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Review of Durability of Bitumen Waterproofing

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Summary

Under normal application, design and maintenance conditions, a service life of more than 35 years can be expected and is generally accepted by the certification bodies for roofs with modified bitumen membranes.

The roofs can be renovated by a new layer of modified bitumen sheet bonded to the existing roof, so in practice the roof can last for significantly longer. It is realistic to renovate the roofs once or twice without removing the old roofing, so working life can be extended to more than 105 years with one or two renovations.

The commonly assumed figure of 30 years' service life of reinforced elastomeric or plastomeric bitumen roofing systems for roof waterproofing, is a conservative (safe) evaluation of the expected service life.

The increase in service life over the last 40 years is due to improvements in the products, workmanship, design and greater focus on maintenance.

Contents

Durability of Bitumen Waterproofing

Foreword

This document considers the complete bituminous waterproofing system, which may consist of one or more bitumen waterproofing membranes and a substrate of insulation, or boards, vapour control layer and load bearing structure.

A literature study has been carried to determine the expected service life of the membrane itself. The other parts of the roof are assumed to be correctly designed and installed. Only waterproofing materials based on polymer-modified bitumen are considered.

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The literature survey includes data from roofs up to 40 years old and the technical evaluations have been carried out by independent institutes.

1. Scope

The purpose of this study is to determine the expected service life (ESL) of bituminous membranes, as this is a key parameter used when calculating the Environment Product Declaration (EPD) of flexible bitumen sheets for roof waterproofing.

This report collects available data on durability and the ESL of reinforced bitumen waterproofing membranes, manufactured in accordance with former national standards or UEAtc guidelines and later with Factory Production Control systems compliant with EN13707. The main application is roofing, but other applications such as basement tanking, damp proof courses are also relevant. However, most of the studies of bitumen waterproofing are for roofing applications, because roofing is considered the most severe application for such membranes.

The bitumen waterproofing membrane is required to prevent water ingress throughout its service life, with normal maintenance being carried out. However, the longevity of the waterproofing system as a whole, is also determined by the design, installation and maintenance etc. of the system and not only by the membrane itself.

2. Definition of bitumen roof waterproofing system

A bitumen roof waterproofing system consists of 1 or 2 layers of reinforced bitumen waterproofing membranes.

A bitumen roof waterproofing membrane consists of the following:

- Protection, if any
- Top coating
- Reinforcement/carrier
- Bottom coating

The reinforcement (carrier) is mostly based on polyester non woven alone or combined with a glass felt, glass net or glass fibres.

The bituminous waterproofing system always contains at least one layer of polyester reinforcement.

The top and bottom coatings are based on modified bitumen. The polymer modifiers used may be either plastomeric (e.g. APP) and/or elastomeric (e.g. SBS) and/or other polymers of the same chemical families.

Modern bitumen membranes are manufactured in accordance with the harmonized product standard EN 13707. However, experience with these membranes is much older than the product standard and this experience is embodied into the product standard.

The first modified bitumen membranes entered the market in 1965 (APP modified) and 1968 (SBS modified). The first technical approvals for these products were issued in 1972 in France. The first technical guideline was published in 1984 by UEAtc, with performance requirements for modified bitumen mixes, modified bitumen roofing sheets and modified bitumen roofing systems.

The bitumen membrane is mostly installed on a substrate of insulation, on a deck of steel or concrete, or directly on concrete, timber boards or plywood.

The membrane can be mechanically fixed, torched, otherwise bonded to the substrate, or loose laid with ballast.

In two-layer systems the top layer is torched or bonded to the bottom layer.

3. Definition of service life

Guidance Paper F -Durability and the Construction Product Directive –CEN 2004 [21] defines 'working life'. There is a distinction between **working life of works (roof system)** and **working life of a single product (roofing membrane).**

3.1 Expected service life

The expected service life (ESL) is the expected time where the essential required performance of the product is maintained at an acceptable level, which for bitumen waterproofing products is the water tightness

3.2 The working life of works

The period of time during which the performance of the works will be maintained at a level compatible with the fulfilment of the Essential Requirement (e.g. water tightness).

In this context the working life of works is the working life (service life) of the waterproofing system

3.3 The working life of a product

*The period of time during which the performance of a product, confirmed by inspection, will be maintained at a level that enables a properly designed and executed works to fulfil the Essential Requirements. The working life of a product depends on its inherent **durability** and normal **maintenance**.*

A clear distinction has to be made between **assumed** economical reasonable working life for a product (design working life) which relies on the assessment of durability in technical specifications and the **actual** working life of a product in works, which depends on many factors beyond the control of the producer. These factors include design, behaviour of the substrate (e.g. insulation), installation, use and maintenance.

It is important to stress that the assumed working life cannot be interpreted as a warranty given by the producers.

The working life of the product is the working life (service life) of the waterproofing membrane itself.

3.4 Durability of a waterproofing product

This is the ability of a product to maintain its waterproofing performance (water tightness) over a given period, or a long period of time, under the influence of foreseeable actions, during its working life. These actions include humidity, temperature, UV-radiation etc.

3.5 Determination of membrane working life

The working life of a bitumen membrane is influenced by several factors such as the level of polymer modifiers, thickness and quality of reinforcement and can vary depending on the in-service conditions.

A clear distinction has to be made between the assumed working life which relies on the assessment of durability of water tightness and the actual working life of the product in service.

Both the assumed working life and the actual working life (service life of the waterproofing membrane) are defined as the mean value of a statistical distributions, as illustrated below. These may be assumed to be 'normal' distributions.

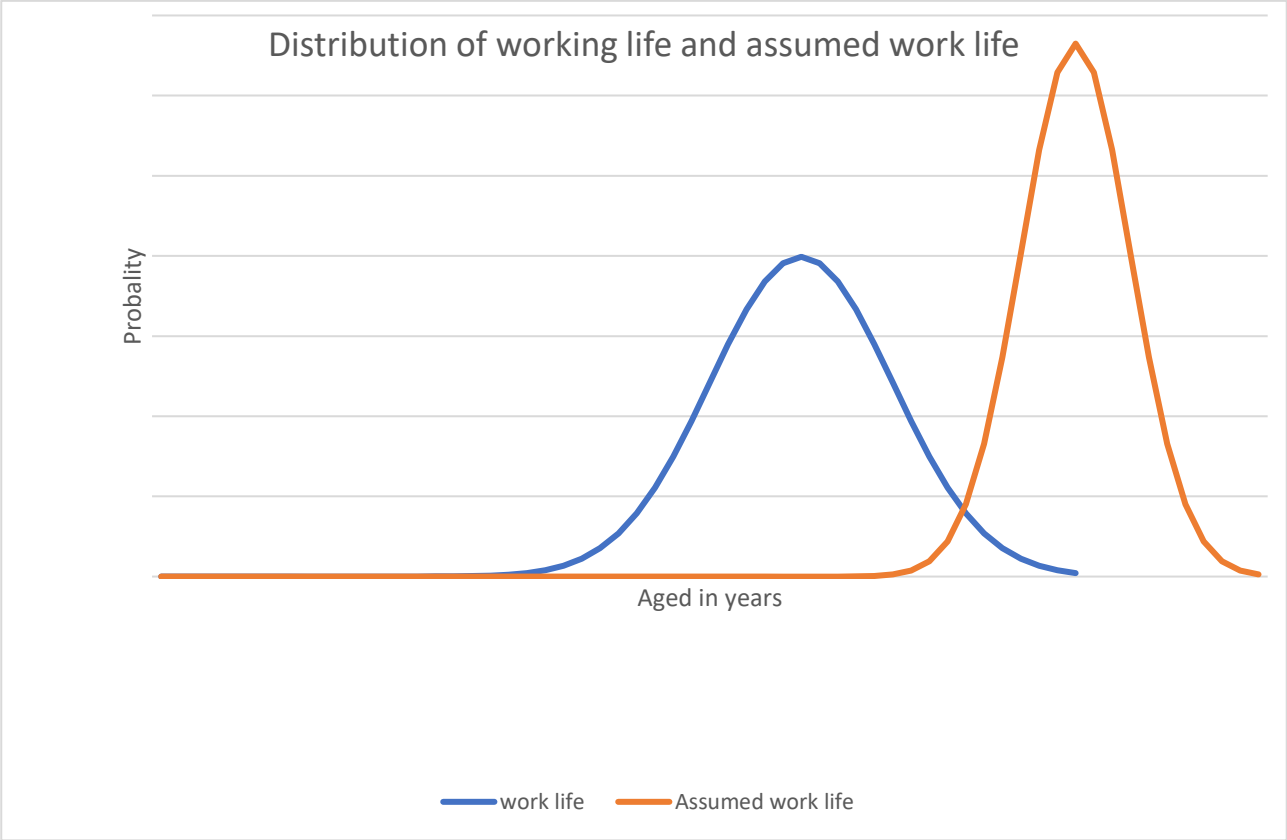

Figure 1: The working life and the assumed working life distribution can be considered normal distributions

The service life shall be determined by statistical analysis of a significant number of roofs. It shall not be determined from a few roofs that have lasted for a long time. Neither shall the service life be determined from a few roofs which have failed early in their lifetime due to mistakes in the design of the roof, or errors in the workmanship.

Apart from the quality of the membrane, the working life is influenced by several factors:

- Design of the roof (details, substrate, flashings, protection etc.)

- Slope and drainage of the roof
- Behaviour of the substrate
- Installation of the roof (workmanship)
- Maintenance of the roof
- Number of layers in the roof
- Use of the roof (green roof, trafficable roof etc.)

There are some circumstances when the membrane may be replaced long before the end of its life. These include renovation to improve the energy performance of the roof, for instance, installing thicker insulation or Photovoltaic systems.

Also, roofs are sometimes replaced due to some minor leakage when all that is required is some maintenance or correct detailing. Such instances cannot be considered as the end of life.

The end of life of the bitumen membrane is when the membrane has to be changed or renovated due to a number of leaks that are unacceptable.

3.6 Indicative design working life

In Eurocode EN 1990:2002 – Basis of structural Design – [24] the indicative working life for building structures is set to 50 years, while replaceable structural parts are set to 10 to 25 years.

Roofing must be categorized as a replaceable part in normal visible roofs. In parking decks, roof gardens and roof terraces the roofing material is not easy to replace and the assumed working life should be longer.

In ISO 15686-1 [25] the assumed working life of major replaceable components is given as 40 years for a design life of the building of 60 years.

3.7 Factor Model

The expected service life (ESL) or working life of a roof waterproofing system (i.e. of the membrane itself as waterproofing key element) can be modelled using the different factors influencing the end of life. This factor model is described in ISO 15686 and in conference papers on service life [30] [31].

ESL = RSL * factor A * factor B* factor C * Factor D * factor E * factor F * factor G

Where

- **RSL is the reference service life** of the roofing system.
- **A relates to the quality of the component** (Represents the grade of the component supplied, which is influenced, for example, by the polymer content,, thickness of membranes etc.)
- **B relates to the quality of the design** (Influenced by the detailed design, slope of the roof, number of layers, the components used, the typical build and the level of protection afforded etc.)
- **C is work execution level** (is typically considering the level of skill and control of the site work, examples are roofer's training program, site inspection before handing over etc.)
- **D is indoor environment** (determined by the use of the building.)
- **E is outdoor environment** (Considers the exposure to outdoor agents and their severity, for instance in industrial areas, farm sites etc.)
- **F is in-use conditions** (Reflects the effect of the use of the building/construction asset, examples are traffic on the roof, number and nature of plant installations etc. on the roof.)
- **G is maintenance level** (Reflects the level of maintenance, examples are regular inspection plans etc.)

The factors are typically in the range of 0.8 to 1.0 –

Note: An example of the relevance of the important parameters is shown in Figure 2, although the numbers require further analysis before they can be used in the Factor Model described.

ESL is equal to RSL Reference Service Life when all the factors are at the highest level.

The factor model has been used in Lithuania and described in [34]. The more complex the roof is the more requirements for properties of the roofing materials.

A report from AMI 2017 [7] shows that the workmanship (work execution level) is the most important factor for synthetic roofing. For bitumen roofing the impact of workmanship is less because, for example, two layer membranes are fully torched compared to synthetic mechanically fastened one layer membranes with welded edges.

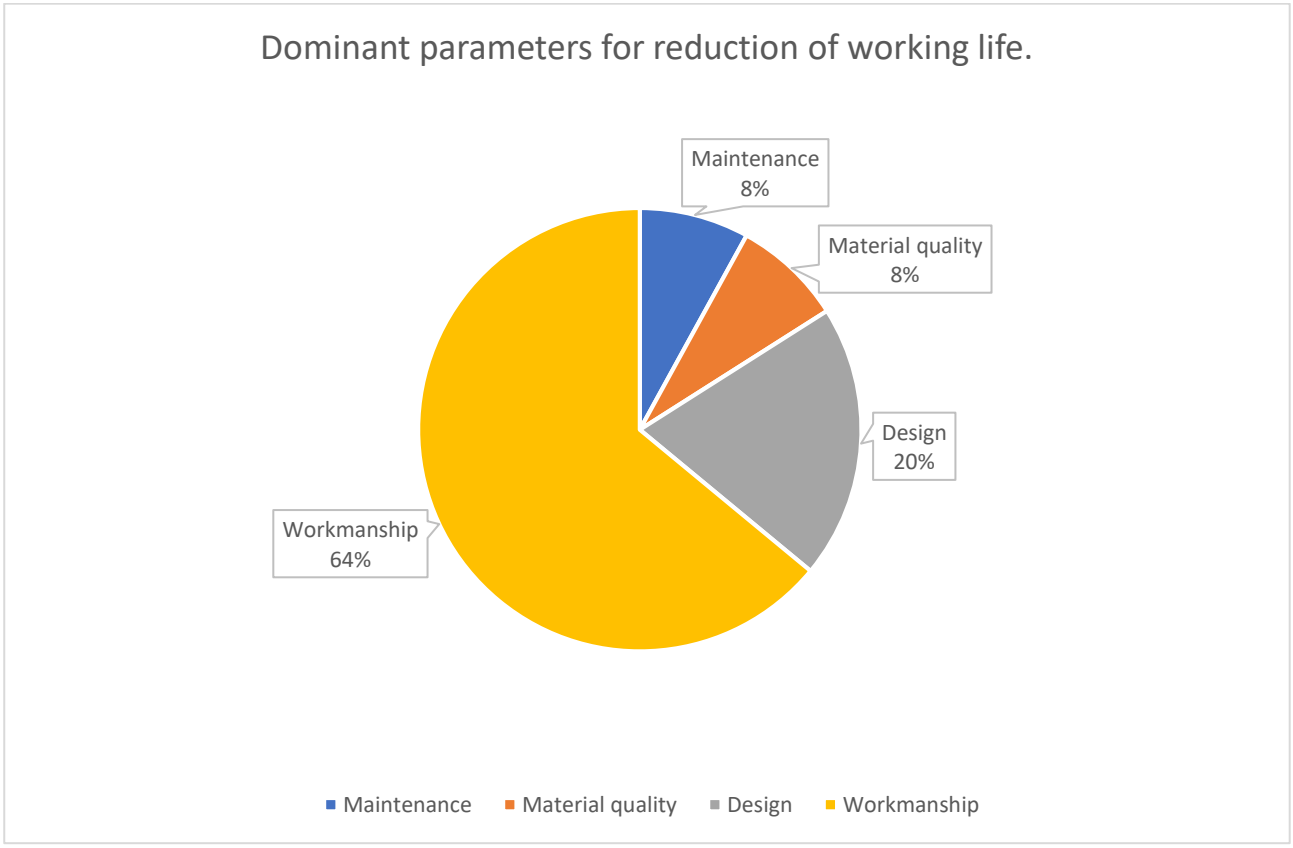

Figure 2: Workmanship followed by design are the dominant factors for reduction of working life of a roof [7].

The assessment of service life of geomembranes has been dealt with in [28], and is similar to roofing as some of the materials are the same.

4. Roof waterproofing membranes

4.1 Bitumen coating

There are two main types of polymer modifier used for bitumen coatings (see *note 1*)

- Plastomeric bitumen: Modified by addition of polyolefin or polyolefin copolymer compounds e.g APP or TPO
- Elastomeric bitumen: Modified by addition of thermoplastic rubbers e.g. SBS

The amount of modifier is 20 – 30 % for plastomeric bitumen and 10 – 15 % for elastomeric bitumen.

The main factors causing ageing of bitumen membranes on roofs are solar heating and UV-radiation. The influence of these is evaluated using test methods in the product standard EN 13707.

One of the first investigations of modified bitumen coatings was by CSTB in 1983 [1]. For SBS they determined the acceleration factor between artificial ageing and ageing in the natural climate and used that to accurately determine the durability of the bituminous membrane. For testing at 70 degrees C the acceleration factor was at least 50.

Note 1: earlier bitumen used for roofing was oxidized bitumen, but since the 1990s oxidized bitumen has increasingly been replaced by modified bitumen, which has much better properties, especially flexibility and durability.

4.2 Reinforcement

Waterproof bitumen sheets are reinforced with a carrier of polyester or glass or a combination of the two. The glass provides dimensional stability and protection against fire, while the polyester provides mechanical properties.

The polyester material has proven to be very resistant to degradation due to UV and furthermore it is protected by the bitumen cover. Some of the results on resistance to degradation come from studies of geotextiles. [19]

The introduction of polyester reinforcement from 1980 to 1990 was key to improved durability of bitumen membranes. [29].

4.3 Protection

The surface of the bitumen membrane can be either protected or unprotected. Membranes based on SBS are always protected while membranes based on APP bitumen can be unprotected. The protection against damage from UV-radiation normally consists of granules of slate

An extensive study carried out in The Netherlands confirmed that these materials are durable for over 30 years [see 29]

4.4 Test methods for artificial ageing

Durability ageing tests have been used in product approvals since the 1980. Current test methods are specified in EN 13707 [16] and UEAtc requirements 2001 (11)

Three types of ageing are carried out and the duration of the tests is determined by the particular membrane application:

- Heat ageing in a ventilated oven at 70°C,
- UV ageing,
- Hot water at 60°C,

After exposure to these conditions for the designated times key properties of the test samples are measured (heat flow and /or cold bending of the sheets, peel and/or shear of the joints)

These test methods do not give results corresponding to the service life conditions in practice, but do ensure the membranes are fit for the intended application.

Some roofing products need no specific ageing tests (e.g. roofs under ballast).

A Swiss study [32] highlighted a different durability according to different systems. Under heavy protection, systems are for sure less exposed to temperature variation and solar radiation, but there are other systems like inverted roof which may have even longer durability.

Ageing of the overlaps are not covered by the product standard EN 13707. Nevertheless, many producers have included the durability of overlaps as part of their product approval process. The reported evaluations are based on experience and roof inspections. [29]

4.5 Agréments

The first approvals or agréments from CSTB, France, for bitumen membranes based on oxidized bitumen were issued in the 1970s. These quoted a service life of 10 years as French law did not allow a longer service life.

Later, durability testing of modified bitumen suggested a service life of at least 20 years [5].

The first approvals or Agréments issued for modified bitumen waterproofing membranes are from the 1980s [17]. They assumed a service life of 20 years.

These Agréments (certificates) continued to be renewed over the years and the service life was increased to 30 years in 2013.

UK BBA Agréments are based on both field experience and laboratory durability tests according to the UEAtc-guideline from 2001[11] and ETAG006 [20] from 2012.

The Agréments [18,22,23] from 2013 and since give a service life of 30 years or more.

5. Roof Waterproofing System Roof inspections

There are a number of studies where inspections of roofs have been combined with laboratory testing. These studies are the most valuable to predict the service life as they include a combination of natural and artificial ageing using materials taken from the inspected roofs.

In a Danish study [3], some 10 -12 years old roofs with SBS-bitumen membranes were inspected and samples of the membranes were analysed. The conclusions extracted from the report were as follows:

4. DISCUSSION AND CONCLUSION

Based on the findings from the visual inspections it is believed that good performing roofs with roof membranes can be achieved provided that the above-mentioned factors are taken into account when designing and executing the roof, i.e.:

- to obtain a good roof a high-class roof covering is necessary,
- two plies will generally provide better protection than one layer
- a roof with a well-defined slope will eliminate/reduce the risk of ponding and decrease the time of wetness and the risk of ice building,
- the construction, including the underlying substrate, shall be stable enough to avoid deflections that may damage the roof covering,
- the roof shall be designed taking into account not only the constructions but also the installations and any complications that may arise due to the severe exposure to water and high relative humidity,
- the structure that supports the roof shall be stable enough to avoid deflections that may damage the watertight layer and the surface covering,
- the fastening shall secure the roof covering and must not cause unintended increased load on the membrane itself,
- all details shall be well described/illustrated, easy to make on the building site and preferably with a good use record (or tested for water tightness),
- pedestrian traffic should be avoided as far as possible or measures should be taken to protect the membrane from direct contact,
- the roof shall be maintained regularly preferably on basis of regular inspections, especially as regards details etc.

Undoubtful the factors mentioned are crucial for the service life. The findings from the visual inspections and the laboratory tests seem to confirm that the service life model - at least for bituminous roof membranes - gives a good estimate of the service life. It should be emphasized that the model is rough and with considerably uncertainties, as some of the factors are based on individual evaluation.

The experience from the few problems in the warranty shows that it is often the details of the roof that fails – which is in accordance with the findings in the survey. Therefore, the service lifetime model should emphasize the use of correct and safe details in the roof design more.

Figure 3: Conclusion from the Danish study [3]

In the 2005 Finish study [14] the following concluded that laboratory tests on SBS modified bitumen membranes showed only a very small effect of ageing and the performance properties of aged samples still exceeded those required of new products

In another Finish study [13] the conclusion was the following:

> The laboratory tests revealed that SBS-modified bitumen sheets have remained their mechanical properties over time. The results of over 30-year-old SBS-bitumen roofing's exceeded the requirements of new similar membranes.

Figure 4: Text from Finish study [13]

In 2008, a literature study of field inspections with both APP and SBS roofing [5], was performed by BWA, and the conclusions were as follows:

> Roof Surveys
>
> The result show clearly a very stable judgement over a period of more than 16 years on the Expected Service Life (ESL) of both APP and SBS modified bitumen roofs concerning a large number of surveys. All the ESL's contain the figure of 25 years. The relatively small variations is primarily due to the length of the period during which the concerning product was at the market in the year of the survey. This also means that the trend on ESL for established products is increasing to at least 30 years.
>
> The eventual limit in the durability/service life of bitumen roofing membranes will be determined mainly by external factors such as:
>
> - Workmanship and installation circumstances
> - Stability of the substrate
> - Use and (lack of) maintenance of the roof
>
> Based on this safe assumption for a general service life declaration for modified bitumen roofing membranes can be taken as 25 – 30 years.
>
> Other literature:
>
> Although there are quite a few publications (in one way or the other) to the durability of bitumen roofing, there are not many statements in terms of Expected Service Life. The few available statements vary from 'at least 15 years' and 'at least 25 years' to 'more than 30 years', the oldest roof being 36 years old. These figures support the above-mentioned assumption for a general Service life declaration for (modified) bitumen roofing membranes to be taken as 25 – 30 years.

Figure 5: Conclusion from the BWA study on roofs with modified bitumen membranes [5]

This study was based on many publications and scientific studies and reported a long list of references.

A Belgian study with a specific roofing material combining SBS and APP [10] reported the following conclusions:

> The conclusion regarding service life is the following:
>
> *We can conclude that, after another period of five years of natural ageing, the membrane installed in different types of roof covering systems, on roofs in different continents across the globe, continues to perform very well.*
> *Bearing in mind that the oldest roofs are now more than 20 years old, we can now state that, provided that the roof surface and the roof details are properly maintained,the life expectancy put forward five years ago can be extended by another five years. Meaning: we believe that a life expectancy of 25 to 35 years is realistic*.

Figure 6: Conclusion from [10]

In other studies, carried out in 1995 and confirmed in 2011 [4][6], the durability of APP roofing membranes with double reinforcement was confirmed in practice. An estimated minimum of 30 years life expectancy was confirmed.

In several other studies of APP roofing materials [11], [17], [18], the expected service life was estimated to be 30 years.

A more recent paper from 2018 reported on a large number of durability studies [29] and is summarised as follows:

Final conclusions and further considerations
1. *The results show clearly a very stable judgement on the Expected Service Life (ESL) of both APP and SBS modified bitumen roofs over a large number of surveys and a period of more than 16 years. All the ESL's contain the figure of 25 years*

2. *The relatively small variation is primarily due to the length of the period during which the concerning product was at the market in the year of the survey. This also means that the trend on the ESL for established products is increasing to 'at least 30 years*

3. *The eventual limit in the durability/service life of Bitumen roofing membranes will be determined mainly by external factors, such as: - workmanship and installation circumstances - stability of the substrate - use and (lack of) maintenance of the roof*

4. *Quite a few of the surveys we did concerned one or more follow-up(s) of earlier surveys. This can be explained easily: Marketing. The manufacturer's liked to show that the ESL of their product was better than the ones of their competitor's*

5. *This was one of the reasons that we decided some years ago to stop with this follow-up surveys with no other objective than to get a higher ESL for a product. We have fixed the maximum ESL-declaration to 30 years*

6. *Other reasons to stop with these follow-up surveys were more practical: in several cases, roofs of more than 20 years old which we had visited 5 years ago simply no longer existed: they were refurbished and a much thicker insulation was installed, but there were also cases were the whole building was replaced by a new building, so it was impossible to find enough roofs to make a proper assessment*

Figure 7: Conclusion from Dutch study [29]

The paper from the study [29] also gives the following final remarks:

Some last remarks
1. *The introduction of modified bitumen (both APP and SBS) has been very important for the durability and sustainability of the modern waterproofing membranes, however for the success of these products there is another aspect which is at least as important: The introduction of the non-woven polyester reinforcements. This introduction coincided. more or less, with the birth of the modified bitumen, which many seem to forget*

2. *During the last 10 years the non-woven have even been developed further, more specifically with the polyester-glass combinations, which really have improved the behaviour of modern bitumen roofing membranes.*

Figure 8. Final remarks from [29]

All these results once again confirm and emphasise the opinion that the problems concerning waterproofing are not usually linked to membranes, but predominantly depend on installation, design and maintenance.

6. Discussion and conclusion

The durability of construction products may be verified using performance-based methods, descriptive solutions (as Factor Model) or a combination of the two.

European technical approvals are based on roof inspections, tests and an assessment of the product giving scope for both types of solutions mentioned above.

A main route to durability assessment involves performance testing of products to determine the change in their performance characteristics under specified ageing conditions.

The ageing conditions are chosen to accelerate the effects of natural ageing to make the test period as short as is reasonable. These accelerated tests are validated by comparing the properties of the materials after test, with those taken from real roofs of various ages.

The process of service life prediction is given in ISO 15686-2 [27] and is a combination of accelerated testing and long-term exposure on real roofs.

Accelerated ageing tests of bitumen roofing membranes are given in EN 13707 and the UEAtc -guideline. These tests alone do not provide enough evidence of good durability and must always be combined with field experience of long-term exposure.

The durability of the roofing membrane alone is not enough to estimate the expected service life of the roofing system. A field study is required to demonstrate the membrane can be installed on the substrates in question and that the detailing is adequate. .

For new roofing membranes approvals can only be issued after some years of practical experience.

There are a number of studies which combine roof inspection and laboratory testing. Such studies provide valuable information to estimate the working life of flat roofs with modified bitumen membranes.

The estimated roof service life indicated by test institutes is more than 30 years and up to 50 years. The oldest roofs with APP and SBS roofing membranes are more than 36 years old, so the service life of the roof and durability can also be estimated by practical experience and long-term exposure.

For practical applications the average working life of bitumen waterproofing is estimated to be more than 35 years. Lack of proper maintenance will lead to a reduction in the service life of the roof. Similarly, poor workmanship and bad design (for example inadequate flashings or a roof slope which is too low) will also reduce the service life of the roof. A roof slope which is too low encourages ponding of water and potential damage, particularly due to ice formation. Workmanship is considered by the approval bodies to be the most significant factor affecting service life. From the literature-study, an even longer service life of more than 35years and up to 50 years can be achieved for individual roofing systems if the design, workmanship and maintenance are all good.

The influence of these factors on the service life can be determined using the factor model described earlier.

With this in mind, the 30 years' service life of such reinforced elastomeric or plastomeric bitumen roofing systems for roof waterproofing, which is commonly used by approval bodies and institutes, can be considered a conservative evaluation of the expected service life. [29, 22, 23]

The increase in service life over the last 40 years is due to improvements in the products, workmanship, design and greater focus on maintenance.

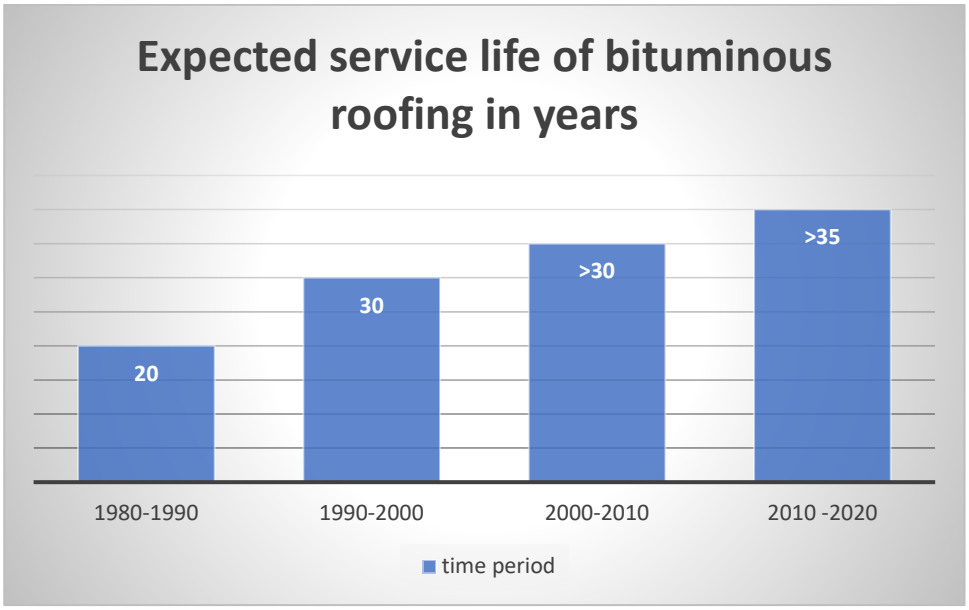

Figure 9. The increase in expected service life of bituminous roofing membranes over the last 40 years.

In the 1990s the estimated service life of 20 years was based on limited practical experience. There is now much more experience.

The conclusion of this literature study is that under normal application, design and maintenance conditions, a service life of more than 35 years can be expected and is generally accepted by the certification bodies for roofs with modified bitumen membranes .

The roofs can be renovated by a new layer of modified bitumen sheet bonded to the existing roof, so in practice the roof can last significantly longer. It is realistic to renovate the roofs 1 or 2 times without removing the old roofing, so the working life can be extended to more than 105 years with one or two renovations.

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