a flat roof, see Figure 6. Pictures from a compact roof where moisture transport caused by large air leakages through the air open joint in the vapour barrier between the roof and the wall are given in Figure 5.

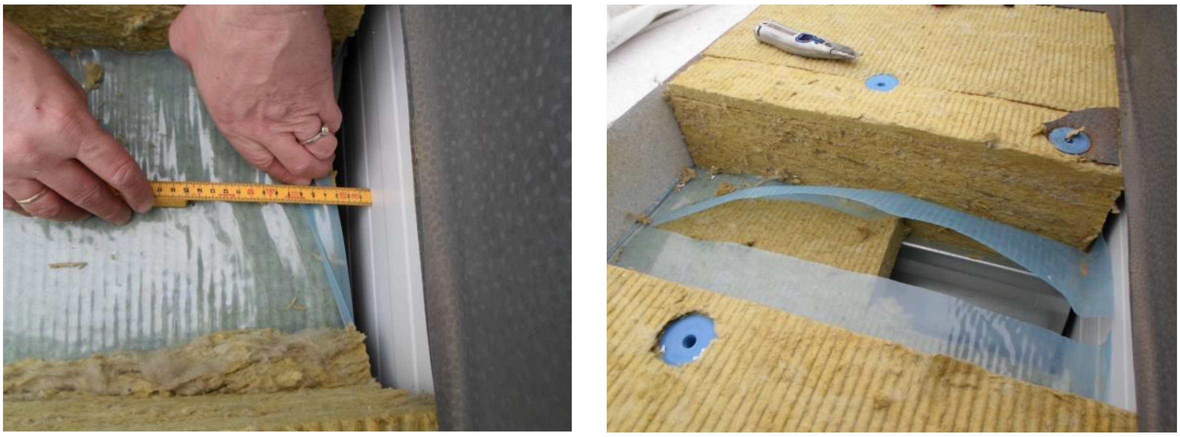

Figure 5. Lacking airtightness of the joint between the vapour barrier of a compact roof and the sandwich wall-element of a large building. Bloating vapour barrier caused by internal overpressure given in the picture to the right (Pictures: T. Bøhlerengen).

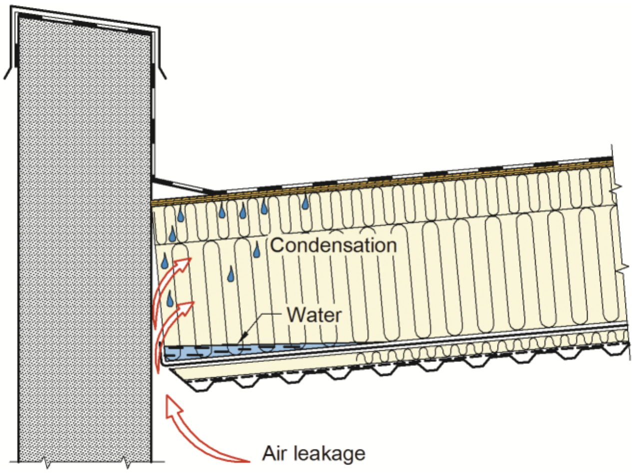

Figure 6. Moist air leaking into the construction causing moisture accumulation.

5 CONCLUSIONS

Calculations of two building models showed that air leakages thorough loose clamped joints in the vapour barrier and standard and incorrect fasteners had a minor effect on the air leakage rate, n_{50}.

Clamped joints with continuous pressure between two plane materials is considered a safe way to ensure the airtightness of joints in the vapour barrier. However, in cases where the conditions are less ideal the measurements show that taping of loose clamped joints may be necessary. Adhesive sealing was found to be useful to ensure airtight joints in and between building parts.

6 ACKNOWLEDGEMENTS

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