RESEARCH REPORT

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100 years' service life of wood material in dry conditions

Authors: Hannu Viitanen

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100 years' service life of wood in dry conditions

Customer, contact person, address	Order reference
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Summary

The **service life of buildings and structures** is an important part of the life cycle planning. The **performance** of wood and wood-based materials with a given level is quantified as the level of ability to withstand load, exposure or deterioration over time in specified service conditions. EN 1995-1-1 defines a set of three service classes which are relevant to a designer when assigning strength and durability for timber elements to be used in a construction. In this work the focus is in the service class 1 (dry condition).

Performance requirement means the **minimum acceptable level of a property of a product**, which can be defined as **a limit state**. This defines the limit between acceptable performance and non-acceptable performance. **Durability** is defined "The ability of a product to maintain its required performance over a given time, under the influence of foreseeable actions, subject to **normal maintenance**". No significant differences on durability between massive wood and wood based engineering products (plywood, LVL, CLT) have been found, and the same service life category can be used for timber and engineering products.

Service life is the period of time after installation during which a building or its parts meets or exceeds the performance requirements. For the insulated building envelopes, most important performance requirement is to keep wood and structure in dry conditions. Humidity and moisture control in building envelope is a key action to prevent moisture excess and damage caused by water, microbes, fungi or other organisms**. Reference service life** (RSL) is the expected service life of a building, material or component situated in well-defined set of conditions.

Design or expected service life is an evaluated service life calculated on the base of RSL and several different factors. Obviously most advanced service life evaluations are shown in the ISO 15686 series: the RSL or standard service life multiplied by a variety of factors based on a more careful consideration of the quality of materials, actual design, construction, use condition, maintenance and climate exposure of a specific building, building material, element, component or equipment.

Using a factor method to **evaluate the service life of insulated wooden building envelope** (service class 1), the most important factors are design and execution. If the values of these factors are high and moisture exposure is not exceeded the tolerances, there is no obstacle to get service life above 100 years using 50 years reference service life in the service class 1 condition. The eventual climatic loading has to be taken care as following: when the service life of wooden loadbearing structure will be higher than 50 years, the natural loading is evaluated to be 10 % higher than that for 50 years' service life and 20 % higher when the expected service life is above 100 years.

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Written by	Reviewed by	Accepted by
Hannu Viitanen, Senior Scientist		Raija Lantto Technology Manager

VTT's contact address

P.O. Box 1000, FI-02044 VTT, Finland

Distribution (customer and VTT)

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Raportin otsikko	
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Summary

Rakenteiden ja rakennusten kestoikä on tärkeä osa elinkaarisuunnittelua. Puun ja puutuotteiden **toimivuus** ja sen taso arvioidaan sen mukaan, miten ne kestävät kuormia, rasitusta ja vioittumista ajan suhteen sekä määritellyissä käyttöoloissa. Standardissa EN 1995-1 (Eurocode) on annettu kolme käyttöluokkaa, jotka ovat tärkeitä suunnittelijan arvioidessa rakenteissa käytettävien puuosien lujuutta ja pitkäaikaiskestävyyttä. Tässä työssä keskitytään käyttöluokkaan 1 (kuivat olosuhteet).
Toimivuusvaatimukset tarkoittavat **pienintä hyväksyttävää tuotteen ominaisuutta eli rajatilaa** (hyväksyttävyystasoa). **Pitkäaikaiskestävyys** tarkoittaa tuotteen kykyä ylläpitää tarvittavaa toimivuustasoa ajan suhteen etukäteen arvioiduissa oloissa, normaalien huoltotoimenpiteiden puitteissa. Puumateriaalin ja vaatimusten mukaan valmistettujen puukomponenttien (vaneri, LVL, CLT) pitkäaikaiskestävyydessä ei ole havaittu merkittäviä eroja, jolloin niiden ja massiivipuurakenteiden osalta voidaan tarkastella kestoikää samoista lähtökohdista.
Kestoikä on vastaavasti se aika, jolloin rakenne pystyy ylläpitämään vähintään vaadittua toimivuustasoa rakennuksen tai rakennusosan asennuksen jälkeen. Lämpöeristetyn rakenneosan kannalta tärkein toimivuusvaatimus on puun ja rakenteen pysyminen riittävän kuivana. Rakenteen kosteuden hallinta on tärkein periaate suojattaessa rakenteita kosteuden kertymistä sekä veden, mikrobien, sienten ja muiden organismien aiheuttamia vaurioita vastaan.
Vertailukestoikä on rakennuksen, materiaalin tai komponentin odotettavissa oleva kestoikä etukäteen määritetyissä oloissa. **Suunniteltu tai odotettu kestoikä** on arvioitu kestoikä. joka perustuu vertailukestoikään ja siihen liitettyjen eri tekijöiden funktioon. Kehittynein kestoikäarviointimenetelmä lienee standardisarjassa ISO 15686 esitetty menetelmä, jossa määritellyn materiaalin, rakenteen tai rakenneosan vertailukestoikään lisätään kertoimina materiaalin laatu, suunnittelu, rakenteet, käyttöolot, ilmasto-olot sekä huolto.
Kestoikäanalyysien mukaan lämpöeristetyn puurakenteen kestoiän kannalta tärkeimmät tekijät ovat hyvä suunnittelu ja rakentaminen. Jos nämä ovat onnistuneet ja runkorakenteen kosteus on sallituissa rajoissa, kuiviin oloihin tarkoitettujen rakenteiden kestoikä voidaan hyvin lisätä 50 vuodesta 100 vuoteen tai ylikin. Laajennettaessa kestoikätavoitetta 50 vuodesta 100 vuoteen, on otettava erikseen huomioon mahdollisista luonnonkuormista johtuva lisäkuormat seuraavasti: suunnitellun käyttöiän ollessa yli 50 vuotta kuormien ominaisarvoja korotetaan 10 prosentilla ja suunnitellun käyttöiän ollessa yli 100 vuotta kuormien ominaisarvoja korotetaan 20 prosentilla.

Luottamuksellisuus	Julkinen

Espoo 26.11.2013

Kirjoittaja	**Hyväksytty**
Hannu Viitanen, Senior Scientist	Raija Lantto Technology Manager

VTT'n osoite

PL 1000, 02044 VTT

Distribution (customer and VTT)

Asiakas, VTT.

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Contents

1. Introduction

The service life of structures is an important part of the life cycle planning of buildings and structures. It has also an essential effect on the carbon footprint of the building, since this determines the length of the use phase of the building or a building part.

Material performance based models to estimate the service life of building materials and structures are very scarce especially for dry conditions in service class 1. There is more work done for the service class 3 and 4 conditions, where the exposure conditions are much harder. Potential factor method is shown in the ISO 15686 series on service life evaluation. Actually the best way to estimate the service life of timber structures is based on existing experience, which can then be to a usable tool by application of the factor method.

2. Scope

The scope of this work was to define and evaluate the service life, performance and durability of wood material in structures under dry conditions (service class 1). Performance of the wood material and wood based products in the structure (protected from moisture) was focused (Figure 1).

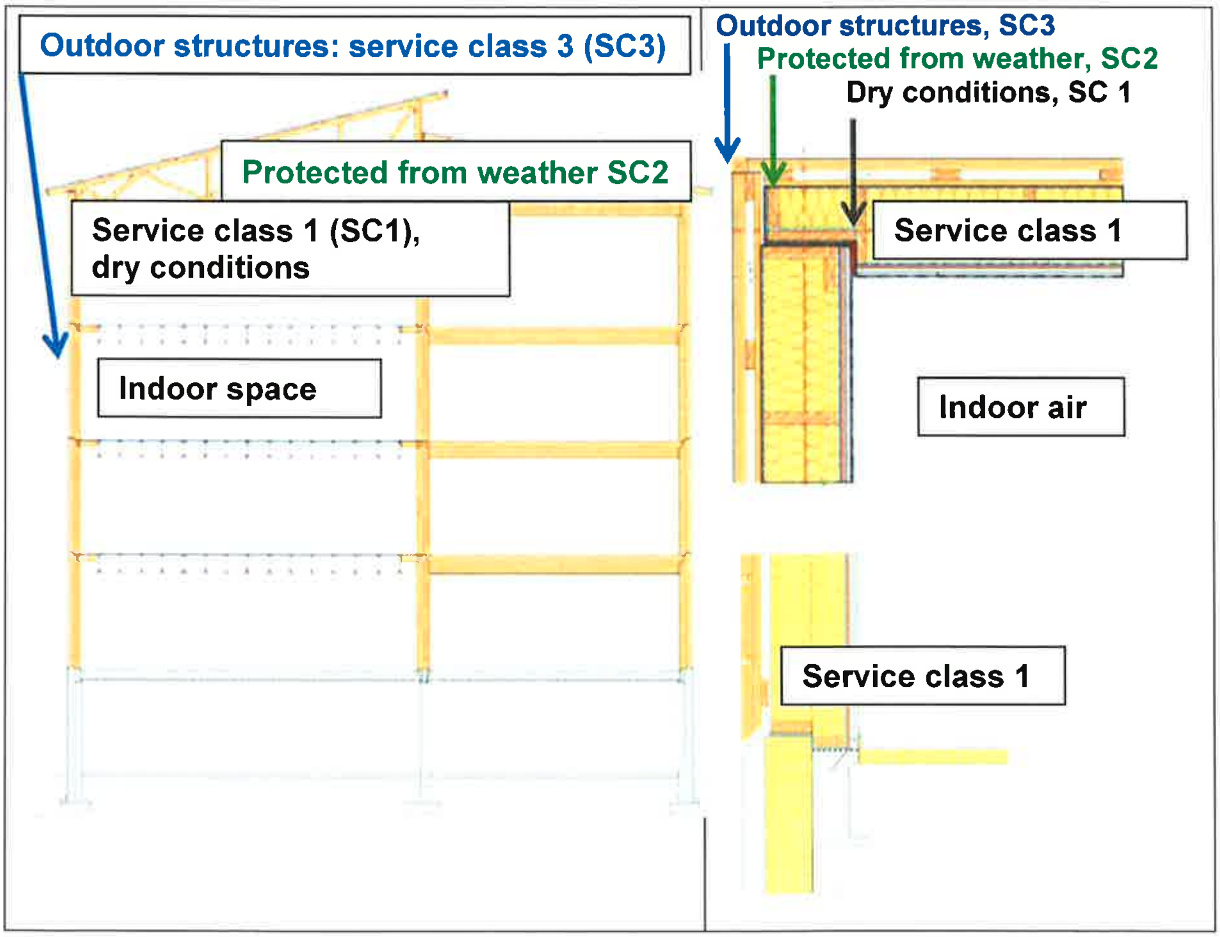


***Figure 1**. The task of the evaluation: the performance and durability of wood material in structures of service class 1, dry conditions.*

In this report, the performance, durability and service life of wood material in structures under dry conditions will be monitored and evaluated. This means that no water damage or moisture risks will be included, or these have been taken care using protection against moisture exposure and drying capacity of the structure. The report is based on the literature review, previous knowledge and standardization.

3. Definitions

3.1 Service class and use class

The performance of wood and wood-based materials with a given level is quantified as the level of ability to withstand load, exposure or deterioration over time in specified use conditions. EN 1995-1-1 defines a set of three service classes which are relevant to a designer when assigning strength values and calculating deformations for timber elements to be used in a construction. These service classes are determined by the wood moisture content corresponding to the humidity and temperature which are expected to prevail in service.

EN 335-1 defines five use classes on occurrence of the potential attack of biological agents: fungi (discolouring, decay), insects and termites. In the service class 1 / or use class 1 condition, there should not be any deterioration processes caused by long lasting humidity or water exposure (Table 1).

Table 1*.Definitions and conditions of service classes and use classes.*

Service class according to EN 1995-1-1	Humidity conditions in a service class	Corresponding use class according to the EN 335 standard
Service class 1	Moisture content in materials corresponding to +20 °C and RH of air exceeding 65 % for a few weeks per year. MC of softwood will not exceed 12 %.	Use class 1. Indoor, dry.
Service class 2	Moisture content in materials corresponding to +20 °C and RH of air exceeding 85 % for a few weeks per year. MC of softwood will not exceed 20 %.	Use class 1. Use class 2 if the component is in a situation where it could be subjected to occasional wetting caused by e.g. condensation.
Service class 3	Climatic conditions leading to higher moisture contents than in service class 2.	Use class 2 Use class 3 or higher if used externally

3.2 Performance

Humidity and moisture control in building envelope is a key action to prevent moisture excess and damage caused by water, microbes, fungi or other organisms, which are the bio-deterioration risk for wood material.

Important part of the performance is the requirements and limit states. **Performance requirement** means the **minimum acceptable level of a critical property**, which can be defined as **a limit state**. This defines the limit between acceptable performance and non-acceptable performance. An example of limit state is the onset of mould growth in the building envelope, which can be regarded as non-acceptable since it may create health problems in a building. This is comparable to a serviceability limit state for structures. In dry conditions, this will not be a limiting factor for the wood performance, excluded the outer part of exterior walls.

Another example is an attack by decay fungi, which will reduce the capacity of a load bearing structure. In this case the limit state can be formulated in the same way as for mechanically loaded structures considering that the capacity of the structure is reduced with time. The effect of decay may be considered as a mass loss of wood caused by the decay fungi, since the mass loss strongly correlates with the loss in strength (Wilcox 1978, Metsä-Kortelainen and Viitanen 2010). The effect of decay fungi is connected to water damage situation and is not considered as an intended use condition.

Permeability to water is one of the key factors affecting the performance of a wooden component, as it conditions the possibilities of form stability, discoloration and fungal decay. For structural components, the water vapor or humidity is the main acting exposure for wood. In the structure in use class 1, the water permeability or natural decay resistance will not have any significant role, except the particular structural part like the lower beam on the foundation or the outer part of the external wall. The performance of the gladding and façade has an important role for the protection of structural elements in the use class 1 condition. The performance of wood in exterior conditions (service class 3 or use class 3.1 shall be separately evaluated.

3.3 Durability

Durability is defined "The ability of a product to maintain its required performance over a given time, under the influence of foreseeable actions, subject to **normal maintenance**". Normal maintenance means repair accidental damage, fast drying of water leakage, repainting of the surface. For structural components in service class 1 condition, dry protected from weather, there should be no moisture or biological exposure situations. For wood material, this means no limits for the durability or service life. According to the standard EN 335-1, the use class 1 condition show no fungal exposure, but insect and termite attack can be expected in some climatic areas.

The durability means many different factors affecting the performance of the building material during the life time of the building and the durability can be evaluated using different limit state levels. The limit states include the strength properties, aesthetic condition, surface quality, etc. For structural part of the building, the strength properties are the most important factors. In use class 1 condition, the wood is be protected from moisture, UV light, high temperature, decay fungi which can effect on the strength properties of wood.

3.4 Strength properties

Wood moisture content, density, grain direction, knots, high temperature (above 80 - 100 °C) and eventual faults and damage can have impact on strength properties of wood (Siimes and Liiri 1952, Toratti and Ranta-Maunus 2002, Naylor et al 2012, Metsä-Kortelainen & Viitanen 2010, Wilcox 1978). Aging of the wood in dry conditions will not have any significant effect on strength properties of wood. VTT has studied the conditions of old wooden piles and according to the results, the compression strength of sound wood (not decayed) in old piles is around the same level as that of new or fresh wood, even the moisture content of wood has been high during long periods (Juvankoski &Viitanen 1989). Same type of results is also obtained from practical findings from existing old buildings in dry conditions (service class 1). If no decay exists wood will show very stable strength properties in dry conditions, but fast wetting-drying cycles have effect on the cracking and form stability of wood.

Strength properties are connected with limit state, design stress, load capacity and load duration. The limit state design means adequate resistance to certain limit states: the ultimate limit state and the serviceability limit state. Ultimate limit state refers to the maximum load capacity and serviceability limit state to the normal use of the construction. The strength properties of materials are defined at RH 65 % for 5 min loading. Design stress should be less than the design strength. K_{mod} is a factor which shifts the design strength, characteristic value of strength and partial safety factor of the material. K_{def} is the factor taking into account the effect of duration of load and moisture content (service class). In different service class situations, the following values of k_{mod} and k_{def} should be used.

***Table 2**. Values of k_{mod} and k_{def} in service classes 1 – 3 (EN 1995-1) for massive wood and plywood. K_{def} values are separately for massive wood and plywood for permanent loading. Long term – short term values are given here only for plywood (in italics).*

Load duration class	k_{mod} in service classes			k_{def} in service classes		
	1	2	3	1	2	3
Permanent	0.60	0.60	0.50	**0.6** / *0.8*	**0.8** / *1.0*	**2.0** / *2.5*
Long-term	0.70	0.70	0.55	*0.50*	*0.60*	*1.80*
Medium-term	0.80	0.80	0.65	*0.25*	*0.30*	*0.90*
Short-term	0.90	0.90	0.70	*0.00*	*0.00*	*0.40*
Instantaneous	1.10	1.10	0.90	-	-	-

In service class 1 there should not be impact of climatic factor, but it should be taken care for evaluating the design service life. This is presented in the chapter 4. Some additives e.g. fire resistance chemicals (e.g. phosphoric compounds) may affect the durability and service life of wood based products including massive wood especially induced by elevated temperature. These reactions are results from acid-catalyzed dehydration or thermal-induced acid degradation (Nurmi et al 2010). Also long-term high temperature (> 80 - 90 °C) will decrease the strength of wood material.

3.5 Service life classification

3.5.1 Wood material and timber

Service life is a concept dealing with many factors affecting the performance, durability and service life of buildings and buildings components. **Service life means the period of time after installation during which a building or its parts meets or exceeds the performance requirements** (ISO 15686). Most advanced service life evaluations are shown in the ISO 15686 series (Table 3). Also in Eurocode, the suggested minimum design service life for components vary from 10 to 100 years (Table 4). In EOTA, there is a bit different service life given for buildings (Table 5). In Canada, the design service lives vary between 10 – over 100 years (Table 6).

The basic number of the years for wood and for other building materials (e.g. concrete) for frames and for gladding will vary. Different numbers of years can be expressed depending on the structures and building components. Wood structures are adaptable and allow for design flexibility to meet changing needs. When they have been designed properly with local climate impacts and exposure in mind, wood buildings can last even centuries. Further, when part of a well-planned regular maintenance program, wood products will last well beyond their planned service life. When it is time to refurbish, wood products can be re-used and recycled.

***Table 3**. Suggested minimum design lives for buildings and components (ISO 15686-1).*

Design life of building	Components			Building services
	Inaccessible or structural	Replacement is expensive or difficult *	Major replaceable	
Unlimited	Unlimited	100	40	25
150	150	100	40	25
100	100	100	40	25
60	60	60	40	25
25	25	25	25	25
15	15	15	15	15
10	10	10	10	10

- *Note 1*: Easy to replace components may have design lives of 3 or 6 years
- *Note 2*: An unlimited design life should very rarely be used, as significantly reduces design options, including below ground drainage

***Table 4.** Indicative design working life (EN 1990,Eurocode)*

Design working life category	Indicative design working life (years)	Examples
1	10	Temporary structures (*)
2	10 to 25	Replaceable structural parts e.g. gantry girders, bearings
3	15 to 30	Agricultural and similar structures
4	50	Building structures and other common structures
5	100	Monumental building structures, bridges and other civil engineering structures

(*) Structures or parts of structures that can be dismantled with a view being re-used should not be considered as temporary

The CIB / RILEM technical committee (CIB W080 / RILEM TC 175-SLM) on methods of service life prediction of building materials and components was created in September 1996. The Factor method is one that has been promoted in the AIJ (Japanese) Guide for Service Life Planning of Buildings as well as in the subsequent ISO standard 15686-1 on Service Life Planning (CIB 2004).

In Japan, work has been carried out for decades on how to deal with methods to predict the durability and service life of materials and buildings both in the planning and the management phase of a building. The outcome of national activities has been published in a Principal Guide (1989) that was published in a short version in English in 1993 [AIJ 1993]. This Principal Guide is intended to show the fundamental concept of durability within each stage of the life cycle of buildings, such as planning, design, contract, construction, utilization, maintenance and modernisation and demolition.

***Table 5**. Assumed service life of works and construction products (EOTA 1999).*

Assumed life of works (years)		Working life of construction products		
Category	**Years**	**Category**		
		Repairable or easily replaceable	**Repairable or replaceable with some more efforts**	**Lifelong** [2]
Short	10	10 [1]	10	10
Medium	25	10 [1]	25	25
Normal	50	10 [1]	25	50
Long	100	10 [1]	25	100

[1]In exceptional and justified cases, e.g. for sertain repair products, a wotking life of 3 to 6 years may be envisaged (when agreed by EOTA, TB or CEN respectively.
[2]When not repairable or replaceable "easily" or "with some more efforts"

Canada has also been active for service life evaluation (Table 6). According to CSA 478-95, the requirements for durability may vary from building to building and from one component to another. These requirements are related to intended use, to cost, and to frequency, difficulty and extent of maintenance, replacement and repair.

***Table 6**. Categories of design service life for buildings in Canada (CSA 1995)*

Category	Design service life for building	Examples
Temporary	Up to 10 years	non-permanent construction buildings, sales offices, bunkhouses, temporary exhibition buildings
Short life	10 to 24 years	temporary classrooms
Medium life	25 to 49 years	most industrial buildings most parking structures
Long life	50 to 99 years	most residential, commercial, and office buildings health and educational buildings parking structures below buildings designed for long life category
Permanent	Minimum period 100 years	monumental buildings (e.g. national museums, art galleries, archives heritage buildings

Requirements for durability are expressed in terms of **design service life** or **expected service life**. The design service life of the building provides one basis for the determination of the design service life of the building components. The **reference service life** will be used as a basic for the factor analysis of service life.

The COST E37 TFPC and TGSLP of WG21 have been considering how the ISO expressed factor method (ISO 15686 series) can be applied to wood products and timber in construction. The ISO factor method includes several general factors in order to evaluate the service life of building components for different performance requirement levels (ISO 15686-1, 2006).

A survey of buildings demolished between 2000 and 2003 in the Minneapolis/St. Paul area demonstrated that the durability or service life was not the main reason for the demolition. The developers demolish most buildings well before the end of the useful life of their structural framing. Wood buildings in the study had the longest life spans, 63 % the demolished wood buildings were older than 50 years at demolition and the majority were older than 75 years. The conclusion was that the expected service life of structural parts of the buildings would be more than 100 years (Woodworks.org 2011).

The service life of wooden commodities is often connected to use class and protection needs of the building components or wood protection. In these analyses and codes the service life evaluation are most often subjected to use class 3 or even use class 4 condition, where structures are more or less exposed to water and bio-deterioration.

Building elements shall with only **normal maintenance** continue to satisfy the performance of this code for accepted service life:

- For the structure, including building elements such as floors and walls which provide structural stability; the life of the building being **not less than 50 years**.
- For services to which access is difficult, and for hidden fixings of the external envelope and attached structures of a building: the life of the building being not less than 50 years.
- For other fixings of the building envelope and attached structures, the building envelope, lining supports and other building elements having moderate ease of access but which are difficult to replace: **15 years**. For linings, renewable protective clothing, fittings and other building elements to which there is ready access: 5 years

3.5.2 Glued materials and products

Glued timber products have been commonly used since the beginning of 1900s. Glulam constructions made for almost 100 years ago with phenolic based adhesives are still performing well. Plywood has been manufactured even longer. LVL and OSB are, in principle, manufactured similar to plywood (Fonselius & Riipola 2013).

According to research results and experience, glued timber products will have around the same service life expectations than solid wood in dry conditions. Major durability problems with glulam and plywood have rather been affiliated with degradation of the timber material itself than with the glue bond quality. This is because a prerequisite for an adhesive to be approved for constructional purposes is that it is – and will remain - stronger than wood material.

Adhesives and glue bond quality are subject for intensive approval and control testing. There are standardised approval test methods for all main types of adhesives for load-bearing timber constructions; EN 301/302-series deals with phenolic and aminoplastic adhesives, EN 15425 with polyurethane adhesives, EN 12436 with casein adhesives, and EN 15416-series with others than phenolic and aminoplastic adhesives. The test programmes are a mix of short and long term loading tests in different climatic conditions, tests of effects of wood shrinkage, tests of chemical effects of the adhesive to the timber material and accelerated aging tests. Also manufacturing provisions are tested like maximum assembly time, minimum pressure and pressing time, and curing conditions. For new types of adhesives, some of the tests may take 3 years to be performed. The adhesive must not been used in load-bearing constructions before it has passed the relevant tests. Very good correlations were found between the results of the automatic boil test and the exposure data by River et al 1991.

An ideal adhesive would be chemically stable against temperature changes, water and other common chemicals, and bonded via irreversible crosslinking reaction. It also should have a rate of expansion and contraction similar to solid wood. Phenolic resins fulfil these conditions and have therefore formerly been the most often used adhesives for glued constructions. For plywood and LVL, the most often used adhesive still is the phenol-formaldehyde adhesive (PF). Phenolic resins are among the most thermally stable polymers known to exist. Amino plastic resins perform similarly under load-bearing conditions. The automatic boil test described in ASTM D3434 involves subjecting the adhesive bond to the major degrading factors of heat, stress and moisture in a cyclic exposure treatment.

Another frequently used adhesive that is resistant to water and has a rate of expansion and contraction similar to solid wood is melamine-urea-formaldehyde adhesive (MUF) that is the most often used adhesive type for glulam.

In plywood manufacturing urea-formaldehyde adhesive (UF) is also used. This adhesive is suitable for use in dry (service class 1) or humid (service class 2) conditions. Some polyurethane adhesives (PU) have been approved for glulam manufacturing, while the use of phenol-resorcinol-formaldehyde adhesive (PRF) is decreased because of the adverse health effects of formaldehyde.

Main concern for degradation of glued constructions is damage caused by ageing. For different adhesives, different ageing mechanisms are relevant. High moisture content and elevated temperature will speed up the ageing procedure and the mechanisms will change when the conditions are changed excessively. In accelerated tests, conditions are chosen so that the ageing mechanism corresponds to the one in intended use conditions, but the velocity of the ageing procedure is much more rapid. Thus, in a reasonable period of time, it is possible to predict whether the adhesive is suitable to be used for construction purposes or not.

Glue bond quality – and thus the durability of the glued product – is substantially affected by numerous factors like moisture content of the timber materials to be glued together, temperature of the timber, cleanness of the surfaces, roughness of the surfaces, mixing ratio of the adhesive and hardener, age of the (mixed) adhesive etc. These are followed during the manufacturing control of the products that is made in accordance with relevant product standards. In addition, most product standards provide for some accelerated ageing testing to be made. These may be of same type as used in approval testing of adhesives. A specific test for glulam is delamination test, where specimens are exposed for water pressure during several hours, oven dried and inspected for any signs of delamination of the glue lines. For plywood, glue bond quality tests comprise inspection of the broken surfaces of aged specimens, where the amount of failure in wood is recorded.

These test methods are challenging and if the product will pass the test conditions it will show a good performance in use. According to a survey of damage cases, deficiencies with adhesive or bonding have not been found to be the causes for damage or collapse of load bearing structures (Kortesmaa 1984).

New adhesives are developed especially in the group of isocyanate-based adhesives (IBAs), called e.g. aqueous polymeric isocyanate adhesives (API), emulsion-polymer-isocyanate adhesives (EPI), polymeric methylene diphenyl diisocyanate (pMDI). Also older adhesive types are continuously improved; the composition of the adhesives can be altered within the same group to suit different environmental conditions and different manufacturing methods. Isocyanate-based adhesives (IBAs) have been known and used for over 60 years since their discovery by Bayer in the late 1930s. The isocyanate chemical group is extremely reactive and can form a chemical bond with any chemical group that contains an active hydrogen atom. Isocyanates are very soluble in many solvents, due to their low molecular weight, and they can easily wet and penetrate into porous structures to form strong mechanical interlocks (Van Langenberg et al 2010). Scoville (2001) concluded that the pMDI adhesive was more resistant to degradation than the PF adhesive when the fracture energy of the adhesive was used as a measure of durability.

When a service life of 100 years is required in service class 1, Plywood and LVL made with phenol-formaldehyde adhesive (PF) and glulam or multiple laminated LVL made with phenolic or aminoplastic adehesives (PRF or MUF), all these adhesive types approved according to standards EN 301/EN 302, will fulfil the requirements on basis of experience and test results. Products where polyurethane adhesives (PU), approved according to standard EN 15425, have been used, do not have such a long history of use, but there are no indications that their service life would not be of the same order as for the other approved adhesives.

3.6 The Construction Products Regulation

The Construction Products Regulations is a basis for performance based building regulations in European countries. Requirements for durability and service life of construction products are implemented into national building regulations in Europe.

For the selection of a particular material or product to serve a particular purpose in a building, there are a number of factors that need to be considered. The seven "essential requirements" contained in the Construction Products Regulation (CPR) defines which properties must be ensured for all construction works during an "economically reasonable working life":

- Mechanical resistance and stability
- Safety in case of fire
- Hygiene, health and the environment
- Safety in use
- Protection against noise
- Energy economy and heat retention
- Sustainability

4. Determination of the service life

4.1 Determination of the reference service life

Reference service life (RSL) is the **expected service life of a component or an assemblage situated in well-defined set of conditions** (ISO 15686). The reference service life will be used as a basic start for the service life evaluation. In order to determine an appropriate estimated or expected service life (ESL), the RSL needs to be modified by taking into account the differences between the object-specific in-use conditions and the reference in-use conditions.

The Factor method described in the ISO Standard provides a systematic way of carrying out a modification. Any possible alternative method of determining the ESL from the RSL should also be based on similar information on in-use conditions. The guidance for reference service life is structured into discussions regarding:

- provision of RSL data utilizing existing general data
- selection of RSL data or general data ;
- formatting of general data into RSL data records .

Manufacturers of building and construction products are usually in possession of considerable knowledge concerning the service life and durability of their products. However, such information is only occasionally made public, typically in product declarations, other documents, company websites and/or databases.

Reference Service life data is the information that includes the reference service life and any qualitative or quantitative data describing the validity of the reference service life. Reference in-use condition is the condition under which the RSL data are valid (ISO 15686-8). Usage condition is the **factor category** of **in-use conditions** that considers the influence on performance due to the use of a building/constructed asset or any human activity adjacent to a building/constructed asset.

The discussion on provision of RSL data is intended for the various providers of data, such as (Figure 2):

- manufacturers of building and construction products;
- test laboratories
- national assessment bodies and technical approval organizations;
- database holders; and
- other data providers.

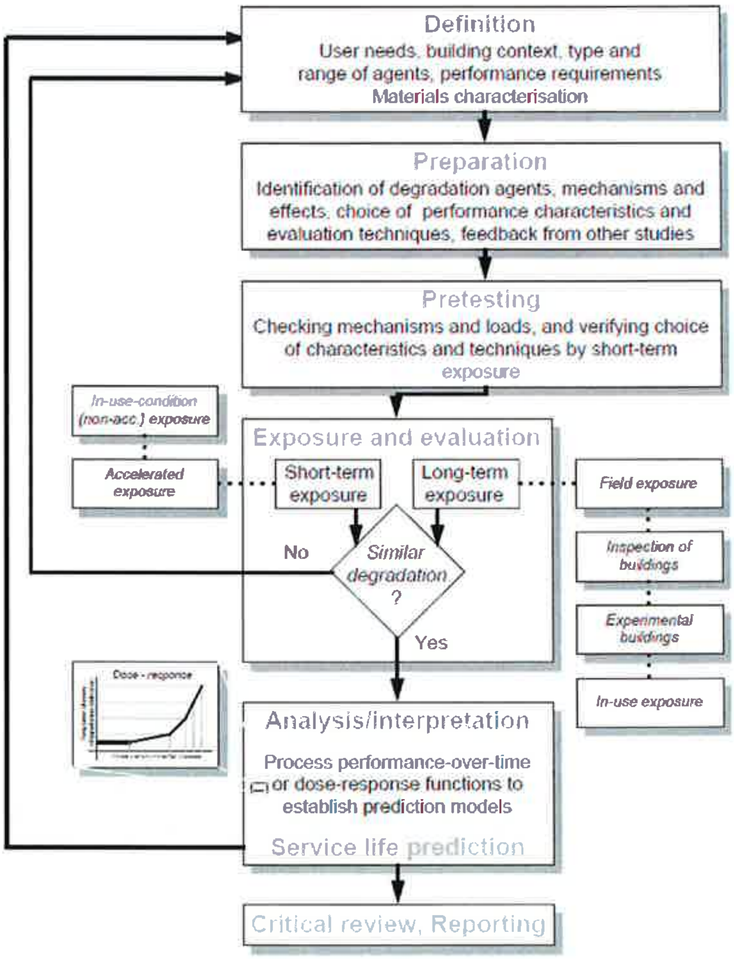


***Figure 2**. Systematic methodology for service life prediction of building components (ISO 15686-2).*

The reference service life can also be stated **as standard service life** when evaluate the potential deterioration state. The time until a deteriorated stage is reached when the whole building or its parts, elements, components or equipment have degraded under any one of specified conditions, under the circumstances of "normal" design, construction, use maintenance and climate exposure. The standard service life has to be predicted on the basis of experience.

RSL data should at least contain general description of the material or component and data on service life, in an indicated outdoor (or indoor) environment, and should preferably encompass all relevant information concerning the generation of the service life data. The following types of data are of particular importance:

- in-use conditions structured according to all corresponding factor categories;
- critical properties;
- performance requirements.

This set of data should form part of a RSL data record (Figure 3)

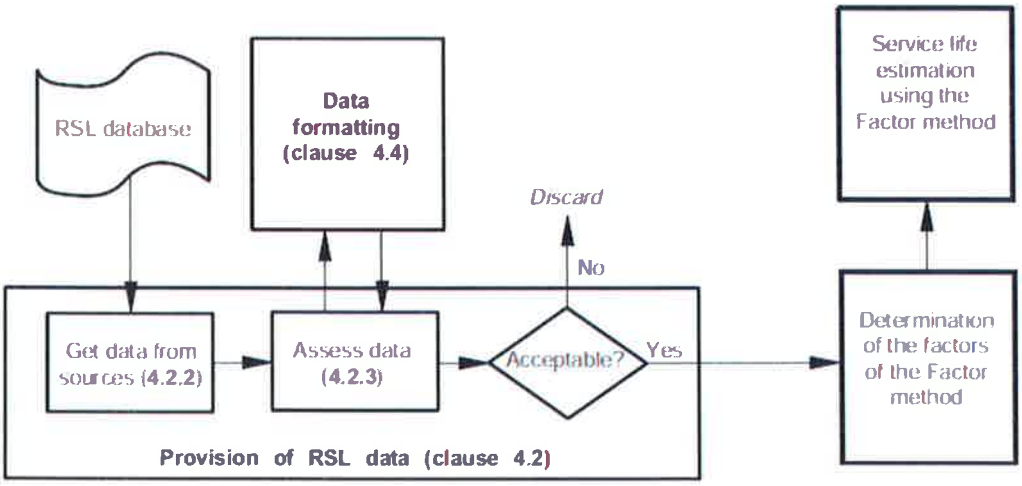


***Figure 3**. The process of selecting RSL data (ISO 15686-8).*

Data sources will be the users and manufacturers information on the service life of structural components in use class 1 situation. In Finland, there are several wooden buildings, where the service life of wood is more than 100 years: e.g. the old wooden buildings in Turku, Naantali, Rauma, Porvoo, Tammisaari, Loviisa, Oulu etc (Table 7). In old Rauma, there were already several buildings in the town plan from 1756, and the age of many buildings is more than 250 years. Today in old Rauma there are c.a. 600 old wooden buildings (http//www.rauma.fi).

***Table 7**. Examples of old wooden buildings or wood structures in Finland.*

Building or structure	Place	Year of construction	Age (years
Buildings in Puuvallila	Helsinki	1910 - >	103
Hvitträsk, Suurtupa	Kirkkonummi	1901 - 1903	110
Church of Juua	Juva	1850 - 1851	162
Old church of Helsinki	Helsinki	1825 - 1826	187
The Petäjävesi old church	Petäjävesi	1763 – 1765	248
The old Rauma buildings	Rauma	before 1756	>250
Church of Karuna	Seurasaari museum	1685 - 1685	328

In Sweden, there are even more old wooden buildings (service life more than 100 years) and still in use. Wooden churches are typical old wooden buildings (table 6), Oldest wooden building in Finland are several hundred years old. The highest risk for the service life of wooden buildings is fire, e.g. old church of Tyrvää in Finland was built in 1510, and old wood interior was built in 1780. The wooden roof and interior part was destroyed by a fire set on in 1997, after which the church was again rebuilt.

For façade and gladding (use class 3.1), the exposure conditions are higher than that in use class 1, but even for gladding, we have found service life above 100 years (Viitanen et al 2010). The most important factor for long service life is the structural protection of wood from water and wetting. For Europe, the Nordic climate is the most suitable for wood material, where temperature and humidity is lower than that in Atlantic climate area.

4.2 Estimation of the service life

Estimated service life / Design service life: the standard service life multiplied by a variety of factors based on a more careful consideration of the quality of materials, actual design, construction, use condition, maintenance and climate exposure of a specific building, part of the building, element, component or equipment.

$$\mathbf{ESLC = RSLC \times A \times B \times C \times D \times E \times F \times G.}$$

The method uses modifying factors for each of the following for service class 1:

A. quality of components (quality marked material, no coatings needed)
B. design level (according to rules of building codes, high level of planning, protection by design, good detailing)
C. work execution level (quality of workmanship, rules of building codes)
D. indoor environment (temperature and RH, according to rules of building codes)
E. outdoor environment (Service class 1: no exposure to weathering or water)
F. in-use conditions (wear, mechanical impacts, natural loads)
G. maintenance level (inspections and repair shall be performed in time when needed)

Reference service life for several structures is 50 years, but for structures in service class 1 it may or should be higher. This is still an open question and RSL depends also on the whole service life estimation methods: which factors are included and which coefficient value is used. The reference service life of 100 years may be in future realistic task for the estimation process of wood structure in service class 1 (dry conditions).

Engineering design method based on equation of factorial method is very similar but there also the distribution of the factors are taken care:

$$\mathbf{PSLDC = RSLC \cdot \mathit{f}A \cdot \mathit{f}B \cdot \mathit{f}C \cdot \mathit{f}D \cdot \mathit{f}E \cdot \mathit{f}F \cdot \mathit{f}G}$$

PSLDC: is the predicted service life distribution of the component based on the reference service life **RSLC**. The factorial indices are same as shown in the service life estimation process.

There is very few data on the service life of wood in the use class 1 structure. This may be caused by the fact, that the research has been focused on the more critical structures like facades, gladding, decking and terraces, where the weathering, moisture exposure and damage risks are higher.

A number of specific factors affecting the moisture safety of wooden buildings have been identified. In order to build moisture-safe wooden building with an appropriate service life or even higher than reference service life 50 years, at minimum following factors have to be considered (Toratti & Arfvidsson 2013):

1. Well-ventilated air gap behind the façade. It has been evaluated, that wooden cladding will be perform better than that of brick façade (Lahdensivu et al 2012)
2. Protection for mould growth in the external wall. This is especially important for the inner part of the wall or constructions connected to indoor air
3. Influence of driving rain and site location. It's especially important to protect the wall behind the cladding for the impact of water penetration
4. Dry out possibilities of water from leakages and initial moisture from the building phase. Moisture in the walls should always have possibility to dry out. Use of protection against weather during building phase is an important part for dry building. In Sweden, the weather protection is used during the whole building process, and some cases, only dry materials are used.
5. Interior vapour barrier of the wall. This is an important part to prevent the moisture transport from indoor air to the structure, but it's also important for prevent the eventual air leakages from the envelope to indoor air.

Using ISO 15686 factor method, important part is to define the most fitted factors and their values. If the factor will not change the expected design service life, the factor has value 1. If the factor is expected to have negative impact, the value is lower than 1 and if positive, the value is higher than 1. The importance of a factor is evaluated using the mathematic calculation or evaluation based on the expertise. Important part of the evaluation is the definition of reference service life (RSL). Most often the RSL is evaluated to be 50 years for cladding and façade in service class 3. For structures in service class 1, the reference service life could be higher, but more research and work should be included. Below two different evaluations are shown:

RSL = 50 years A = 1.1 (high quality wood material) B = 1.2 (high quality of design) C = 1.1 (work execution, dry conditions using protective means) D = 1.1 (separate indoor environment) E = 1.5 (well protected from weather) F = 1.0 (normal use condition) G = 1.1 (maintenance taken care in time) ESL = 130 years	RSL = 50 years A = 1.0 (normal quality wood material) B = 1.2 (high quality of design) C = 1,1 (work execution, dry conditions using protective means) D = 1.0 (normal indoor environment) E = 1.2 (protected from weather) F = 1.0 (normal use condition) G = 1.3 (maintenance taken well care in time) ESL = 102 years

If RSLC would be 100 years, the factor analyse can give even higher results if the same factors and values are used.

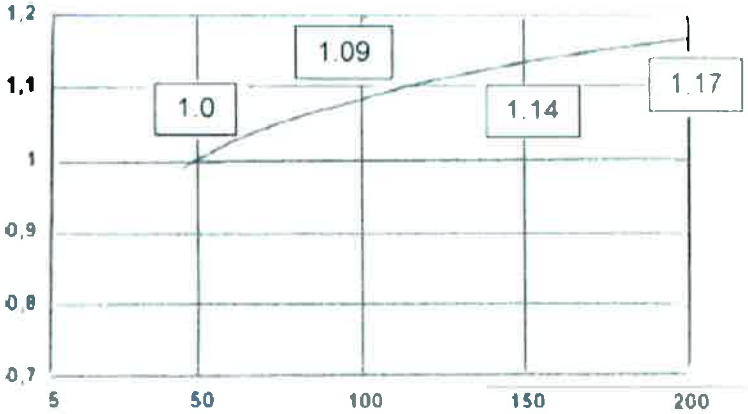
In Germany, the expected service life for roof structures and for structures in use class 1 is over 100 years. In the German standard, there is also use class 0, which mean that there should not be any risk of insect attack. In use class 1, a low potential of insect attack may exists (DIN 68 800). In France the definition of use class 1 is: no exposure to exterior climate and > 20 cm from soil. This is classified as lasting class L1 and expected service life is > 100 years. In UK, the minimum service life period of the long life buildings is 120 years. They are e.g. civic and high quality buildings.

The service life of wooden commodities is often connected to use class and protection needs of the building components or wood protection. In these analyses and codes the service life evaluation are most often subjected to use class 3 or even use class 4 condition, where structures are more or less exposed to water and bio-deterioration.

Most advanced service life evaluations are shown in the ISO 15686 series (see Table 3). In Eurocode, the suggested minimum design service life for components vary from 10 to 100 years. In Canada, the design service lives vary between 10 – over 100 years (Table 4).

4.3 Effect of variable loads

When the service life of wooden loadbearing structure will be higher than 50 years, the eventual loading caused by climatic factors (wind, snow, rain, ice) has to be taken care. For buildings which service life is expected to be longer than 50 years, eigenvalues shown in the figure 8 have been calculated by Weck (2013, Figure 4). For buildings which service life is expected to be longer than 50 years, following eigenvalues could be used: for 50 years 1, for 100 years 1.09 for 150 years 1,04 and for 200 years 1.17. In the new building code (RakMK, part B1, draft 2014), the design service life and loading will be taken care as following: when the design service life is above 50 years, the characteristic values of loading shall be10 % higher, and for above service life of 100 years, the characteristic values of loading shall be 20 % higher than that for 50 years design life.



Design service life (years)

***Figure 4**. Interdependence of the eigenvalue of climatic load and design service life in relation of the eigenvalue of the design service life of 50 years. Climatic loads are snow, wind, ice and variation of the temperature of outer air. The load of climate is based on the Gumbel-distribution with variation factor of 0.26 (Weck, 2013, Tikanoja 2013).The values less than 50 years are removed from the graph.*

The durability and service life of wood constructions in service class 1 conditions is also depending on the function of cladding and other protective structure. In WoodExter project, service life of gladding in several different countries was surveyed (Suttie et al 2011). The estimated mean service life of all claddings is 63 years and the mean age of the claddings during the survey was 29 years.

It has been shown that for claddings a 50 year service life is achievable with the correct materials and coatings and with a proper design and detailing. Even longer (more than 100 years) service lives may be achieved for cladding. This of course requires maintenance of the surfaces as indicated by the recommendations given by the coating/paint producer or material producer. Nordic continental climates seem to be more advantageous in this respect (Viitanen et al 2011).

Comparing the results of cladding in service class 3 conditions, the service life of wood structure in service life 1 condition can be expected to be above 100 years, when the moisture damage will be avoided and drying after eventual moisture exposure has been taken care in accepted time schedule. Fasteners, nails, joints and junctions have to be performed according to the rules and building codes. Special attention should be arrested to design of joints, drying capacity, deformation of the materials.

5. End of service life and critical limit states

5.1 End of the service life

All design methods require clear definitions of the end of the service life. They are often connected to critical limit states. This is however not a universal and easily defined value. In general terms it is **the point in time, when the foreseen function is no longer fulfilled** (CIB 2004). Properties of a building part can be split up into several sub-properties, e.g.

- **Safety:** The integrity of the building part is maintained at the standard level of safety,
- **Function:** The required function is fulfilled, (i.e. deflections are still within limits, a window can easily be opened and closed, etc.),
- **Appearance:** The expected appearance is given (i.e. the surface of the building part is of acceptable appearance, the glazing of windows has not deteriorated or turned opaque, etc.).

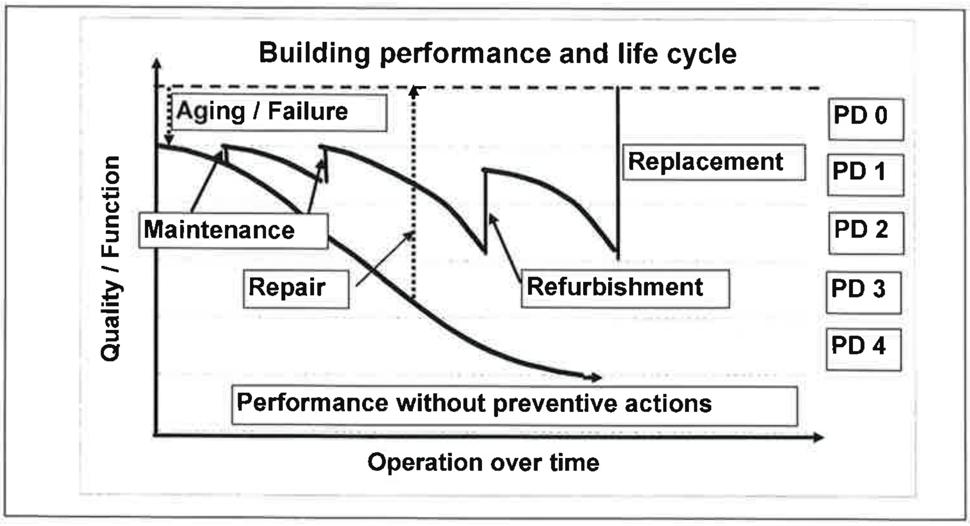


Figure 5*. Building performance, performance degree (PD) during the life time of a building for high exposure conditions. Maintenance, repair, refurbishment and replacement may be needed during the service life of building depending on the exposure factors and aging of the building components. Performance degrees: PD 0 = performance fine, no symptoms of problems, PD 1 = normal performance, light symptoms, PD 2 = lowered performance, medium symptoms, PD 3 = not accepted performance, strong symptoms, PD 4 = no performance left, totally unacceptable, collapse and malfunction (based on ISO 15686 – 7).*

Building maintenance is important factor to guarantee to fulfil the needed quality. During the service life of a building, several maintenance and repair work will be included for obtain the needed or wanted performance level and limit states, depending on the service conditions (Figure 5). In service class 1, no exposure to weather and water should be expected when there is lower needed maintenance and repair than that in service class 3 (exposure to weather).

5.2 Quality of building process and critical conditions

5.2.1 General

The primary objective to protect wood from moisture loads is to keep water out of the building envelope and to balance the moisture content within the building itself. Moisture control by means of accepted design and construction details is practical method of protect wooden building against faults and damage. Details of construction have most important role to avoid moisture exposure and accumulation into the structures (Lahdensivu et al 2012, Toratti & Arfidsson 2013). There are several old buildings having well function structure and long service life. Very fine examples of well function of structural protection of wood are stave churches in Norway build in 1500 – 1600. The indoor structure of churches are well protected from the weather using protecting roofs and eaves and covered decking around the indoor structure,

For the use class 1 situation, the structure should be protected from exposure to weathering, when only eventual short high humidity exposure should be expected. The service class 1 means, that the humidity of ambient air of the structure should only exceeding RH 65 % for a few weeks per year.

For quality assurance in building execution several crucial tasks should be considered (Toratti 2011, Toratti & Arfvidsson 2013): 1) project description, 2) initial risk assessment, 3) structural design, 4) risk analysis and external supervision of design, 5) moisture control plan, 6) assembly planning, 7) maintenance manual of the building.

Materials that are located in the outer section of the wall are occasionally exposed to conditions that might cause mould growth in the structure. Adding a mould-resistant insulation board on the outside of the insulation layer next of the air gap improves the situation (Toratti & Arfvidsson 2013).

5.2.2 Critical conditions

Humidity and moisture control in building envelope is a key action to prevent moisture excess and damage caused by water, microbes, fungi or other organisms, which are the bio-deterioration risk for wood material. Water, solar radiation and temperature extremes are the main environmental factors that affect the performance of materials. Water is responsible for the swelling and bio-deterioration of organic materials and the corrosion of metals. It is also involved in the freeze-thaw deterioration of porous materials like concreter and the swelling of soils. Solar radiation attacks the chemical composition of organic materials like plastics, PVC, paints, caulk compounds and others. Changes in the ambient temperature cause many materials to expand and contract like metals and concrete. Materials become more rigid in cold temperature and some may shatter unexpectedly when the temperature falls below their glass transition temperature.

The first step to evaluate the exposure conditions for moisture exposure is the macroclimate conditions. The driving rains, moisture, temperature and also the solar radiation are the most important factors for the exterior structure and components in use class 3 and 4 conditions.

For use class 1 conditions, there should not be any moisture exposure. However, some accidental humidity and water exposure should take care.

For the performance of building materials, the microclimate condition of the material is most important factor (Figures 6 and 7). Microclimatic means the climate conditions close the materials and structure, and it is a result of several simultaneous factors: macroclimate (rainfall, temperature, humidity, air pressure conditions etc.) and meso-climate (location of the building, structural details and the materials used). The micro-climate conditions are the basic level for building physical and microbial activity evaluations.

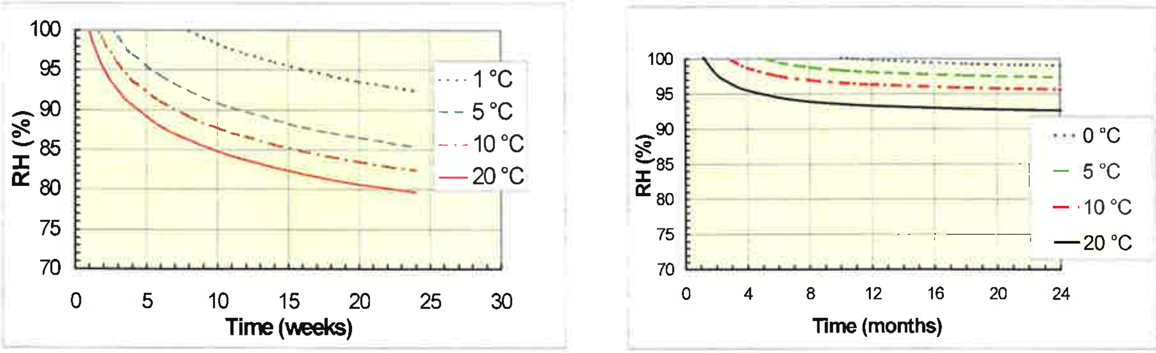


Figure 6. *RH and temperature isoplets as a function of time for start of mould growth (left) and early stage of decay development (right) in pine sapwood (Viitanen 1996, 1997a, b)*

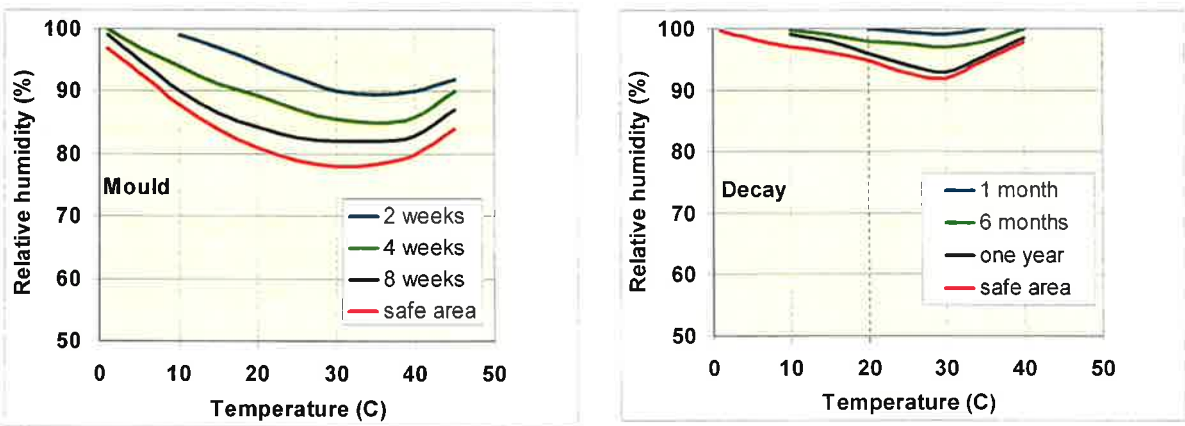


Figure 7*. Isoplets of ambient relative humidity, temperature and exposure time of microclimate for development of mould growth (left) and decay development (right) in untreated pine sapwood. Wood moisture content is more critical for decay development than ambient relative humidity of the microclimate. Wood moisture content is around 30 % at RH of 99 % and around 25 % at RH of 95 %.*

The effect of eventual humidity and water exposure can be evaluated using e.g. different bio-deterioration models. E.g. the mould and decay models can be incorporated with climatic and building physic models to evaluate the effect of different exposure conditions on the durability and service life of wooden products. **Period of wetness** of the substrate and the actual moisture and temperature condition is the determining factor for the development of mould and decay in timber. Long period, high moisture levels may start biological growth on timber surfaces, first mould or stain fungi and finally decay (Viitanen 1996).

For start of the growth of decay fungi and decay development, the ambient critical humidity level of microclimate should be above RH 95 – 100 % and moisture content of pine sapwood above 25 – 30 % (Viitanen 1996). The humidity and moisture limits were based on large laboratory work on pine and spruce sapwood. According to experience, the decay will develop when moisture content of wood excess the fibre saturation point (RH above 99.9 % or wood moisture content 30 %. Morris *et al.* (2006) have modelled decay development in wooden sheathing and found the critical ambient humidity condition for decay development is around RH 98 - 99 %, depending on the temperature and exposure time.

The models on bio-deterioration and mould growth can be used as a tool for building physic performance and service life evaluation. Models can been incorporated in a hygrothermal calculation tool like Wufi and Ojanen and Salonvaara (2000) have used the "VTT mould growth model" implemented in another building physic simulation model TCCC2D for evaluate the risk of mould growth in different humidity exposure conditions in building envelope.

6. Conclusions

For the use class 1 situation, the structure are protected from exposure to weathering, when only eventual short high humidity exposure should be expected. The service class 1 means, that the humidity of ambient air of the structure should only exceeding RH 65 % for a few weeks per year. For quality assurance in construction, several crucial tasks should take care: 1) project description, 2) initial risk assessment, 3) structural design, 4) risk analysis and external supervision of design, 5) moisture control plan, 6) assembly planning, 7) manual of the maintenance for the building. If these factors are well managed, there are no limitations to get service life of 100 years or more in the service life 1 (dry) conditions.

Obviously most advanced service life evaluations are shown in the ISO 15686 series: the RSL or standard service life multiplied by a variety of factors based on a more careful consideration of the quality of materials, actual design, construction, use condition, maintenance and climate exposure of a specific building, building material, element, component or equipment. Using a factor method to evaluate the service life of insulated wooden building envelope (service class 1), the most important factors are design and execution. If the values of these factors are high and moisture exposure is not exceeded the tolerances, there is no obstacle to get service life above 100 years using 50 years reference service life in the service class 1 condition. When the service life of wooden loadbearing structure will be higher than 50 years, the eventual loading caused by wind, snow, ice has to be taken care as following: when the service life of wooden loadbearing structure will be higher than 50 years, the natural loading is evaluated to be 10 % higher than that for 50 years' service life and 20 % higher when the expected service life is above 100 years.

When a service life of 100 years is required in service class 1, Plywood and LVL made with phenol-formaldehyde adhesive (PF) and glulam or multiple laminated LVL made with phenolic or aminoplastic adehesives (PRF or MUF), all these adhesive types approved according to standards EN 301/EN 302, will fulfil the requirements on basis of experience and test results. Products where polyurethane adhesives (PU), approved according to standard EN 15425, have been used, do not have such a long history of use, but there are no indications that their service life would not be of the same order as for the other approved adhesives.

7. Summary

The **service life of buildings and structures** is an important part of the life cycle planning. The **performance** of wood and wood-based materials with a given level is quantified as the level of ability to withstand load, exposure or deterioration over time in specified service conditions. EN 1995-1-1 defines a set of three service classes which are relevant to a designer when assigning strength and durability for timber elements to be used in a construction. In this work the focus is in the service class 1 (dry condition).

Performance requirement means the **minimum acceptable level of a property of a product**, which can be defined as **a limit state**. This defines the limit between acceptable performance and non-acceptable performance. **Durability** is defined "The ability of a product to maintain its required performance over a given time, under the influence of foreseeable actions, subject to **normal maintenance**". No significant differences on durability between massive wood and wood based engineering products (glulam, plywood, LVL, CLT) have been found.

Service life is the period of time after installation during which a building or its parts meets or exceeds the performance requirements. For the insulated building envelopes, most important performance requirement is to keep wood and structure in dry conditions. Humidity and moisture control in building envelope is a key action to prevent moisture excess and damage caused by water, microbes, fungi or other organisms.

Reference service life (RSL) is the expected service life of a building, material or component situated in well-defined set of conditions. **Design or expected service life** is an evaluated service life calculated on the base of RSL and several different factors. Obviously most advanced service life evaluations are shown in the ISO 15686 series: the RSL or standard service life multiplied by a variety of factors based on a more careful consideration of the quality of materials, actual design, construction, use condition, maintenance and climate exposure of a specific building, building material, element, component or equipment.

Using a factor method to evaluate the service life of insulated wooden building envelope (service class 1), the most important factors are design and execution. If the values of these factors are high and moisture exposure is not exceeded the tolerances, there is no obstacle to get service life above 100 years using 50 years reference service life in the service class 1 condition. The eventual climatic loading has to be taken care as following: when the service life of wooden loadbearing structure will be higher than 50 years, the natural loading is evaluated to be 10 % higher than that for 50 years' service life and 20 % higher when the expected service life is above 100 years.

8. Tiivistelmä

Rakenteiden ja rakennusten kestoikä on tärkeä osa elinkaarisuunnittelua. Puun ja puutuotteiden **toimivuus** ja sen taso arvioidaan sen mukaan, miten ne kestävät kuormia, rasitusta ja vioittumista ajan suhteen sekä määritellyissä käyttöoloissa. Standardissa EN 1995-1 (Eurocode) on annettu kolme käyttöluokkaa, jotka ovat tärkeitä suunnittelijan arvioidessa rakenteissa käytettävien puuosien lujuutta ja pitkäaikaiskestävyyttä. Tässä työssä keskitytään käyttöluokkaan 1 (kuivat olosuhteet).

Toimivuusvaatimukset tarkoittavat **pienintä hyväksyttävää tuotteen ominaisuutta eli rajatilaa** (hyväksyttävyystasoa). **Pitkäaikaiskestävyys** tarkoittaa tuotteen kykyä ylläpitää tarvittavaa toimivuustasoa ajan suhteen etukäteen arvioiduissa oloissa, normaalien huoltotoimenpiteiden puitteissa. Puumateriaalin ja vaatimusten mukaan valmistettujen puukomponenttien (liimapuu, vaneri, LVL, CLT) pitkäaikaiskestävyydessä ei ole havaittu merkittäviä eroja.

Kestoikä on vastaavasti se aika, jolloin rakenne pystyy ylläpitämään vähintään vaadittua toimivuustasoa rakennuksen tai rakennusosan asennuksen jälkeen. Lämpöeristetyn rakenneosan kannalta tärkein toimivuusvaatimus on puun ja rakenteen pysyminen riittävän kuivana. Rakenteen kosteuden hallinta on tärkein periaate suojattaessa rakenteita kosteuden kertymistä sekä veden, mikrobien, sienten ja muiden organismien aiheuttamia vaurioita vastaan.

Vertailukestoikä on rakennuksen, materiaalin tai komponentin odotettavissa oleva kestoikä etukäteen määritetyissä oloissa. **Suunniteltu tai odotettu kestoikä** on arvioitu kestoikä. joka perustuu vertailukestoikään ja siihen liitettyjen eri tekijöiden funktioon. Kehittynein kestoikäarviointimenetelmä lienee standardisarjassa ISO 15686 esitetty menetelmä, jossa määritellyn materiaalin, rakenteen tai rakenneosan vertailukestoikään lisätään kertoimina materiaalin laatu, suunnittelu, rakenteet, käyttöolot, ilmasto-olot sekä huolto.

Kestoikäanalyysien mukaan lämpöeristetyn puurakenteen kestoiän kannalta tärkeimmät tekijät ovat hyvä suunnittelu ja rakentaminen. Jos nämä ovat onnistuneet ja runkorakenteen kosteus on sallituissa rajoissa, kuiviin oloihin tarkoitettujen rakenteiden kestoikä voidaan hyvin lisätä 50 vuodesta 100 vuoteen tai ylikin. Laajennettaessa kestoikätavoitetta 50 vuodesta 100 vuoteen, on otettava erikseen huomioon mahdollisista luonnonkuormista johtuva lisäkuormat seuraavasti: suunnitellun käyttöiän ollessa yli 50 vuotta kuormien ominaisarvoja korotetaan 10 prosentilla ja suunnitellun käyttöiän ollessa yli 100 vuotta kuormien ominaisarvoja korotetaan 20 prosentilla.

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