DURABILITY OF AIR TIGHTNESS SOLUTIONS FOR BUILDINGS

Peter Ylmén, Magnus Hansén and Jörgen Romild

SP Technical Research Institute of Sweden
Box 857
SE-501 15 Borås, Sweden

ABSTRACT

The aim of the project was to evaluate how the air tightness of buildings changes over time and how the sealing materials are affected during the expected life length of 50 years. The project was divided into two parts were one was laboratory tests of different products with accelerated ageing, and the other part were evaluation of older existing buildings. The laboratory test was conducted in a temporary room with lightweight construction in wood and different sealing products. The room was then heated to 80 °C and had changing relative moisture content in the air. The results showed that most products still maintained their function after accelerated ageing but some products considerably lost their ability to seal air through the building envelope.
In the testing of existing buildings, six single family houses that are between ten to twenty years old have been tested for air leakage. Test reports regarding air tightness from when the buildings where newly constructed were compared to new measurements. Three buildings had made changes to the building envelope while the other three had original structures. The results from the measurements showed that two of the tested buildings had considerably more air leakages than when they were new but that the rest had not changed. The change in air tightness for the two buildings are very likely due to changes made in the building envelope a few years after they were build.

KEYWORDS

Air tightness in buildings, durability, testing, infiltration, jointing, taping

1 INTRODUCTION

The method of constructing houses and buildings in Sweden changed successively during the 60’s and 70’s. Fiberglass and mineral wool insulation were starting to be used on a large scale instead of for example, massive wooden construction.
This change in building method led also to an increase in the use of tightening and barrier layer solutions to reduce the flow of moisture and air through the different construction sections. Different flexible barriers and seals of plastic were introduced and tested on the market, an early example of which is polythene film (PE-film), which had begun to be frequently used as air and moisture barrier in the wall building envelope.
The oil crisis in the 70’s led to a requirement to reduce energy consumption. One method to help with this is to decrease thermal losses in houses by means of, for example, the use of more airtight windows and doors.
By the beginning of the 70’s it was apparent that these new methods of construction resulted in some accompanying problems. Moisture problems could arise resulting in different types of moisture damage in house and buildings. Many of these problems could occur and be found very early after the completion of construction. In certain cases it was possible to see that the durability of a building had already been compromised by the use of sub-standard polythene, which had broken down, become cracked, opened up and caused damage.
In the interest of everybody, an extensive investigation with further research project was started. Statliga planverket (now Boverket), Sweden’s plastic federation SPF (plastic

manufacturers) and the National testing establishment (now SP Technical research institute of Sweden) all worked in cooperation on this. The aim of the project was to obtain a more reliable and durable quality of specific chosen building products (in the first case material for the air and vapour barriers) and tightening solutions. One result of this was the example that the Works Norm (VN) was designed as a basis for voluntary quality and type approval marking for a more reliable higher quality of plastic building products. Included in this was also the requirement that the built in material, not least because of the high cost involved with maintenance or even replacement, should have a minimum life length of 50 years. This means that in the Swedish building trade today it has become the "norm" to use a durable building polythene film with a minimum life length of 50 years.
One example of the works norm for air and vapour barrier using LD-polythene film (which was also the first) is:
[1]. Material requirements plus other demands are written down here, together with, amongst others, how the film should be mounted, how clamped joints and overlaps should be formed as well as requirements for jointing aids. "Joints, including joint material shall meet the minimum requirements set out in the Works Norm for the barrier layer, especially when considering age durability. Joints and joint material shall not affect the function and properties of the building film in a negative manner." [2].
A common problem today regarding the choice of building material is that the question "How long is the product expected to work without the need for maintenance or replacement?" cannot be answered by just looking at the material specification.
There can be many reasons as to why this information isn't available. It can be too expensive or impossible to find out how long the material can work. There may also not be any methods or knowledge available regarding the evaluation of the life length of a building material.
There are a number of investigations that show the importance of airtight construction together with the possibilities of energy savings if the building has good air tightness [Emmerich 2005]. It has been shown that infiltration losses in some cases are higher than the intentional losses from ventilation and much higher than transmission losses.
Air tightness in a building is created by having an airtight barrier with airtight joints and voids/services/penetrations. In many instances the airtight layer is created using a flexible material, such as polythene sheeting. The jointing for this sheeting usually involves the use of stapling, clamping or the use of joint adhesives, bands or tape. Both the polythene sheet and joint material age/degenerate with time, which can lead to a reduction in the air tightness of the building. The same principle applies to joints and voids/services/penetrations in massive constructions. The ageing of the material can be caused by many factors, some of which are heat, cold, moisture, sun (UV radiation) oxygen, ozone, chemicals and mechanical impacts. Furthermore, materials in and around the joints can affect each other by, for instance, the migration of plasticizers.

2 AIM

The aim of the project is to evaluate how the air tightness of a building changes over time, and show which air tightening solutions that are good and durable, and those which are not so good and should be avoided, and transfer this knowledge to the building industry.

2.1 Method

No literature describing durability testing for how building materials affect each other could be found for the project; therefore it was necessary to create a new test method. Since the air tightening materials are to be found inside the building construction and to a certain extent protected from air borne pollution and sunlight when construction is complete, then these parameters were deemed to have a negligible effect regarding durability. However, moisture content in the construction does vary since the relative humidity inside and outside varies throughout the year. The parameters chosen for accelerated ageing of the material were increased temperature together with varying air moisture content. A test rig with humidity and temperature controls was constructed in order to produce a representative scale for actual buildings as well as measuring as many different material combinations as possible.

Construction of test rig

It is most usual with durability testing that smaller samples of material are tested then their physical properties evaluated, for example the measurement of tensile strength. For this testing a 2.2 m square by 2.4 m high room was built, see attached figure 1, together with the different air tightening solutions built in as with a normal building. The material was therefore used in realistic amounts and lengths and subjected to realistic movements that would be expected in a real building.

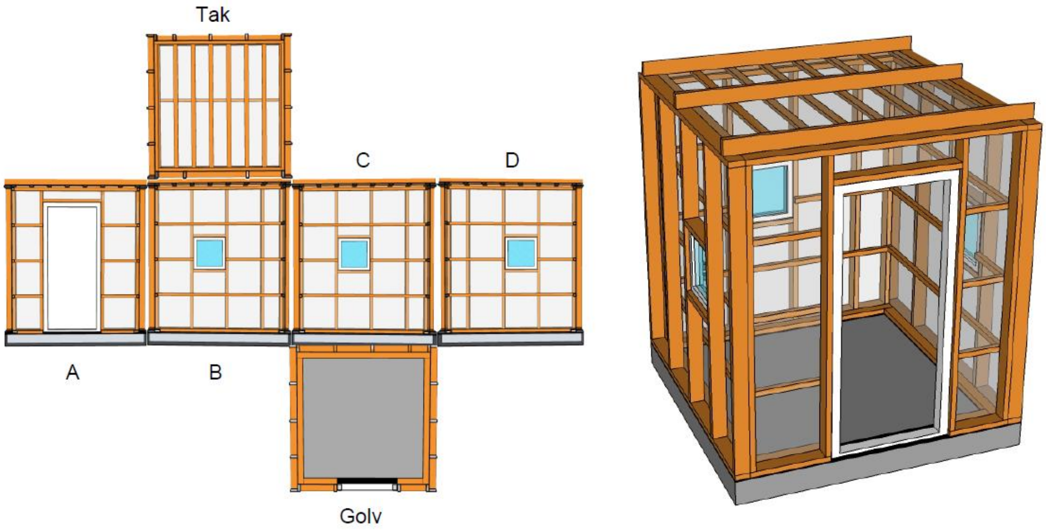

Figure 1. Diagram of the test room construction.

Different methods of jointing polythene sheeting, in particular where the sheeting meets concrete flooring/other concrete sections plus forming around doors, windows, services etc, in other words different variations of taping, jointing, stapling and sill sealing were all prioritized in the construction. This was because of the frequency of problems that arise regarding these particular points with respect to air tightness of a building. The choice of sealing products was governed by those that are readily available in Sweden. Interviews were also conducted with test and construction representatives from Skanska, NCC and Wäst bygg to ascertain which were the most commonly used air tightness solutions used in the industry. This was complemented with information collected from building site visits. The sealing products used were also ones that were described in the manufactures product information as suitable for this type of construction, and that the material could withhold it's durability up to to the 80 °C temperature used in testing.

The building framework was made from wood with fiberglass insulation. The walls were sealed with polythene plastic sheeting, and the joints taped with polythene tape. The floor was in situ cast concrete. At the sill level the polythene sheet was clamped between the inner and outer sill and folded under the inner sill. Sill insulation or joint sealant was applied between the concrete floor and the polythene sheet.

At the eaves the roof plastic sheet was drawn down behind the wall plastic sheet with an overlap of 0.5m. The sheet joints were taped at the top plate and clamped using battens and inner wall studs. Alternative air tightening solutions were used on walls A to D, see attached figure 1.

The air tightness solutions used are explained in figure 2. Service pipes were mounted through walls B, C and D to test alternative sealing methods around services. The pipes used were:

- Zinc plated ventilation canal, marked in grey in Figure 2.
- PVC-free conduit for electricity, marked in red in Figure 2.
- PEX-pipe, used usually in heating systems, marked in green in Figure 2.
- PP-pipe, used usually in heating systems and drainage, marked in blue in Figure 2.
- Copper pipe, used in the test for chemical interest, and is most often clad in insulation, marked in yellow in Figure 2.

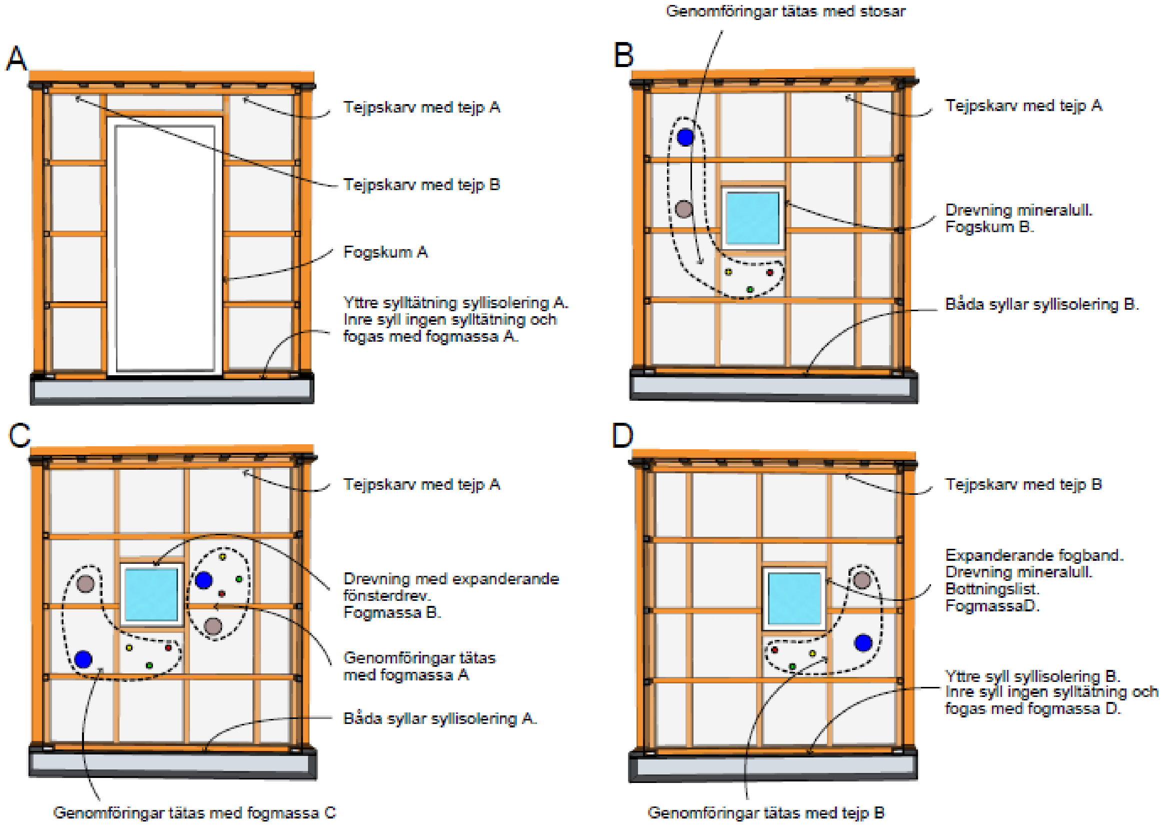

Figure 2. Air tightness solutions for walls A, B, C and D.

Three windows and one door were mounted in the test room, each with a unique individual solution for air tightening.
There are several ways of fixing the plastic sheeting around the windows. For the purpose of this testing it was chosen to fix the sheet in place on the timbers around the windows with double side butyl band. Therefore the air tightening between the window frame and the wall was not protected by the polythene sheet.

Testing and measurement
As a time horizon the durability was chosen as a minimum of 50 years, which roughly speaking was assumed to be equivalent to one year at a temperature of 80 °C and relative humidity of around 50 % in intended use. With the assumption that an increase in temperature of 10°C doubles the acceleration rate of ageing, then one year at 80°C roughly equates to a thermoxidative degradation of the material over a period of 50 years at 20°C. The relative humidity was reduced for one week to 30% to simulate the inside moisture content under the winter season. Heat in the test room was provided by two sauna heaters and a small hole was made in the wall for low ventilation so that emissions from the materials could be aired away. Temperature and relative humidity were continuously logged with a sensor placed in the

middle of the room. A fan was mounted internally in order to reduce temperature variations in the room. The temperature was increased gradually after the start of the test to release any tension in the materials.
Visual inspections were carried out on a regular basis to understand how the materials were affected by the climate under the test period.
Pressure testing was carried out on the test room before and after ageing to see how much air tightness had been affected. An air speed sensor was used at the same time as the pressure testing to find any specific air leakage locations.
When the test was complete the room was dismantled and the individual tightening solutions removed and examined visually for any changes that have occurred under the 50 year period, for example, is the material still in position, has it broken down or has it had any effect on the other materials surrounding it. Specific areas we were looking at were if:

- The materials were still in position and were not loose.
- The elasticity of the materials has degraded so much that some cracks have appeared and/or have released from surrounding materials.
- The materials have shrunk resulting in a decrease in airtightness.

Free standing samples in the test room

Test samples were placed in the room of different sealing products which could be tested for tensile strength and shear after completion of the ageing process. 30 x 40 cm test specimens of the same type and material were also constructed with joint dimensions 12x12x50 mm.

Table 1. Products tested as free standing samples in the room.

Nr.	Product	Description	Test type	Evaluation
1	Tape A	Single sided tape	Film joint	Shear test
2	Tape B	Single sided tape	Film joint	Shear test
3	Spigot	Rubber spigot with single sided tape	Film joint	Shear test
4	Butyl tape	Double sided band of butyl rubber	Film joint	Shear test
5	Joint sealant A	Butyl sealant in a tube	Film joint	Shear test
6	Joint sealant B	Silane polyurethane polymer	Concrete/concrete joint	Tensile strength
7	Joint sealant D	Moisture curing MS polymer	Wood/wood joint	Tensile strength
8	Joint foam A	Moisture curing polyurethane foam	Wood/wood joint	Tensile strength

The constructed joint samples were placed and subjected to the ageing process in the test room in order to evaluate and compare them using the tensile tester with reference samples. After exposure the joints/sealants were tested for tensile strength or shear. The evaluation of taped joints, tape against film was carried out according to SP-method 1380, third edition for materials 1-5.
Evaluation of joint sealants/joint foam was carried out according to SP-method 4372, edition 2.3 for materials 6-8.

On site measurements in existing houses

Testing was executed in older properties in order to see how air tightness is affected by time. One of the requirements for choosing which houses should be tested was that the houses were already tested for air tightness when new plus the method and documentation were still available, as well as any relevant leakages. It was therefore necessary to go through all the documentation from measurements carried out by SP on primarily small houses. For buildings made up of apartments it is very difficult in practice to measure air tightness for the whole building since all the doors of the apartments need to stand open when measurements are taken. It has not been possible either to find sufficiently reliable documentation from

earlier measurements for any apartment blocks. This means that it is only small houses that have been investigated.
A request was sent to several house owners that had a suitable test house, and six owners decided to allow testing.
Testing of the buildings climate envelope was carried out according to Europe standard EN 13829:2000.
A Minneapolis fan equipment Blower Door was used for the measurement of the buildings air tightness. A survey of air leakage at around 50 Pa inside pressure in comparison to outside pressure was undertaken. Negative pressure was formed by use of the fan to measure the buildings airtightness, plus air speed sensors and thermal cameras were used to find air leakages.
Building extensions have been included in the testing which has meant that in three cases the envelope area has been corrected. This also means that changes can have been made in the original building envelope which can give another source of error. Optimally it would have been best if no changes had been made to the houses measured. However, we had only these six houses available so measurements were carried out even if the house had an extension.

3 RESULTS

3.1 Results from the test room

Air leakage through the building envelope at 50 Pa pressure difference calculated according to EN 13829 was 0,11 l/(sm²) before ageing and 0,22 l/(sm²) after ageing.
Most of the solutions have maintained their air tightness after a representative ageing period of 50 years. Solutions which have resulted mainly in a deterioration in air tightness are tape A, tape B, spigot tape, sill insulation B plus sealants C and D.
Solutions using tape on the plastic sheeting have become less airtight because of channels formed in the tape, most likely caused by differences in shrinkage rate of the two materials, see figures 3 and 4.
A similar phenomenon occurred with the only sill insulation of rubber seals which were glued to a plastic strip, see figure 4. Tape joints in the eaves had also similar channels as the tape in other sections, but the leakage wasn't as much here because the joint was clamped by the studs and battens.

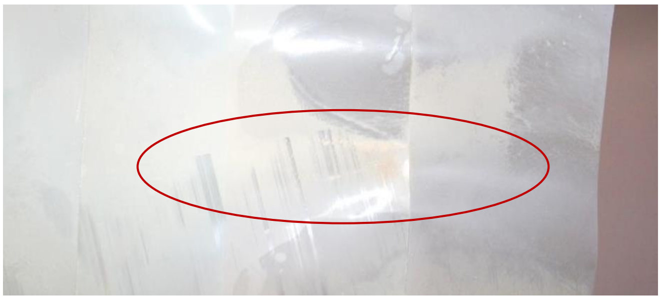

Figure 3. Air channels forming in the tape joint

Figure 4. Air channels in the spigot tape (on the left) and sill insulation (on the right)

It is worth mentioning that the butyl band used in this test also creased together with the plastic sheet, but it was very well fixed to the plastic sheet and no air channels were formed, see figure 5

Figure 5. Butyl band had creased together but maintained an airtight joint.

The joint sealants used in this test which became dense and hardened homogenously remained so, whilst other less dense sealants had set in an uneven manner, with hard sections and soft sections..

This can be caused by the less dense joint sealants do not harden or cure sufficiently quickly and thus are not able to cope when the building sections move , with cracks occurring as a result, see figure 6.

Besides the results from the free standing samples, the visual inspection of the joints doesn't appear to show any chemical reaction with the different building materials, such as wood, concrete, frame paint and the service voids. It appears to be that it is the chemical and mechanical factors in the products themselves which lead to a decrease in air tightness, such as movements in the material and shrinkage (dimensional stability). The results from all the samples are documented in appendix 2.

Figure 6. Joint sealant around a window.

During testing the materials were checked about once a month for any noticeable changes. Channels and cracks were first noted from between one to three months, however, not from the sill insulation as this was a hidden construction. A deterioration of air tightness occurred amongst the tested products before completion of the ageing of 50 years, or not at all. One to three months of accelerated testing represents an ageing time frame of four to 13 years. Furthermore, the size of the channels and cracks increased gradually as the test progressed.

3.2 Summary of results from free standing samples

The results from the free standing samples are summarized below in table 2. The requirements that the products have been compared with in this case is described in the report. The results must be compared with the visual results obtained from the in-built products of the test room as well as the air tightness measurements of the room to obtain an overall picture. The results and requirements must also be compared with the installation method and form of the tested products. The results refer only to the tested properties of the tested materials. The raw data from the tensile strength and shear testing is reported in appendix 3.

Table 2. Summary of the results from the standardized tests of the smaller test samples

Product	Fulfils requirements of SP-method 1380/SP-method 4372
Tape A	Yes
Tape B	Yes
Rubber spigot with tape	No
Butyl tape	Yes
Joint sealant A	Yes
Joint sealant B	No
Joint sealant D	No
Joint foam A	No

Materials 1-2 and 4-5 fulfil the requirement for shear strength and appear to be “visually vapour tight” with no noticeable channels, cracks or damage. Material 3 did not fulfil the requirement, with damage and air channels clearly visible.
Materials 6-8 did not meet the requirements. Joint sealant D was already “broken” after the ageing process and before tensile strength evaluation. Joint foam A did not meet the requirement for air tightness with 3 mm elongation, and also the maximum tension requirement was not fulfilled >0.3MPa after exposure.
Joint sealant B had a reduction in elongation of 38 % at maximum peak force compared with the result from an unexposed sample of joint sealant.

3.3 Summary of results from on-site measurements

The results obtained for air tightness of the investigated houses is shown in table 3 below.

Table 3. Summary of investigated houses.

House	Year built	Air leakage when built [l/(sm²)]	New measurement of air leakage 2011-2012[l/(sm²)]	Changes made to the building/climate envelope
1	1990	0,14	0,95	Yes
2	1990	0,17	0,21	No
3	1993	0,92	1,54	Yes
4	1990	1,11	1,05	Yes
5	1990	0,64	0,57	No
6	2001	0,25	0,23	No

Houses 1, 3 and 4 have all had extensions which mean a change to the original climate envelope. The air tightness of houses 1 and 3 has decreased substantially since the construction of their extensions; however, the same result was obtained for house 4 as for 22 years ago. The reduction in air tightness in two out of the three houses that have had extensions can point towards variations in construction techniques and/or the level of precision used I carrying out these changes to the building envelope.
No changes to the climate envelope have been made over the years to houses 2, 5 and 6, and the results are roughly the same as for 10-22 years ago.
Fewer areas of poor air tightness were noted from house 6, which is 10 years younger than houses 1-5. We cannot explain exactly why this is so, but as house 6 was built as a passive house and therefore with the awareness of building airtight, then this can be a contributable factor for the better result.
To summarize, changes have been made to the climate envelop in three of the six houses, two of which (house 1 and 3) showed an increase in air leakage. In the remaining three houses no

changes have been made to the climate envelope and they have maintained their original air tightness.

4 DISCUSSION

After the measurement of air leakage in six existing houses, it has been shown that it is possible to build a house without risking the durability of its air tightness. Regarding building extensions or renovations then there is a large risk that the new section doesn't come up to the same standard as the older section. This is not a surprising result, but it is worth pointing out because at some stage or other many people will extend or renovate their houses.

It would be of great value from this project if there were a few pointers as to how build a comparably airtight extension on an existing property. Above all the jointing between the old and new construction can be difficult to make airtight. The tested houses were all less than 50 years old, mainly because there were no older houses that had sufficient data to enable an evaluation of how the air tightness had changed over the years. We cannot be sure that 50 year old buildings could have contributed anything to the results or summaries as the construction techniques were quite different from the airtight solutions that are used today. It is also not possible to know exactly which solutions were used in these houses as it would involve a destructive testing of the construction.

The results from the accelerated ageing does show however that the construction material used and application methods can have a great influence on the durability of the air tightness of that building.

At the start of the 90's it was most usual to clamp the plastic sheeting between the wooden sections that make up the wall, whereas today more specialized sealing products are used.

We have not investigated in the laboratory the potential migration of volatile agents from the materials used in the test room (compatibility test). However, it is possible to evaluate each material individually to rule out "infection", and not least the joints in the vicinity of all the other materials in the test room. These migrations can both increase and decrease a material's durability properties.

We have not looked at other properties such as settlement, relaxation etc. Therefore this project must be seen as a screening of the materials involved and not the absolute truth. All the products tested in the test room could not, because of practical implications, be tested as per the standardized test methods. It is worth noting though that there was a difference in the results of the standardized tests of smaller test objects and the results from test room with regard to joint foam A, joint sealant B, tape A and tape B. There are two possible explanations as to why the joint foam and joint sealant failed the standardized tests but passed when in the test room. Firstly, only visual inspections were carried out in the test room whereas the standardized tests requires mechanical loading. Secondly, more of the material was used in the test room, which makes it harder to form cracks through the material. In the standardized tests there is an in built safety margin to ensure that the products make the grade, so it is of no surprise that certain materials fail the standardized test but make the grade in the test room. However, the properties of the tested tapes clearly deteriorated after the ageing process, but passed the standardized tests. The most likely explanation for this is that the smaller sample lengths do not give rise to air channels and are more dimensionally stable in comparison to longer joint length samples.

Furthermore, the plastic sheeting was clamped fast on the internal wooden framework of the walls of the test room, and as a result cannot "move with" when the tape shrinks, whereas the movement of the test joints was not restricted.

The laboratory samples tests that have been carried out in the scope for this project is just a screening and is not suitable for every product type. The laboratory tests of the different tape products in this testing show that they are not a durable solution when used in jointing, plus

we cannot comment on if other tape products give a better durability than the ones tested here. With this project as a background, it would be interesting to execute further testing and study on not just tape but other joint solutions not included here. These further investigations could also be used to see if there is a requirement for the standardized methods to be developed. It can be seen to be wise though to plan the layout of the plastic sheeting so that the joints are clamped in the internal timber framework of the walls.
Since many of the products tested withstood the ageing process and kept their air tightness, then this leads us to believe that today’s methods can give a life length of around 50 years. This was also apparent with the houses tested with unchanged building envelopes which had maintained their air tightness up to 22 years after construction. One should however when choosing materials be sure that they have been tested for durability.

5 CONCLUSIONS

Based on the results obtained from this project, the following conclusions can be drawn:

- It is possible to construct buildings using plastic sheeting as a vapour barrier and maintain its air tightness. Testing of actual buildings have shown that this solution is durable for at least 20 years, and the laboratory tests show that if the right materials are used then a durability of 50 years is possible.
- There is a large risk that the air tightness of a building will decrease if the building is redeveloped or extended.

There has been only a small amount of each product type used in the laboratory testing, so no general conclusions can be drawn from this, only that the results are applicable only to the tested products. The tested products do show however:

- The chosen tape products pass the durability tests for smaller test samples, but were not airtight in the test room with larger joints. This can mean that the methods used for the testing of tape should be reviewed, as well as the methods for how the tape is used.
- The chosen joint foam products failed the standardized durability testing but maintained their air tightness in the test room.
- Some of the joint sealants became more airtight through accelerated ageing/hardening whereas others had poor durability. There was a difference here also between the results obtained from the standardized tests and the results from the test room. These differences can be attributed to the thicker joints used in the test room plus the in-built safety margins of the standardized tests.
- The durability of one sill insulation became worse after the ageing process, with a similar property change as that which occurred with the tape – air channels form because of different dimensional stabilities in the different materials in the air tightening solution.
- There are no indications that the materials used in the test room lead to inferior durability of air tightening products under normal building conditions. However , the effect of large mechanical loading for example wind load, or the impact of free water on all the materials has not been investigated

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