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Climate data

Climate conditions in Europe

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Ambient microclimatic conditions, especially moisture conditions, are the most important factors for durability of wood. The classification of use conditions in WP1 (climate data) of the project Woodexter is based on the evaluation of the water exposure during the use. Decay is the more severe result of high moisture exposure of wooden structures when the materials are wet for long periods. For generating critical humidity and temperature conditions needed for start of decay, a model based on the previous studies at VTT was developed. For evaluation the climatic exposure conditions, the empirical wood decay model were first used for the ERA-40 data for air temperature, humidity and precipitation at 6 hour intervals. ERA-40 is a massive data archive produced by the European Centre of Medium-Range Weather Forecasts (ECMWF). The ERA-40 domain covers all of Europe and has a grid spacing of approximately 270 km. The decay index mapping for Europe with respect to macro-climate was developed. The results will give inputs to WP 4 (service life) to evaluate the effect of macroclimate as classified factors to be used for service life evaluation and engineering model. The inputs to modelling were in first step general, and the local conditions have been more detailed. Different climatic exposure areas or zones could be detected: Northern European (north and south), Continental, Atlantic (north, middle and south), Mediterranean zone (wet and dry). The classifying will give a relative values for decay risks in different part of Europe. The exposure of horizontal exterior surfaces to solar radiation of Europe was simulated using the average solar radiation values (GW/m^{2}s) of 30 years' period. The solar radiation is lowest in North Europe even the days during summer time are longer. The highest solar radiation was found in the Southern Europe. In the second stage, a dose response model was used to evaluate the climate conditions in selected places in Europe in the WP4 (Service life model).

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Abstract

Ambient microclimatic conditions, especially moisture conditions, are the most important factors for durability of wood and the classification of use conditions in WP1 (climate data) of the project Woodexter is based on the evaluation of the water exposure during the use. Decay is the more severe result of high moisture exposure of wooden structures when the materials are wet for long periods. 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%, depending on the temperature and exposure time. For generating critical humidity and temperature conditions needed for start of decay, a model based on the previous studies at VTT was developed.

For evaluation the climatic exposure conditions, the empirical wood decay model were first used for the ERA-40 data for air temperature, humidity and precipitation at 6 hour intervals. ERA-40 is a massive data archive produced by the European Centre of Medium-Range Weather Forecasts (ECMWF). The reanalysis involves a comprehensive use of a wide range of observational systems including, of course, the basic synoptic surface weather measurements. The ERA-40 domain covers all of Europe and has a grid spacing of approximately 270 km. The decay index mapping for Europe with respect to macro-climate was developed in collaboration with WP 4 (Service life model). The results will give inputs to WP 4 to evaluate the effect of macroclimate as classified factors to be used for service life evaluation and engineering model. The inputs to modelling were in first step general, and the local conditions have been more detailed evaluated in co-operation with the WP 4 (Service life model). Different climatic exposure areas or zones could be detected: Northern European (north and south), Continental, Atlantic (north, middle and south), Mediterranean zone (wet and dry). The classifying will give a relative values for decay risks in different part of Europe. The exposure of horizontal exterior surfaces to solar radiation of Europe was simulated using the average solar radiation values (GW/m^{2}s) of 30 years' period. The solar radiation is lowest in North Europe even the days during summer time are longer. The highest solar radiation was found in the Southern Europe. In the second stage, a dose response model was used to evaluate the climate conditions in selected places in Europe in the WP 4.

Preface

This report is a part of the large WoodWisdom net project “Service life and performance of the exterior wood above ground”. This report concern on the WP 1 “Climate and exposure conditions”.

Project consortium:

Work Packages	WP leader	Participating partners
WP 1 – Climate and exposure	**VTT**	LTH, BRE, FCBA
WP 2 – Durability indicators	**BRE**	FCBA, HfA, SP, VTT
WP 3 – Wood / coatings inter	**HfA**	FCBA, VTT, UGött, BRE
WP 4 – Engineering modelling	**LTH**	BRE, FCBA, NFLI, SP, VTT
WP 5 – Dissemination	**SP**	All
WP 6 – Co-ordination	**SP**	WP leaders

The key issue of the WP 1 of the Woodexter project is the transformation of climatic data into a suitable format to take climate factors affecting the progress of decay into acount. The WP consists of three major tasks. The first task WP 1.1 involves a classification of main exposure conditions for use class 3 (EN 335) components. The second task WP 1.2 will involve an experimental set up for the selected applications to investigate the effect of design and detailing on the microclimate. Finally in WP 1.3, based on data from the first two tasks, a model for the climatic impact on exterior wood structures will be proposed to be used for the service life model. This report will concentrate to the tasks 1.1 and 1.3.

Contents

1. Introduction

During their functional life, building and building components are exposed to several environment conditions in numerous ways. For wood material, moisture stress and biological factors like mould and decay fungi are often critical, especially in cladding and decking structures in exterior use conditions. For mould and decay development, different mathematical modeling exists based on laboratory and field studies. These can be used also for evaluating the different material properties for durability and service life of wooden products.

In the future, the life time expectations and analyses of different building products will need more data on the durability of products, service life and resistance against mould and decay, not only data on wood material itself. Also the effect of other factors, like solar radiation, surface erosion, mechanical impact has a role for the durability of wood. The first step to evaluate the exposure conditions is the macroclimate conditions. The driving rains, moisture, temperature and also the solar radiation are the most important factors. 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. These models can be used to support the service life evaluation of building and building components. A basic method for service life evaluation is the factor method presented in the standards ISO 15686. For wooden components, the most important factors are wood material and coatings, design and execution of structure, exposure conditions of environment and maintenance of the wood structure and surface.

The long term durability of building structures depend typically on several factors, but the first stage for evaluation of durability and service life consist on evaluation of the exposure conditions (ISO 15686-1): e.g. climate, type of local environment, building type and orientation, design and details of the structure. For wood material, the microbes play often a key role for the durability of material, especially in high humidity conditions. The microbial activity is often highest in the tropical and subtropical climate and lowest in the boreal and arctic climate. There are several climatic approach for biological activity. Koeppen's climate classification was originally developed for the botanical and agricultural use, but it will give an overview on the world macro-climate mapping for environmental biological activity. There are several main climate areas based on temperature and precipitation. A new version of the climate classification was presented by Kottek et al. (2006).

For evaluation of the effect climate on decay development, the Scheffer index was developed (Scheffer 1971), and it has long been used for mapping the decay hazard areas in the USA. In Europe, EuroIndex for decay development has been presented (Grinda and Carey 2004, VanAcker 2003).

1. Introduction

Brischke and Rapp (2007) found a poor correlation between decay rate and cumulative Scheffer index values over the 4 years double decking test at 22 sites in Europe. They develop a “Dose reponse model” to evaluate the effect of decay on the durability and service life of different wood materials. Dawson et al. (2005) used two Climate Index (CI) models to compare the climate of Braunschweig, Germany and Rotorua, New Zealand: a) CI_{EU} and b) CI_J, which are based on a) global radiation, days of rainfall and total precipitation, or b) mean of monthly highest temperature, total sunshine and number of rainy days. In Australia the decay development in above ground in different climatic conditions was modelled using lap-joint field test results and weather conditions of the sites, and also a software for calculating the decay risk was developed (Wang et al. 2008, Wang and Leicester 2008).

The 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 microclimate conditions are the basic level for building physical and microbial activity evaluations. There are several different programmes for evaluate the moisture and temperature behaviour of structure (Ojanen et.al 1994, Künzel 1995). Mathematical models on mould development have been introduced to these programmes to evaluate the eventual risk of mould growth (Ojanen and Salonvaara 2000, Viitanen and Salonvaara 2001, Sedlbauer 2001, Moon 2005, Viitanen et al. 2009).

For durability aspects, there are so many factors that mathematical models are needed to handle the complicated relations (Leicester et al. 2003, MacKenzie et al 2007, Wang et al. 2008). For microclimate level close the studied structure the time of wetness is a useful factor when evaluating e.g. risks for corrosion of steel structures or mould growth on materials, but it alone does not give adequate information about the durability risks for organic, wooden materials. Long period, high moisture levels may start biological growth on timber surfaces, first mould or stain fungi and finally decay (Viitanen 1996). The time of wetness in the exterior climate, however, does not necessary correspond with the time of wetness in different parts of the building envelope.

The ISO 15686 factor method include several general factors in order to evaluate the service life of building components for different performance requirement levels (ISO 15686-1, 2006). Service life means the period of time after installation during which a building or its parts meets or exceeds the performance requirements, which means the minimum acceptable level of a critical property, and can be defined as limit states. The life time expectations and analyses of different building products will need more data on the durability of products, service life and resistance against mould and decay, not only data on wood material itself. The complicated interaction of different factors may be analyzed using different mathematical models.

A guideline has been developed in the European research project Woodexter and can be seen as a first prototype for a quantitative design tool in the area of wood durability (Thelandersson et al. 2011a, b). It is based on a defined limit state for onset of decay under a reference service life of 30 years. Onset of decay is defined as a state of fungal attack according to rating 1 in EN 252 (1989). The approach is to determine the *climate exposure* as a function of geographical location, local exposure conditions, sheltering, ground distance and detail solution. The exposure is then compared with the *material resistance* defined in five classes and the design output is either OK or NOT OK. The present version of the guideline mainly covers applications for decking and cladding. The data included in the guideline have partly been estimated with the help of a dose-response model for decay, which was used to derive relative measures of decay risk between different locations and between different detail solutions. Some other elements in the guideline have been estimated in a semi-subjective manner based on expert opinions as well as from review of experience from field testing.

2. Evaluation of climate conditions

The type of data which is needed depends on the type of exposure and degradation mechanism considered. Moisture and temperature is generally very important factors for biological and chemical processes, the acting factor for the durability of materials is the humidity / moisture and the temperature close the materials. In the first stage, climate data are needed at the boundary of the wood element for evaluate the microclimate conditions. The conditions of microclimate depend on varied and many factors. The starting point here is meteorological data defining the “regional climate” in the area where the building is situated. Examples of data are temperature, relative humidity, solar radiation, rain and wind intensity and duration. The next step is to define the “local climate”, i.e. the climate conditions close to the building but still undisturbed by the properties of the wood material and the shape of the structure. Local climate depends on e.g. building components shadowing solar radiation and rain such as a roof overhang.

The micro climate, which could be evaluated from regional and local climates, can be expressed as

- the equivalent air temperature close to the structure and the temperature distribution
- humidity and wetness at the surfaces and moisture conditions of the materials
- solar radiation on the surface.

The macro-climate is one of the first steps to define the exposure conditions of the outdoor structure. Köppen climate classification is one possible way to evaluate the macroclimate condition (Kottek et al. 2006). Köppen climate classification will give on overall view on the world climate classification and zones (Figures 1–2). This classification in intended for the botanical needs, and will not give a detailed overview on the exposure conditions of buildings.

The climatic parameters need to be estimated in terms of variability, extreme values and time variation. Data are also needed for critical states leading to decay, mould growth or other undesirable effects (Viitanen 1997a, b). This can be a critical moisture threshold often dependent on the duration of the moisture exposure, temperature, type of wood material considered etc. This may be seen as a material property, whose variability also has to be taken into account in a risk based design procedure (Isaksson 2008).

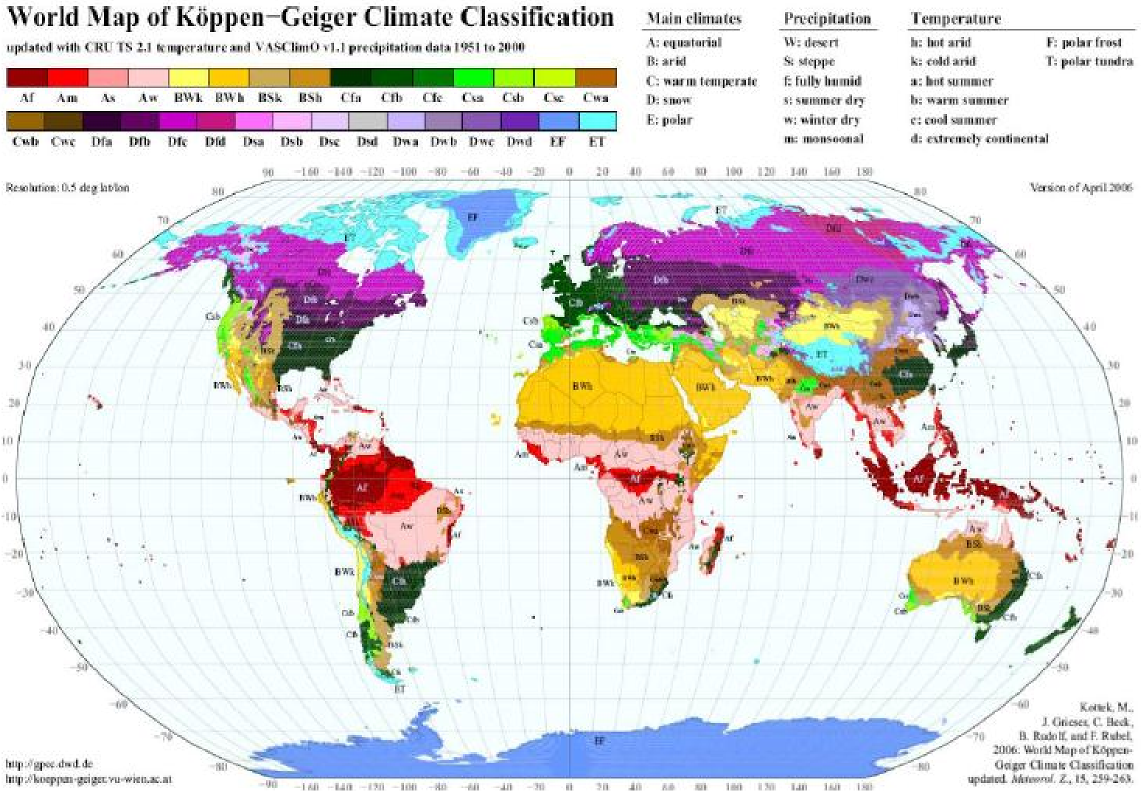


Figure 1. The Köppen-Geiger climate classification.

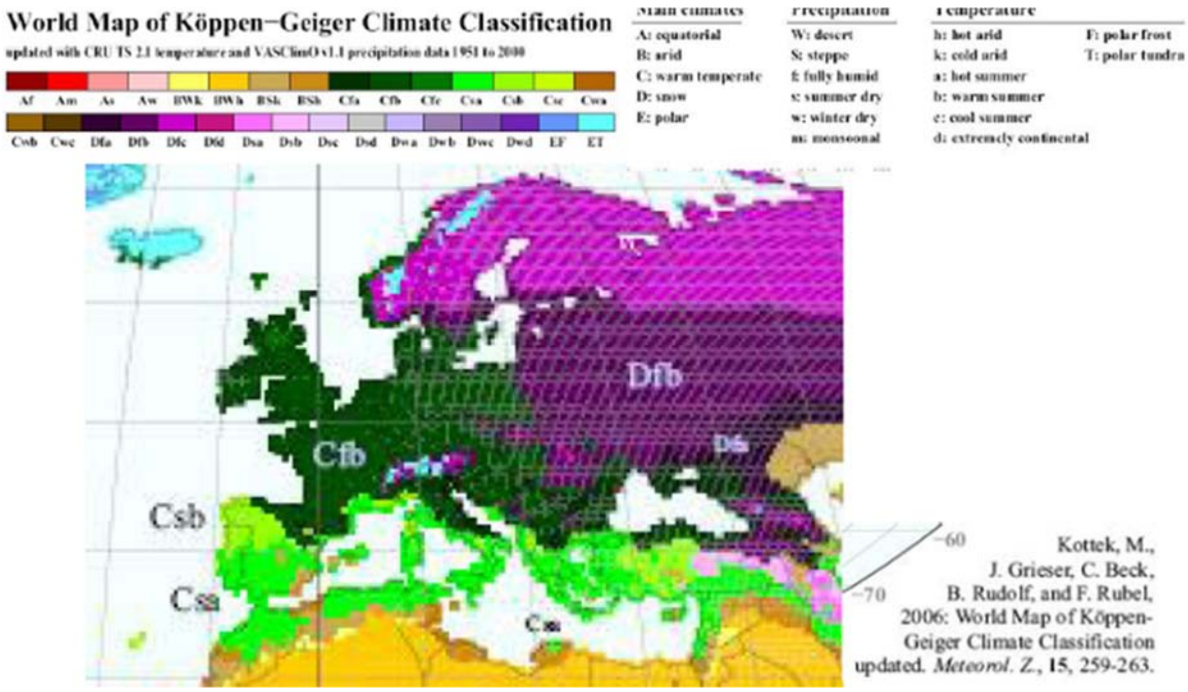


Figure 2. The Köppen-Geiger climate classification for Europe.

The Scheffer (1971) index is developed to evaluate the decay risk in different parts of the USA based on temperature and distribution of rainfall. The Scheffer index may give an overview on the macroclimate conditions for decay development but it does not take account the local and macroclimate conditions. Morris et al. (2008) presented a new map based on the index.

In Europe, Francis and Norton (2006) found the Scheffer Index to correlate better with decay rates in L-joint tests when data from one hot day site was excluded. In Australia the decay development in above ground in different climatic conditions is modelled and also a software for calculating the decay risk is developed (MacKenzie et al. 2007, Wang et al. 2008). The climatic data used for the modelling (Wang and Leicester 2008) were: annual rainfall (mm/year), number of dry months (months/year), number of rain days (days/year), time of wetness (hours/years), dry-bulb temperature (°C), wet-bulb temperature (°C), wind speed (km/h) and wind direction (degrees from the north). Also the data on decay in ground contact and termite attack connected to climatic data is used for modeling (Leicester et al. 2003a, b). In the Australian studies (Wang et al. 2008), an exposure mapping of decay development in different part of Australia was based on the results of outdoor field tests conducted in the different part of Australia using the climatic data mentioned above.

Dawson et al. (2005) used two models to compare the climate of Braunschweig, Germany and Rotorua, New Zealand: a) CI_{EU} and b) CI_J, which are based on a) global radiation, days of rainfall and total precipitation, or b) mean of monthly highest temperature, total sunshine and number of rainy days. It was found, that rain fall, sunshine, mean daily global irradiance and mean daily temperature were higher in Rotorua than these in Braunshweig, but the mean daily relative humidity was higher in Germany. The New Zealand site had a climatic index 50% more challenging for performance of wooden products.

In Europe, Brischke and Rapp (2005, 2007) and Brischke (2007) have evaluated the effect of different test conditions on the decay development in different wood species. In sapwood and heartwood, the decay development was different depending on the exposure conditions, and the average weather data was not sufficient for estimation decay development. Brischke and Rapp proposed a roadmap to specify the performance of wood durability, and Brischke developed a “Dose-Response Model” to evaluate the effect of exposure conditions to develop decay in different wood materials. Also a COST decay index has been started to develop. An example of the European work is the Woodexter project, where a new format of the basic decay model according to Viitanen (1997b) was developed (Viitanen et al. 2009, 2010).

3. Evaluation exposure conditions

3.1 Critical part of the building for exposure

The time of wetness can be calculated by summing up the length of time over one year when the relative humidity RH is above 80 or 95% at the same time when temperature is above $0^{o}C$. The atmosphere can be characterized in relation to its fatality by calculating the time of wetness using the temperature and the relative humidity of the ambient air. The time of wetness in the building envelope parts, however, does not necessarily correspond with the time of wetness in the exterior climate. The time of wetness may be high in the building structure even in cold and dry climates if the moisture performance of the structure is poor.

A basis for a quantitative probability based design is the definition of a so called limit state or performance degree. Performance degree will be changed during the life time of the building and different level of performance degree can be achieved depending on the maintenance, reparation and replacement of the building components (Figure 3). This is a more or less precise definition of the limit between acceptable performance and non-acceptable performance. An example is onset of mould growth and discoloring in materials in the building envelope, which can be regarded as non-acceptable since it may create aesthetic problems in a building. Another example is attack from decay fungi, which will reduce the capacity of a load bearing structure. During the life time of a building, different level of maintenance and repair will be needed for acceptable performance. For wood material in exterior use, the maintenance is normally involved for the service life evaluation depending on the exposure conditions and structure.

The technical function of the cladding or facade is to protect building against weather. Cladding can be fully or partly protected / exposed depending on the design (Figure 4). According to the standard EN 335-1, the use conditions of wood and wooden products are classified for the evaluation of the activity of different biological agents to wooden structure. The classification is, however, very general, and in reality, many details are often important for the durability and service life of the whole structure or building. For damage to develop, several different organisms can be involved (Figure 5).

3. Evaluation exposure conditions

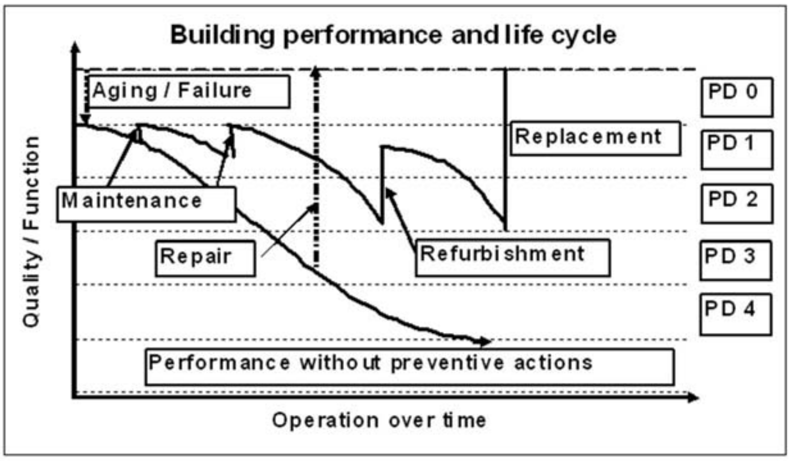


Figure 3. Building performance life cycle as a function of quality, performance degree (PD), failure, maintenance, refurbishment, repair and replacement (based on ISO 15686-7, 2006).

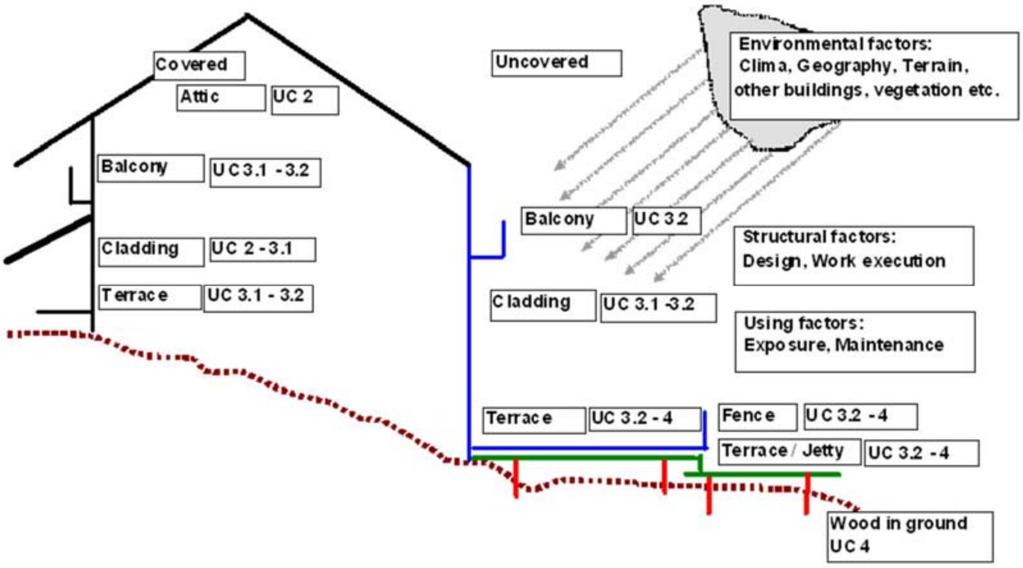


Figure 4. A general exposure situation of wooden products used in different structure and exposure types. The suggestion of use class evaluation for develop the use condition classification is also shown (Viitanen et al. 2009).

The aim of the evaluation work of service life of wood products is to simulate and calculate the complicated interactions of different factors of exposure of gladding and decking during the intended use conditions. The damage cases shown in the Figure 5 are mainly caused by the excess of water by malfunction of the structure and the damage is not within the intended use conditions.

For service life evaluation, the climate data simulation will give an overall estimation of the macro-climate part of the exposure of ideal or model structure. The more complicated interaction of the meso-climate like the effect of environment and structural components (driving rain, details) can be evaluated e.g. by using a building physics calculation model like WuFi programme (WuFi 4.1 Pro software).

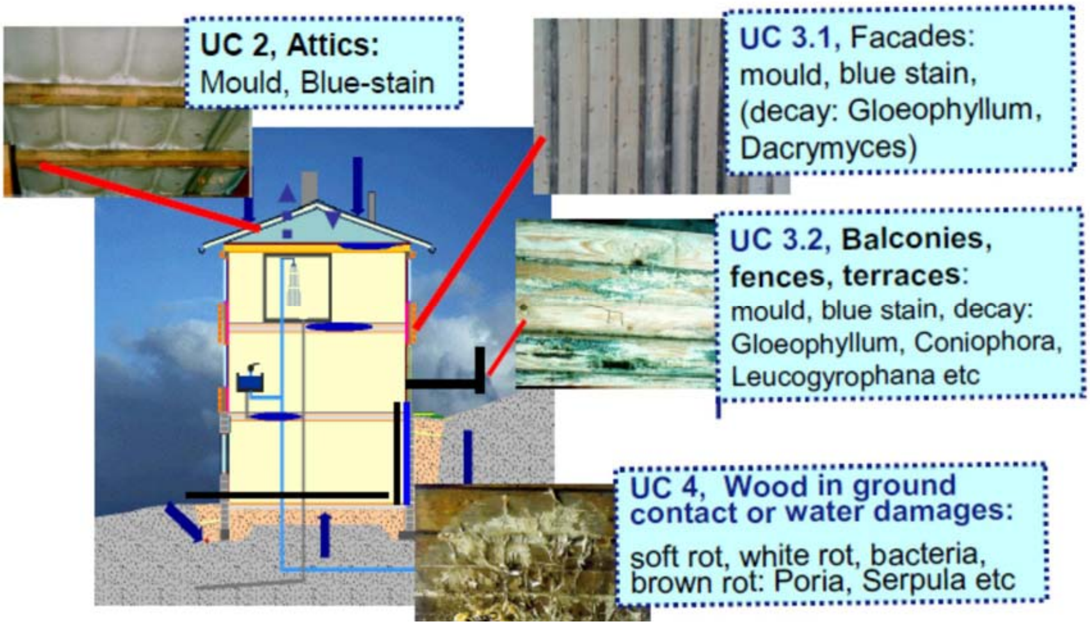


Figure 5. Example of the fungi causing damage in different parts of buildings. The damages are caused by moisture exceeded the tolerances of the materials and structure e.g. by water leakage, faults of function of the structures, especially critical details.

Mould and blue-stain fungi can cause injuries of the surface of materials and coatings. Discoloration is a common term for the problem, especially on paint films. Mould fungi will grow on outer surface of materials and blue-stain fungi will also penetrate in to the material and cause damage also in coatings and paint films.

Figure 6. Mould and blue stain are the first step for the development of grayish color of wood surface. The response of wood to ambient humidity and discoloring vary (left). The decay damages are located in the details where water will be accumulated (right).

The most critical parts of the cladding are details where water can be accumulated and decay will be started (Figure 6). These part of the cladding, however, are not the intended use conditions. The decay is most often caused by the low quality of design, and for these details, the models of decay development can be valid.

3.2 Modeling development of mould or decay

3.2.1 Data generated using laboratory work and field tests

Ambient microclimatic conditions, especially moisture conditions, are the most important factors for durability of wood and the classification of use conditions is based on the evaluation of the water exposure during the use. For generating critical humidity and temperature conditions needed for mould and decay development, first step is using laboratory conditions.

There is always a wide variation within the growth conditions of different fungus species, and we need an overall evaluation of the growth activity and decay development of a “typical” example fungi (mixture of mould/blue-stain fungi) or typical decay fungi (e.g. *Coniophora puteana* or *Gloeophyllum sepiarium*). There are different types of models concerning the development of biodeterioration, mould growth or decay development. Some of the models are based on the laboratory studies, some on the field studies and some on the hygrothermal properties of materials (Figure 7).

The first isoplets or models were based on the laboratory studies on agar culture using different mould and decay fungi (Ayerst 1969, Block 1953, Smith and Hill 1982, Grant et al. 1989). On the base of results, different functions or s.c. isoplets on critical humidity and temperature levels were developed. The hygrothermal models are based on osmotic potentials for the spore germination and start of the mould growth in different materials (Sedlbauer 2001).

The models developed by Hukka and Viitanen (1997) and Viitanen et al. (2000) are based on laboratory work using Scots pine sapwood exposed to mould fungi and decay fungi under different humidity and temperature conditions for varied periods. The basic regression models are general isoplets for mould growth and decay development in untreated pine sapwood.

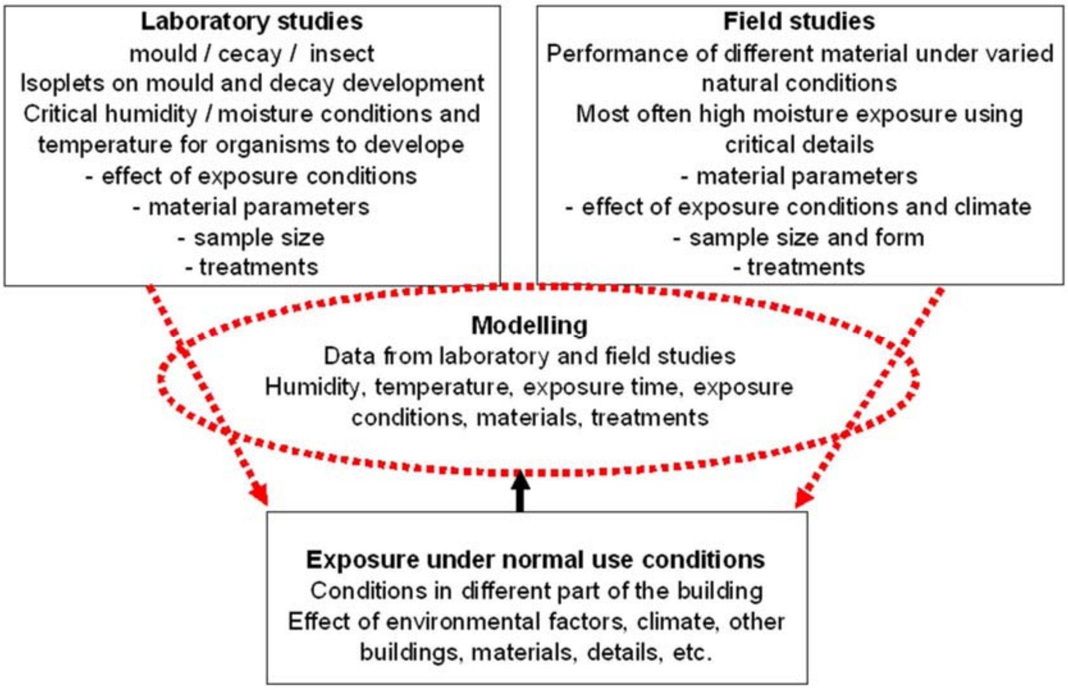


Figure 7. Use of data from tests to model the durability of materials under different exposure conditions.

Mould

The most often found discolouring fungi species are *Alternaria dianthicola*, *A. tenius*, *Aspergillus flavus*, *A. versicolor*, *A. niger*, *Aureobasidium pullullans*, *Cladosporium cladosporioides*, *C. sphraerospermum*, *Fusarium* sp., *Chaetomium* sp, *Paecilomyces* sp, *P. variotii*, *Penicillium* species, *P. brevicompactus*, *Phoma* sp., *Trichoderma* sp. and *Ulocladium* sp. (Gillat 1991). Under tropical climate, like in India, the primary invaders of paint films are *Genera Alternaria*, *Aspergillus*, *Aureobasidium*, *Bipolaris*, *Chaetomium*, *Cladosporium*, *Curcullaria*, *Fusarium*, *Mucor*, *Nigrospora*, *Paecilomyces*, *Penicillium*, *Phoma*, *Rhizopus*, *Trichoderma* (Joshi et al. 1997).

One of the first biological signs of ageing is mould growth that does not affect durability as such but can cause discoloration and health problems. Discoloration is often connected also to paint and surface treatment properties. The first isoplets (graphs on critical humidity and temperature) or models for mould growth were based on the laboratory studies on agar culture using different mould fungi (Ayerst 1969, Block 1953, Smith and Hill 1982, Grant et al. 1989). On the base of results, different functions or s.c. isoplets and critical humidity and temperature levels for spore germination and mould growth were developed (Figure 8).

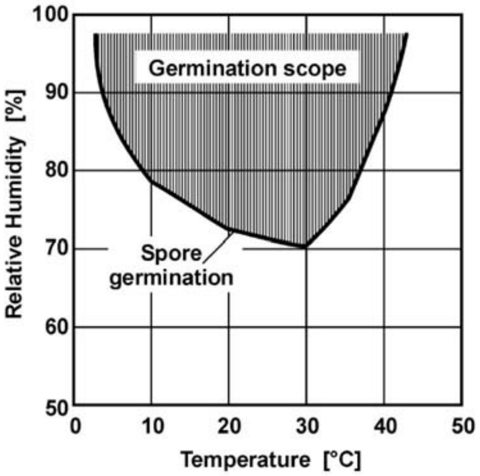


Figure 8. Relative humidity and temperature for the start of mould growth (Sedlbauer 2001).

The time-of-wetness or varied humidity and temperature conditions is important for the mould development (Adan 1994, Viitanen 1997a). The TOW is defined by the ratio of the cyclic wet period (RH ≥ 80%) and the cyclic dry periods. For mould development, the ambient critical humidity level of microclimate is between RH 80 and 95% (Figure 9, left) and time of high humidity followed by dry periods is important (Figure 9, right) and varied cyclic conditions can be taken under consideration and basic information for modeling (Hukka and Viitanen 1999).

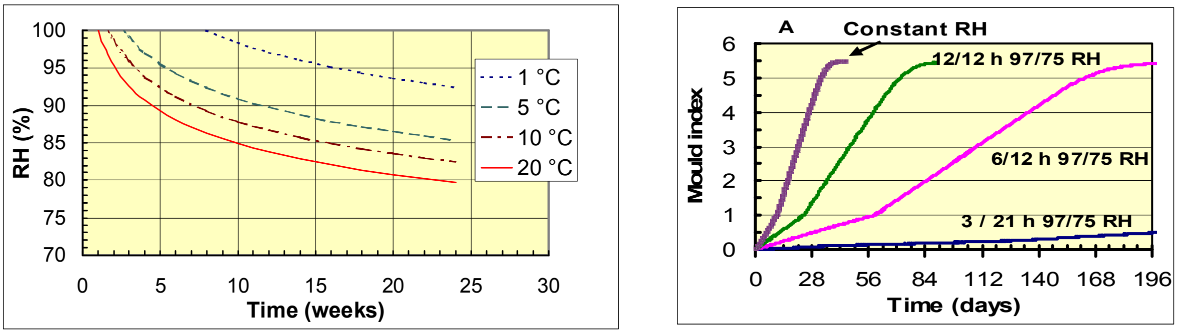


Figure 9. RH and temperature isoplets as a function of time for start of mould growth (left) and effect of wet time (high humidity) on the development of mould growth (right) in pine sapwood (Viitanen 1996, Viitanen et al. 2003). Modeling is based on large laboratory work (Viitanen 1997a).

Greyish colour of wood surface and aging of coated wood is caused by the combined action of water, UV light and micro-organisms (mould and blue-stain fungi). The isopleths shown above can be used for evaluation of dose – response relation between mould / decay and humidity, temperature and exposure time. For mould and decay to develop, different dose response relations exist.

The models on biodeterioration and mould growth can be used as a tool for building physic performance and service life evaluation. Sedlbauer (2001) has evaluated the spore moisture content and germination time based on calculated time courses of temperature and relative humidity in various positions of the exterior plaster of an external wall. This model has been incorporated in a hygrothermal calculation tool Wufi (Wufi 4.1 Pro software). 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. Isaksson (2008) has presented the state of art situation on methods to predict wood durability.

Decay

Decay is the more severe result of high moisture exposure of wooden structures when the materials are wet for long periods. Mould growth and decay development are separated processes and also the models will be different. 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% (Figure 10).

There are several different fungus species. The most often found fungus species in damaged wood claddings are *Gloeophyllum sepiarium*, *Dacrymyces stillatus*, *Coniophora puteana*, *Ghaetomium globosum*. In decay damage conditions, several different decay fungi can be found like *Serpula lacryman*, *Poria placenta*, *Gloeophyllum sepiarium Coniophora puteana* etc. *Coniophora puteana* is a brown rot fungus used for long time as a test organism for decay resistance tests. Viitanen and Ritschkoff (1991) used *Coniophora puteana* as a test fungus to study the critical lowest ambient humidity conditions needed for the growth of fungus and develop of decay. Based on the results of laboratory studies, a regression model of the growth of fungus in pine sapwood was developed (Viitanen 1996):

$$\begin{aligned} ML(RH,T,t) &= -42.9t - 2.3T - 0.035RH \\ &+ 0.14T \cdot t + 0.024T \cdot RH + 0.45RH \cdot t \end{aligned} \tag{1}$$

where T is temperature (°C) between 0..30 and RH relative humidity (%) between 95–100.

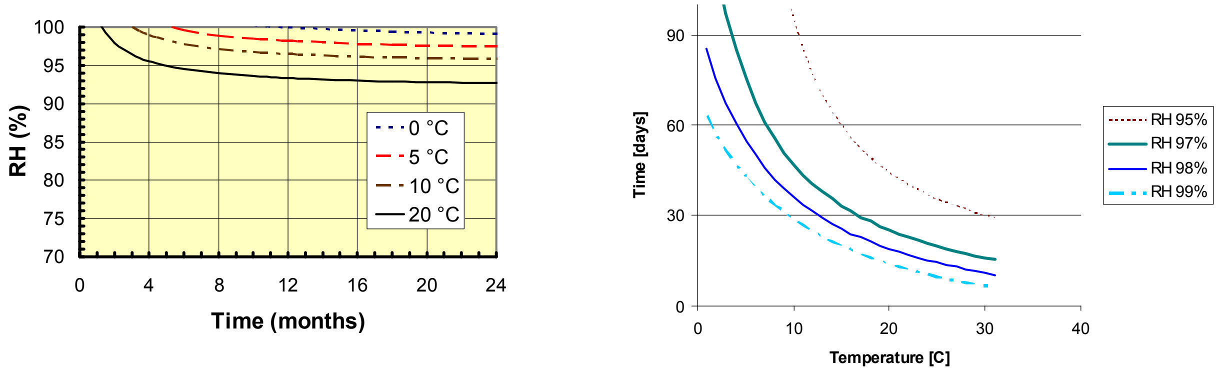


Figure 10. RH and temperature isoplets as a function of time for early stage of decay development in pine sapwood (Viitanen 1996, 1997b) (left). The isopleths are based on the results of formula 1. Calculated critical time before decay (mass loss process) initiates at different constant temperatures (x-axis) and relative humidity levels of ambient air (different curves) (right).

The humidity and moisture limits were based on large laboratory work on pine and spruce sapwood (Viitanen and Ritschkoff 1991, Viitanen 1996). 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.

On the basis of the laboratory work on the decay development of brown rot in spruce and pine sapwood in different constant relative humidity and temperature conditions a decay model was presented by Viitanen (1996). The decay growth model, expressed as mass loss, thus only applies in temperature ranges of T = 0…30°C and in relative humidity's 95% and above. It is noted that mass loss does not occur immediately when the wood is exposed to these environments (Figure 4). Thus, there is a time lag or as named here, and activation period in the beginning. Based on the experimental findings presented above, a model for variable conditions is proposed. This model is a time stepping scheme. The development of decay is modeled with two process:

a) Activation process: This is termed as α parameter, which is initially 0 and gradually grows depending on the air conditions to a limit value of 1. This process is able to recover favorable conditions (dry air) at a given rate (although no experimental evidence of recovery is available).
b) Mass loss process: This occurs when the activation process has fully developed (α = 1) otherwise it does not develop. This process is naturally irrecoverable.

These processes only occur when the temperature is 0…30°C and the relative humidity is 95% or above. Outside these condition bounds, the activation process may recover, but the mass loss process is simply stopped. The activation process is as given in the following equations. The recovery rate (when the air conditions are out of the bounds given above) is assumed to be 17 520 (h) (2 years). This time means that α may recover from a value of 1 back to 0 in this time, when the conditions are outside the bounds of decay growth.

$$\begin{aligned}
&\mathit{Activation\ process}\,\alpha = 0..1\\
&\alpha(t) = \int_0^t d\alpha = \sum_0^t (\Delta\alpha)\ ,\mathit{where}\\
&\Delta\alpha = \frac{\Delta t}{t_{crit}(RH,T)}\quad or\ (in\ favorable conditions\ of\ decay)\\
&\Delta\alpha = -\frac{\Delta t}{17520}\ (in\ unfavorable conditions\ of\ decay)\\
&t_{crit}(RH,T) = \left[\frac{2.3T + 0.035RH - 0.024T\times RH}{-42.0 + 0.14T + 0.45RH}\right]\times 30\times 24\quad [hours]
\end{aligned} \tag{2}$$

The mass loss process proceeds the activation process, when α has reached 1.

$$\begin{aligned}
&\mathit{Mass\ loss\ process\ when}\,\alpha \geq 1\\
&ML(t') = \int_{t\,at\,\alpha=1}^{t'} \frac{ML(RH,T)}{dt}dt = \sum_{t\,at\,\alpha=1}^{t'} \left(\frac{ML(RH,T)}{dt}\times\Delta t\right)\\
&\frac{ML(RH,T)}{dt} = -5.96\times10^{-2} + 1.96\times10^{-4}T + 6.25\times10^{-4}RH\ [\%/hour]
\end{aligned} \tag{3}$$

The selected time step of humidity and temperature is an important factor and short periods (hours, days) of favourable and unfavourable conditions may be too short to give positive input for the start of activiation process and decay development.

3.2.2 Using a model in variable temperature and relative humidity

The model presented in previous chapter is used here to see how the decay growth would develop in varied humidity and temperature conditions. In the first case, the measured weather conditions in Helsinki area of temperature and relative humidity is given (origin of data to be given). This climate is shown in the figure 10 for a one year period. According to the model, this climate seems to induce a low mass loss of 1.1% in 4 years (Figures 11 and 12).

During the first year, no decay development will occur in untreated pine sapwood. After 3 and 4 years exposure, some early findings on decay process only in the surface of unprotected pine sapwood can be expected. Under normal use conditions, the cladding is protected using paints or other coatings when water will not affect direct to wood surface and decay development will be significant retarded or even neglected in the surface.

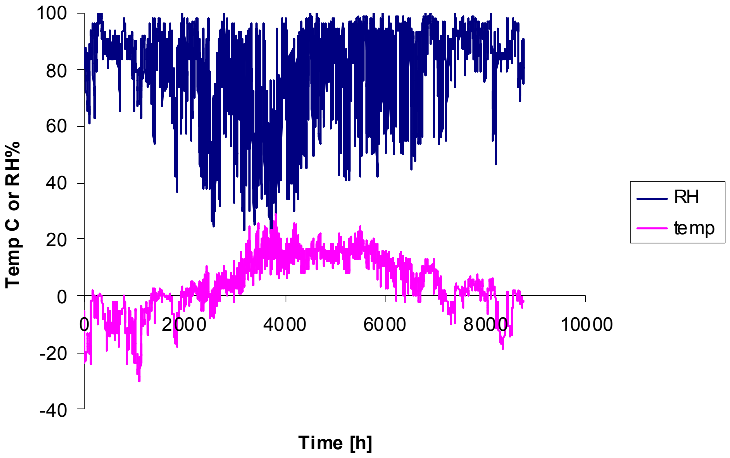


Figure 11. Measured climate data (Helsinki) used in the decay model for one year.

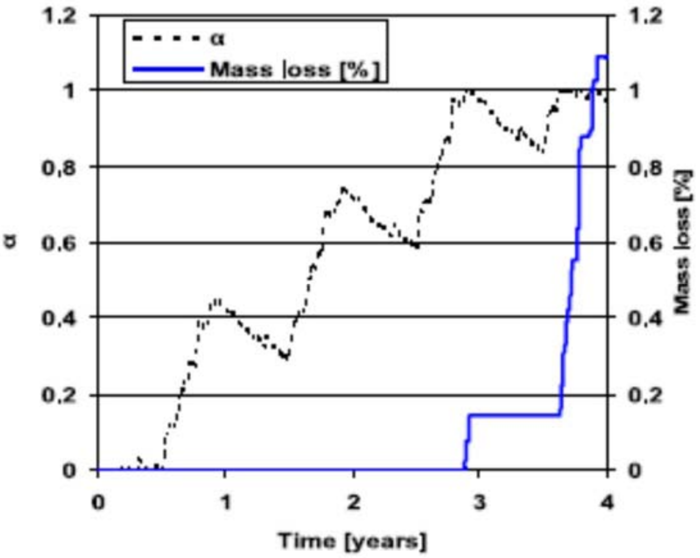


Figure 12. No activation of growth or decay development during the first and second years, an activation of decay process after 4 years exposure may be expected (Viitanen et al. 2010).

When applying the models for evaluation of service life in certain microclimatic conditions, the great natural variability of materials, coatings, structures, different treatments and organisms should also be taken into consideration (VanAcker et al. 1999). Different type of microbial growth will be found on stone based material and on insulation material than that on wood material. The ageing of material and accumulation of dust and other material on the surface of building material will change the response of the material to moisture and biological processes. (Theander et al. 1993, Sedlbauer 2001, Viitanen et al. 2003.

4. Performance model

A performance model is needed to evaluate whether the limit state is reached or not under a given micro-climate exposure. For this purpose a dose-response model is used, where the dose is given as a function of wood moisture content and temperature (Thelandersson et al. 2011a, b). Starting with a time series of interconnected daily average values of moisture content u_i and temperature T_i for day i the accumulated dose D_N for N days can be calculated from

$$D_N = \sum_{i=1}^{N} D_u(u_i) \cdot D_T(T_i) \tag{4}$$

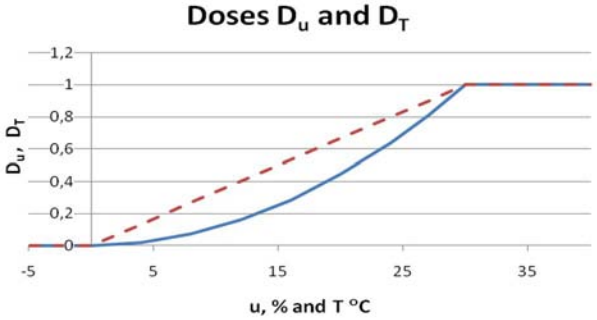
where $D_u(u_i)$ is the dose related to moisture content (kg/kg) and $D_T(T_i)$ is the dose related to temperature (°C) given by

$$D_u(u_i) = \begin{cases} (u_i / 0.3)^2 & \textit{for } u_i \le 0.30 \\ 1 & \textit{for } u_i > 0.30 \end{cases} \tag{5a}$$

$$D_T(T_i) = \begin{cases} 0 & \textit{for } T_i < 0 \\ T_i / 30 & \textit{for } 0 \le T_i \le 30 \\ 1 & \textit{for } T_i > 30 \end{cases} \tag{5b}$$

These relations are illustrated graphically in Figure 13. The formulation is a simplified and modified version of the dose-response model proposed by Brischke & Rapp (2008), which was developed on the basis of results from double layer field tests performed at a number of different sites all over Europe, Brischke (2007). The materials used in these tests were Pine sapwood as well as Douglas fir heartwood. The duration of the tests was of the order 8 years with continuous measurements of moisture content and temperature at each site during the whole test period. The test specimens were regularly evaluated with respect to decay according to EN252 (1989). The tests show that the time in calendar days until onset of decay is of the order three times longer for Douglas Fir than for Pine sapwood. One of the main reasons for this is that Douglas fir heartwood is much more resistant to moisture uptake than pine sapwood.

The performance model is based on the simple fact that the fungi spores need favourable moisture and temperature conditions during a sufficiently long period of time in order to germinate and grow. It is therefore reasonable to assume that variable moisture and temperature conditions which occur in practical situations should to some degree have an inhibiting effect on the biological process.



D_u

Figure 13. Illustration of the dose-response model described by Equations 2 and 3 (Thelandersson et al. 2011 a).

For instance, if the organisms are subjected to periods of dry and cold conditions the biological development will stop and may also be reversed. Such a plausible “restraint mechanism” is so far not included in the performance model, due to lack of data to quantify the effect. This must be borne in mind when interpreting the results from the model. This “restraint” effect is probably one of the reasons why the resistance for Douglas fir mentioned above is significantly larger than for Pine sapwood. In the double layer tests, the pine specimens were more or less above the fibre saturation point during the whole test period, while the Douglas Fir specimens oscillated regularly between wet and dry conditions.

The performance model proposed above and illustrated in Figure 2, is greatly simplified and somewhat unrealistic since the dose should be zero for moisture contents lower than 20–25%. The present formulation is however chosen to give a non-zero measure also for dry situations so that the margin to critical states can be estimated with the model. For this reason and due to other uncertainties mentioned above, the model in its present version should only be used *in a relative sense*, i.e. to compare different exposure situations with each other. This is how it has been utilized to derive the data included in the present version of the guideline (Thelandersson et al. 2011a).

5. Mapping of exposure conditions for decay

The evaluation of the exposure conditions can be performed at general macroclimate level like using European Climatic simulation model (Uppala et al. 2005) and at a building component level using building physics calculation programme like WuFi (WuFi 4.1 Pro software). WuFi is not intended for the exterior applications but was developed for building physics calculations in the building envelope. The results of calculations of the exterior gladding should be interpreted with care and they are not direct appliceable for gladding conditions.

For evaluation the climatic exposure conditions, the empirical wood decay model presented in the previous chapter can be used for the ERA-40 data for air temperature, humidity and precipitation at 6 hour intervals. ERA-40 is a massive data archive produced by the European Centre of Medium-Range Weather Forecasts (ECMWF). The reanalysis involves a comprehensive use of a wide range of observational systems including, of course, the basic synoptic surface weather measurements. The ERA-40 domain covers all of Europe and has a grid spacing of approximately 270 km. The nature of the data and the reanalysis methods of ERA-40 are described in detail in Uppala et al. (2005).

The resulting modelled mass loss in 1961–1970 at the calculation points of the ERA-40 grid were analyzed by a chart production software producing a maps of wood decay in Europe (Figure 14). In these calculations, the α-factor of the empirical wood decay model was reduced during non-decay periods by the rate that corresponds to the recovery time of two years.

In the simulation, the calculation was based on the relative humidity and temperature in air so that the humidity of air was set to 100% during precipitation, at non-freezing temperatures. The present maps on Europe of decay development are based on evaluation of decay activity studied in laboratory. However, they will give theoretical evaluation on the effect of climatic conditions on the decay development in different geographical area. In the second stage, the exposure mapping presented in Figure 9 was simplified to be used for service life evaluation (see chapter 2).

The risk of decay activity in different part of Europe can be evaluated on the map. If we evaluate the decay activity rate in Helsinki to be 1, then the decay risk in north-western part of Portugal and in West Ireland is 2 times and in Atlantic part of France and Belgium it will be between 2 and 2.5 times higher than that in Helsinki. In North Scandinavia it would be between 0.5 and 0.25, which will point out, the effect if climate on risk of decay development in outdoor structure varied vide within Europe. These coefficients can be used as one step to evaluate the effect of macroclimate conditions on service life of cladding and decking.

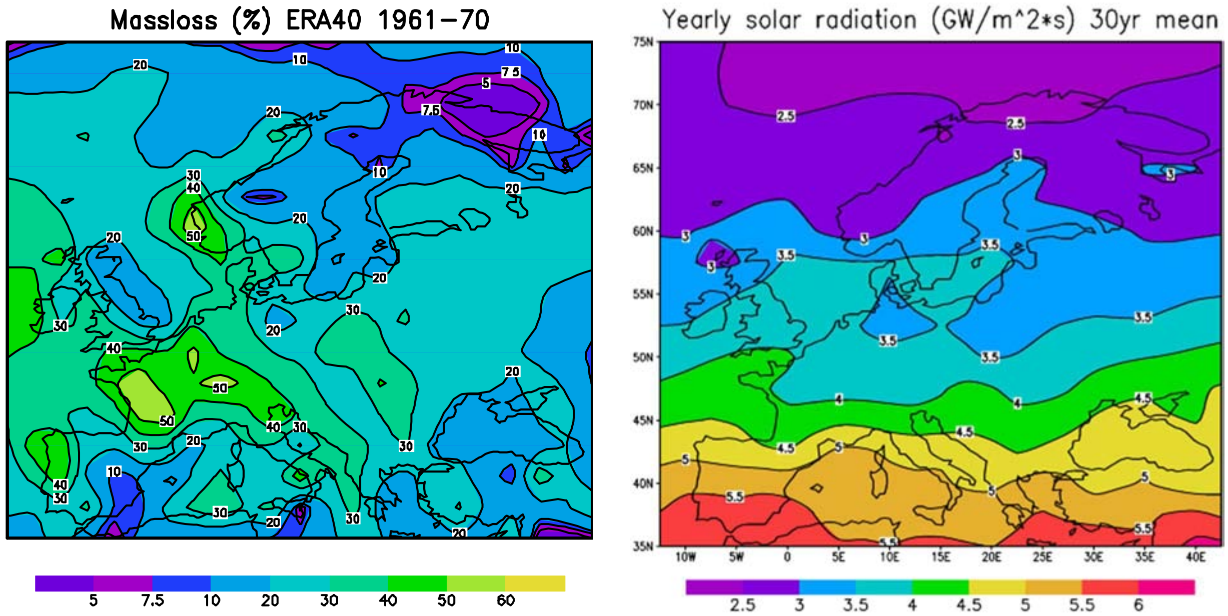


Figure 14. Modelled mass loss (in %) of small pieces of pine wood that exposed to rain in 10 years in Europe (according to Toratti et al. 2009), (left). Simulated solar radiation in Europe (right).

The effect of macroclimatic conditions on decay development is significantly lower in the continental and northern part of Europe than that of zones near the Atlantic Ocean. The highest exposure conditions may be found in North-West part of Portugal, in South-West of France and in South West of Norway, but along the area affected by Atlantic Ocean, the decay risk may be higher than that in North Europe. Around Mediterranean Sea, the climatic exposure is varied caused by partial low humidity exposure.

The solar radiation is also lowest in North Europe even the days during summer time are longer. The highest solar radiation are found in the Southern Europe.

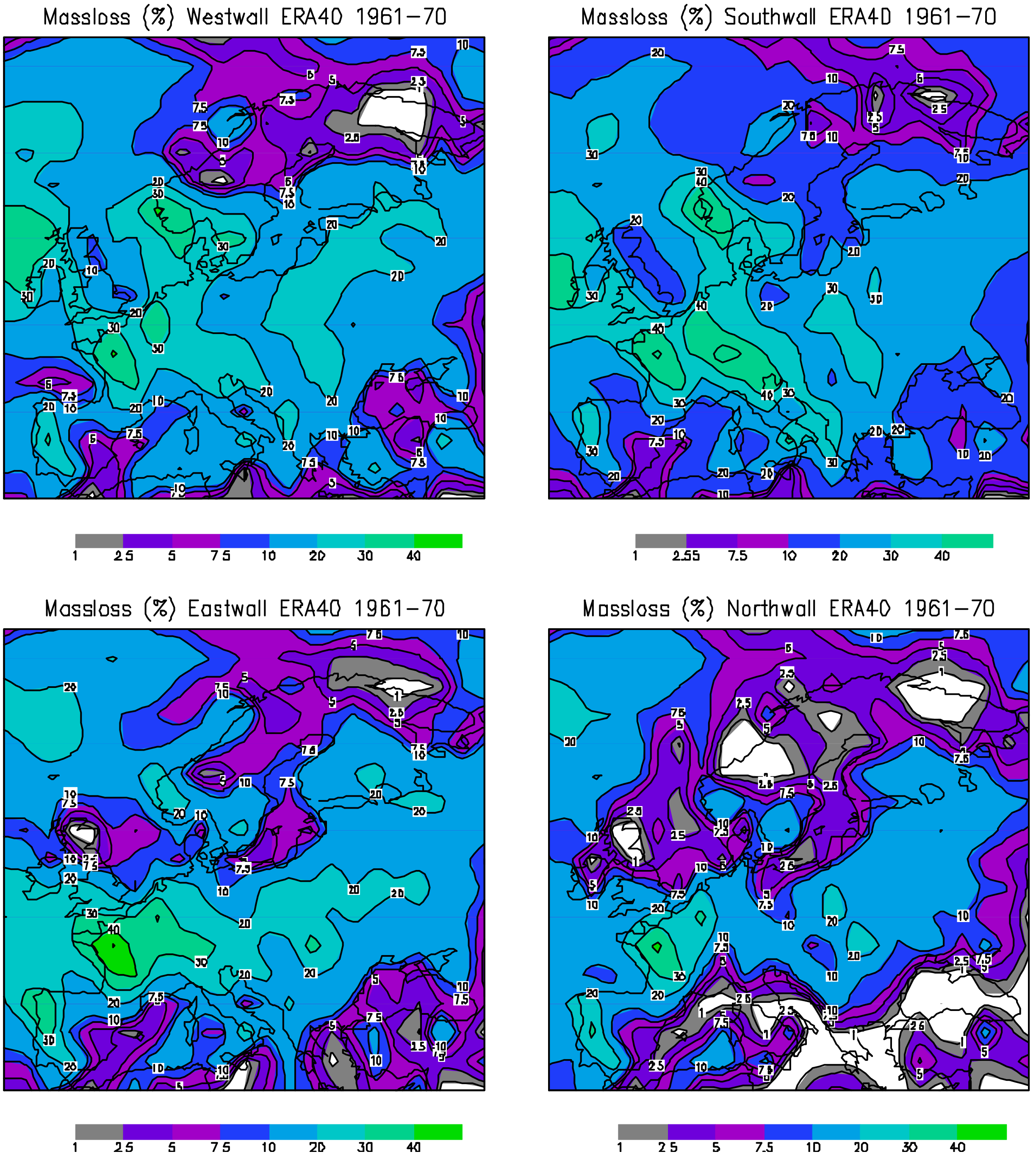


Figure 15. Modelled evaluation of exposure conditions based on the mass loss (in %) of pine wood on differently aligned vertical surfaces exposed to driving rain in ten years in Europe (Viitanen et al. 2010).

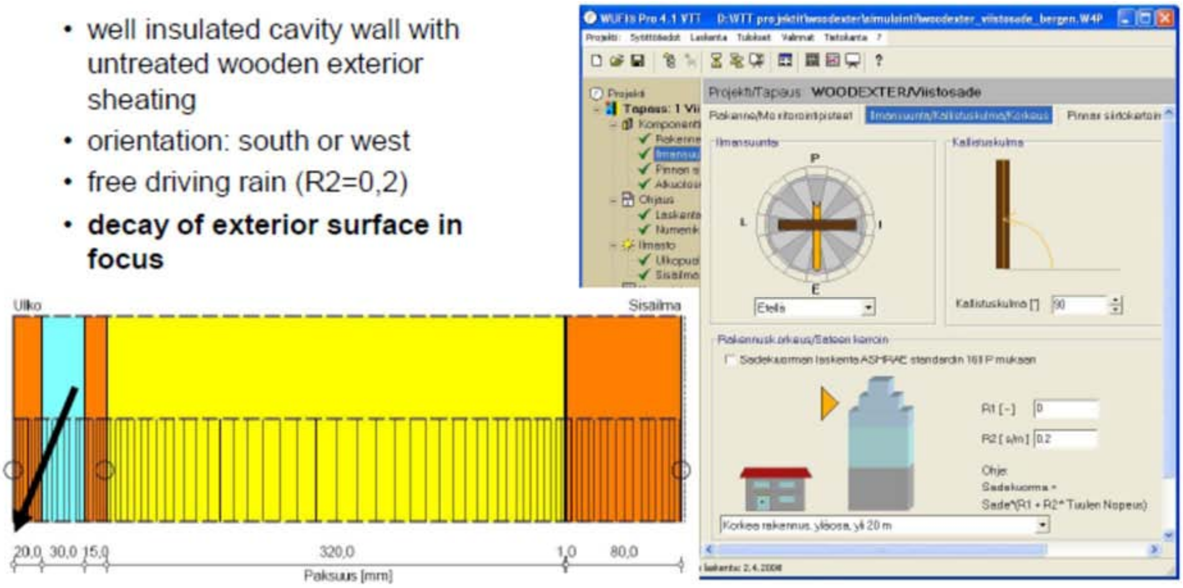
Rain exposure on external walls and other components of buildings at a location is usually related to some typical wind directions because of driving rain. During rain at moderate or high wind the façades that are facing the wind are wet while the ones on the opposite side of the building remain dry. During long periods, this will result in a different exposure and risk of decay on wooden components. It was considered that a façade gets wet during rain when the wind speed exceeds 1 m/s. The wet facades at each time step were considered in this modelling as in the rain-exposed situation. The effect of compass direction and driving rains was analyzed using the same simulation method as shown in previous chapter. The figure is more complicated, but the same type of exposure zones could be find as shown for the whole Europe (Figure 15).

6. Evaluation of performance using wufi

The developed mathematical model for decay is suitable to be used to post-process the results of hygrothermal dynamic simulations of building components. As example a well insulated cavity wall with untreated wooden exterior gladding is used (Figure 16). The decay (mass loss) of exterior surface is in focus. The geographical location and orientation, together with different assumptions for driving range can be used as variables (Figure 17). The simulations are performed with a hygrothermal simulation model Wufi (Wufi 4.1 Pro software) which solves the dynamic temperature and moisture conditions in a construction and can e.g. take into account the amount of water absorbed to a construction due to driving rain. The driving rain load S_d, is calculated as in Equation 4:

$$S_d = s \cdot (R_1 + R_2 \cdot v) \tag{4}$$

where *s* is free rain, *v* is wind velocity in orthogonal direction to surface. R_1 and R_2 are coefficients, e.g. $R_1 = 0$ for vertical facades and $R_2 = 0.2$ for in-disturbed rain (Wufi).



- well insulated cavity wall with untreated wooden exterior sheating
- orientation: south or west
- free driving rain (R2=0,2)
- **decay of exterior surface in focus**

Projekti/Tapaus **WOODEXTER/Viistosade**

Ilmansuunta: Etelä

Kallistuskulma [°] 90

☐ Sadekuorman laskenta ASHRAE standardin 160 P mukaan

R1 [-] 0

R2 [s/m] 0.2

Ohje:
Sadekuorma =
Sade*(R1 + R2* Tuulen Nopeus)

Korkea rakennus, yläosa, yli 20 m

Figure 16. A cross section of a well-insulated (320 mm) cavity wall with ventilated air cap (30 mm). Exterior climate is on the left hand side and more detailed explained in Figure 16.

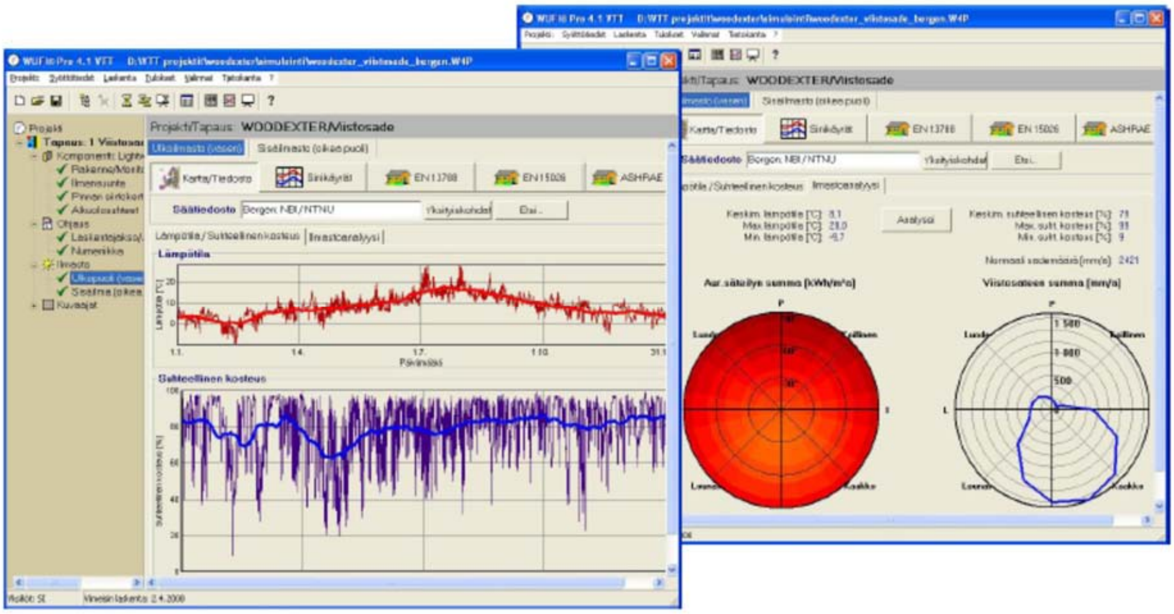


Figure 17. The evaluated exterior climate condition, an example of the WuFi simulation.

The case is studied for west oriented wall in 3 very different locations in Europe: Grenoble, Bergen and Sodankylä. The impact of the driving rain is studied by assuming either free driving rain ($R_2 = 0.2$) on façade or reduced driving rain ($R_2 = 0.07$) on the centre of the facade due to the pressure field around a typical building.

Following results show some examples on the output and the use of the developed model for decay in assessment of the building structures. Figure 18 shows the impact of different climates on the decay development. The mass loss is much higher in a humid location as Bergen than in Central France. A cold location in Northern Finland gives no decay during 3 years.

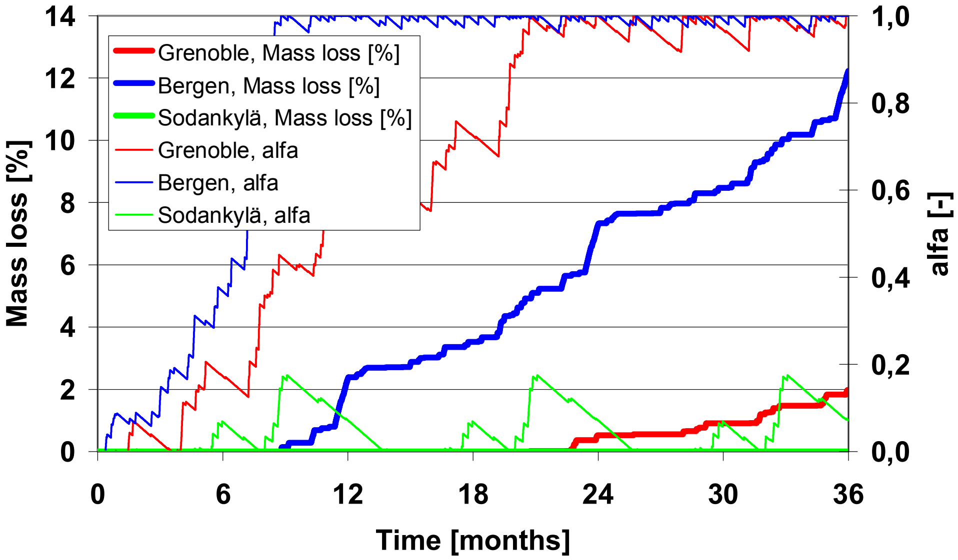


Figure 18. The decay development and activation parameter during 3 years in different locations in Europe. Alfa means the lag phase of decay development and mass loss the degree of decay during active phase of decay development (according to Viitanen et al. 2009).

When applying the models for evaluation of service life in certain microclimatic conditions, the great natural variability of materials, structures, different treatments and organisms should also be taken into consideration. Different type of microbial growth will be found on stone based material and on insulation material than that on wood material. The ageing of material and accumulation of dust and other material on the surface of building material will change the response of the material to moisture and biological processes.

7. A model for the climatic and exposure impact on exterior wood structures for the service life model

7.1 Service life evaluation of wood products and components

The long term durability of building structures depend typically on several factors, but the important stage for evaluation of durability and service life consist on evaluation of the exposure conditions. The ISO 15686 identifies a wide range of parameters important to Service Life Prediction:

A = quality of components e.g. wood natural durability, treatment and coatings
B = design level e.g. protection by design
C = work execution e.g. joints and details
D = indoor environment, e.g. temperature, RH, condensation
E = outdoor Environment e.g. climate, driving rain, shadow
F = in use conditions e.g. wear, mechanical impacts
G = maintenance level e.g. repair, revisions, repainting.

For wood materials and components, the factors B, C, E and G are obviously the most important (Vesikari et al. 2001, Viitanen 2005). However, values for these parameters could be determined regionally, taking into account all the local effects of the external factors considered to be important. The quality of components means different wood species, including sap and heartwood parts (Figure 19). Natural durability of wood, however is mainly based on heartwood only (EN 350-2, 1994). Wood based products, however, include different impregnated and modified products which give more wide use conditions.

For normal use condition in Nordic Countries, the coated spruce boards and paint base film coated birch plywood have been used for long time in exterior conditions without any significant durability problems when best practices are followed (Viitanen et al. 2008b). In Table 1 a list of factors for service life of wooden claddings are presented. The list is long and shorter list for practical solution and use may be needed. For decking, the effect of wood material is more important than that for cladding. For decking material, most often impregnated or modified wood is used.

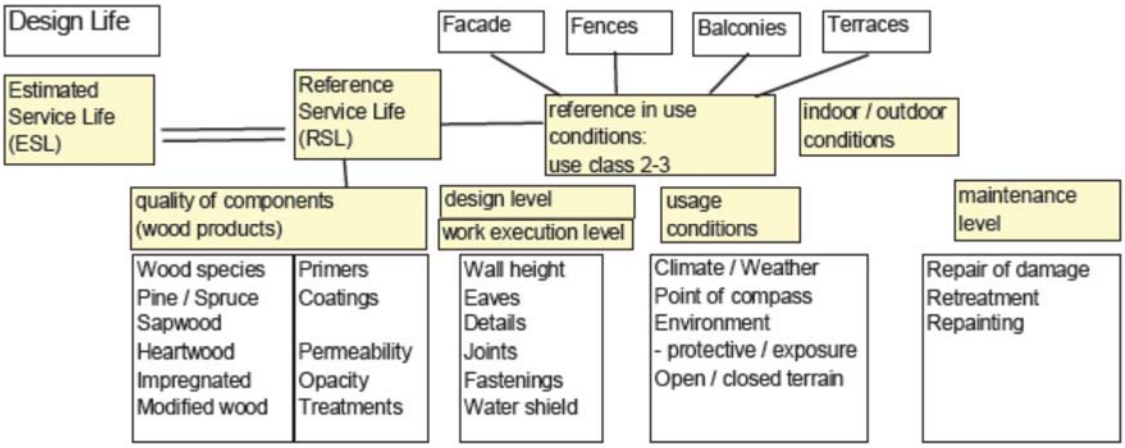


Figure 19. The overall picture on the different factors dealing with the durability and service life of different wooden structure.

In Task Force Group of COST E 37 (2007) much of the discussion ranged around the subject of service life evaluation and durability testing. It was accepted that a great deal of work needs to be done to determine values for the relevant parameters. However, it was recognized that if certain parameters are understood and controlled they should be taken into account when estimating service life or specifying the level of durability required. What would be needed to align with ISO 15686 is a system that allows establishment of a durability rating from the existing test methods. These would then be used to set a value for Factor A (quality of components) to cover e.g. treated commodities in each Use Class. The durability classes would then be related to accepted reference products used within the biological tests. It is increasingly recognized that there is a need to determine a range of effectiveness and define durability of components within a range, as is done with natural durability of wood. For relationship of damage and strength properties of wood, decay have an important effect. The effect of mass loss, however, is depending on the timing, decay type and the sample size focused (Van de Kuilen 2007).

Table 1. Factors for service life of wooden facades (Vesikari et al. 2001).

Code	Factor	Parameters / factors for estimated service life
A 1	Wood material	Wood species, decay and weather resistance, water permeability, board quality, dimension, modification, preservation
A 2	Coating	Coating type and properties (thickness, opacity, color), needs for repainting (maintenance)
B	Structure, design, especially details	Structure of the houses: eaves, height of the wall and foundations. Structure of the façade; board type, bonds and joints, ventilation, protection of joints and end grains, fixing
C	Work execution	Achievements and treatments details, fixing, wood moisture content, storage condition
D	Exposure conditions (weather, environment)	Point of compass, type of environment (protective – exposed) macroclimate → microclimate, exposure to driving rains
E	Use conditions	Indoor environment, moisture stress, mechanical injuries
F	Maintenance	Care of accidental damage, serviceable, repainting (opaque – stains) time of repaint, cleaning of the old surface

Use classes presented in standard EN 335-1 (see Figure 4) will give a general overview on exposure conditions of wood and wooden products in different intended use conditions classified according to the expected biodeterioration risks (discoloration and decay fungi, insects, termites and marine organisms) and ambient humidity conditions close the evaluated material and structure (microclimate conditions). The use classes can be used as a guide for designing and manufacture of wooden products. Service life evaluation, however, is more fitted to the actual situation of material and structure. The evaluation may be more complicated (as shown in the Table 1) or more simple based on the classified simple construction and material types.

7.2 Evaluation and modeling of the exposure conditions for service life evaluation

7.2.1 Australian studies

For the service life evaluation and decay development, a basic model, where different factors are included, was developed by the Australian studies (Figure 20). The model is based on the results of field studies and different factors are then added for evaluate the decay in different structures having varied types of materials and design. The main k-factors included were: wood species, paint type, dimensions of the wood product, design and execution (assembly), and climate condition. In the Australian studies (MacKenzie et al 2007, Wang et al. 2007, 2008a,b,), an exposure mapping of decay development in different part of Australia was based on the results of outdoor field tests conducted in the different part of Australia using the climatic data (Figure 21). The durability and service life of different wood products in fences in different climatic zones was evaluated (Figure 23).

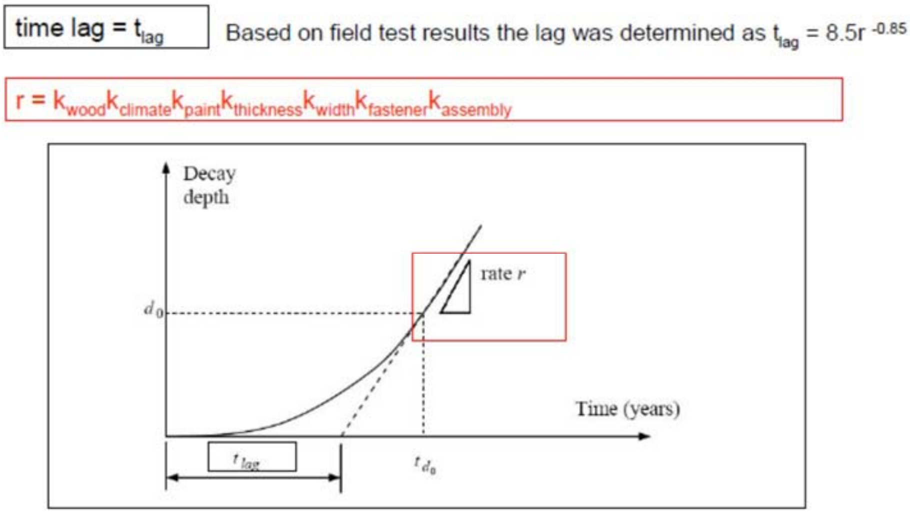


Figure 20. The basic model for timber decay based on results from field tests (Wang et al. 2008a).

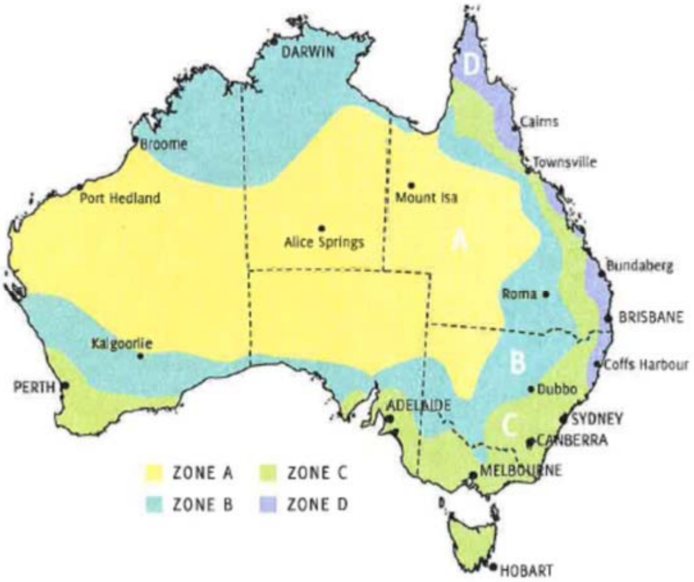
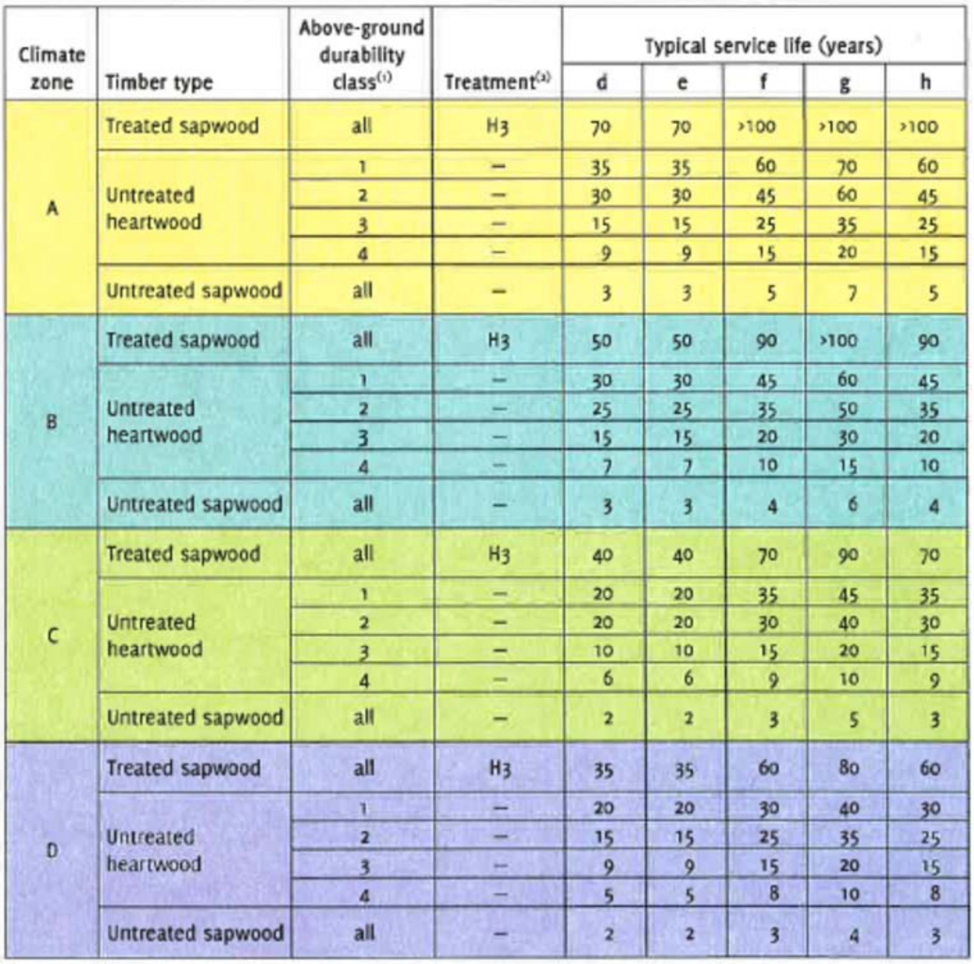


Figure 21. The climatic zones for decay development above ground (MacKenzie et al. 2007).



Climate zone	Timber type	Above-ground durability class(1)	Treatment(2)	Typical service life (years)				
				d	e	f	g	h
A	Treated sapwood	all	H3	70	70	>100	>100	>100
	Untreated heartwood	1	–	35	35	60	70	60
		2	–	30	30	45	60	45
		3	–	15	15	25	35	25
		4	–	9	9	15	20	15
	Untreated sapwood	all	–	3	3	5	7	5
B	Treated sapwood	all	H3	50	50	90	>100	90
	Untreated heartwood	1	–	30	30	45	60	45
		2	–	25	25	35	50	35
		3	–	15	15	20	30	20
		4	–	7	7	10	15	10
	Untreated sapwood	all	–	3	3	4	6	4
C	Treated sapwood	all	H3	40	40	70	90	70
	Untreated heartwood	1	–	20	20	35	45	35
		2	–	20	20	30	40	30
		3	–	10	10	15	20	15
		4	–	6	6	9	10	9
	Untreated sapwood	all	–	2	2	3	5	3
D	Treated sapwood	all	H3	35	35	60	80	60
	Untreated heartwood	1	–	20	20	30	40	30
		2	–	15	15	25	35	25
		3	–	9	9	15	20	15
		4	–	5	5	8	10	8
	Untreated sapwood	all	–	2	2	3	4	3

Figure 22. The service life of different wood product in fences in Australia (MacKenzie et al. 2007).

7.2.2 European exposure conditions – Macroclimate zones

The more detailed maps shown in Figure 9 was used as a basis for evaluate the macroclimatic zones of Europe (Figure 23). The colors are according to the area shown in the map.

In the figure of European climate zones, the K factors and the zones are based on the evaluation of the decay development based on the climate data from ERADATA years 1961–1970. The numeral values shown in the figure 23 are the climate data from ERADATA of year 1999. The numeral values (in parenthesis) is the Meteonorm data, which source is from Thelandersson et al. (2011a).

Based on the evaluation results, The ERADATA years 1961–1970 is quite close to the value given by meteonorm. The ERADATA year 1999 gives a slightly different result. It should be pointed out, that the climate is by nature very variable and climate exposure will vary during different years and periods. More cities from western Europe could be analyzed for the mapping.

European macroclimate, humidity (Map 1)	D1
Nordic climate zone, North	0,50
Nordic climate zone, South	0,80
Continental Europe climate zone	1,00
Atlantic climate zones, North	1,50
Atlantic climate zones, Middle	2,00
Atlantic climate zones, South	2,50
Mediterranean climate zone 1 (wet)	1,50
Mediterranean climate zone, 2 (dry)	0,80

European macroclimate, solar radiation	D2.1
Nordic zones, North	0,70
Nordic zones, South	0,85
Middle Europe, North	1,00
Middle Europe, South	1,14
Southern Europe	1,30
Southern Europe, Southern parts	1,60

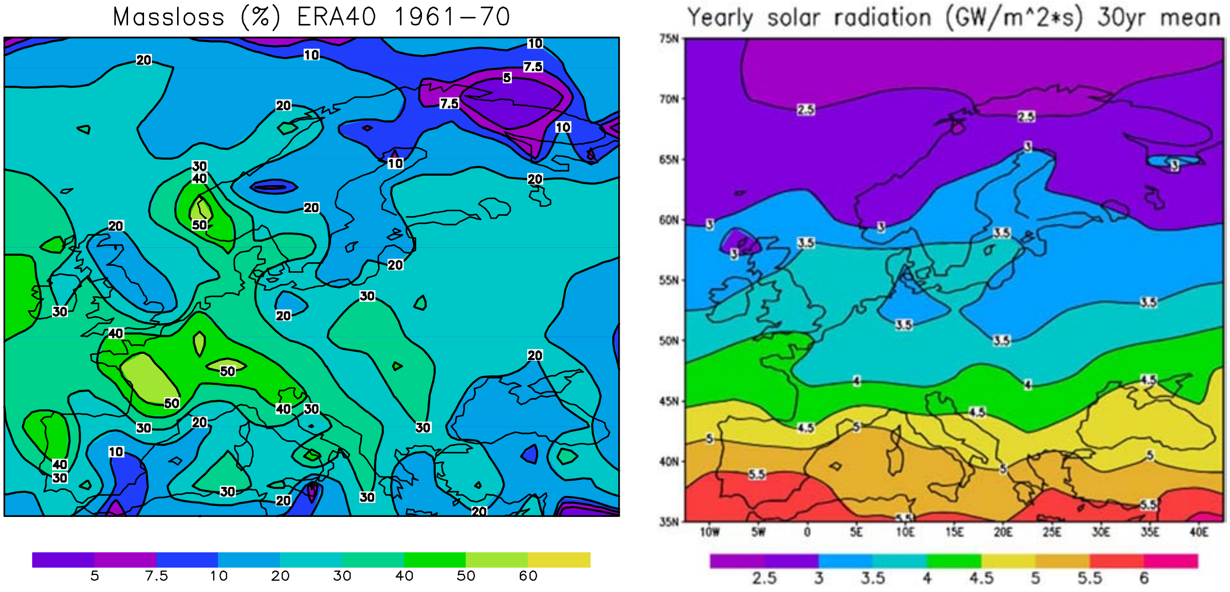


Figure 23. The macroclimatic zones of Europe based on wetting and solar exposure.

7.3 Characterisation of exposure for engineering tool

The performance model (in the form of dose-response relationship) describes the combined effect of moisture content, temperature and the variation in time of these parameters on the potential for decay fungi to germinate and grow.

The design condition on the engineering level is quantitatively formulated in the following way (Thelandersson et al. 2011a, b):

$$I_{Sd} = I_{Sk}\gamma_d \leq I_{Rd} \tag{4}$$

where I_{Sk} is a characteristic exposure index, I_{Rd} is a design resistance index and γ_d depends on consequence class. The consequence class refers to the expected consequences if the limit state is violated. If the condition in Equation 4 is fulfilled, then the design is accepted, otherwise it is not accepted.

The definitions of I_{Sk} and I_{Rd} are related to the following reference situations

- Exposure situation: The exposure to outdoor temperature, relative humidity and rain of a horizontal member with no moisture traps, is used to define a basic exposure index depending on geographical location.
- Material: Norway spruce (*Picea abies*), uncoated, corresponds to $I_{Rd} = 1.0$
- Consequence class 3 (most severe) corresponds to $\gamma_d = 1.0$

Since the reference exposure is a favourable design condition for avoiding decay, things normally get worse when accounting for moisture traps and various design details. This is considered by various exposure factors described below. The consequence class depends on the severity of consequences in case of non-performance The idea is that the user shall consider the consequences and select a level according to the particular situation at hand.

The exposure index I_{sk} can be conceived as a “characteristic (safe) value” accounting for uncertainties. The exposure index is assumed to depend on (Thelandersson et al. 2011a):

- geographical location determining global climate
- local climate conditions
- the degree of sheltering
- distance from the ground
- detailed design of the wood component
- use and maintenance of coatings.

The exposure index is determined in the guideline from

$$I_{sk} = k_{s1} \cdot k_{s2} \cdot k_{s3} \cdot k_{s4} \cdot I_{so} \cdot c_a \tag{5}$$

where

I_{so} = basic exposure index depending on geographical location/global climate
k_{s1} = factor describing the effect of local climate conditions (meso-climate)
k_{s2} = factor describing the effect of sheltering
k_{s3} = factor describing the effect of distance from ground
k_{s4} = factor describing the effect of detailed design
c_a = calibration factor to be determined by reality checks and expert estimates.

The exposure index intends to describe the severity in terms of combined moisture and temperature conditions favourable for development of decay fungi.

The effect of climate variability on risk for decay of wood exposed outdoors was investigated using the performance model described in Chapter 6 by Thelandersson et al. (2011a, b). The climate data used was obtained with the program Meteonorm (www.meteonorm.com), Remund & Kunz (1995). In Meteonorm, desired climate parameters for any place can be obtained. The program includes a database with more than 8 000 stations where the climate has been measured during many years, and a “standard year” is produced from these measurements. Then for any location, the climate can be modelled by interpolation between different stations. For the present purpose, hourly values of temperature, relative humidity and rain were chosen as output values. In the performance model, however, daily values are used. Therefore, hourly values of temperature and relative humidity are averaged and hourly rain is accumulated to daily values.

For application of the performance model, wood moisture content is calculated from the global climate data. Moisture content depends on the relative humidity ϕ and is calculated as, see Tveit (1966):

$$u(\phi) = 0{,}7\phi^3 - 0{,}8\phi^2 + 0{,}42\phi + 0{,}0077 \tag{6a}$$

$$u_{01}(t_i) = u\left[\bar{\phi}(t_i)\right] \tag{6b}$$

$$\bar{\phi}(t_i) = \frac{\phi_1(t_{i-1}) + \phi_1(t_i)}{2} \tag{6c}$$

The daily average moisture content $u_{01}(t_i)$ in equilibrium with relative humidity is estimated on the basis of the average value of relative humidity ϕ for two full days (Equations 6b and c). This is assumed to account for a certain delay corresponding to diffusion into the wood.

Additionally, moisture content is increased by rain events. For each 24 hour period it is assumed that rain occurs if the accumulated rain is at least 4 mm. A rain period is then defined as an uninterrupted sequence of 24 hour periods with rain. The duration of a rain period is denoted t_r. A drying period is defined as the time after a rain period during which the moisture content returns to equilibrium with ambient relative humidity. The duration t_d of the drying period depends on the length t_r of the rain period. Based on Van den Bulcke et al. (2009) it can be estimated as $t_d \approx a \cdot t_r$ where a is an empirical parameter of the order 2–3. Here, a = 2.5 was used.

For each day i with rain, the daily average moisture content $u_1(t_i)$ is calculated according to Equation 7 where k_r is the relative increase of moisture content due to rain. According to data in Van den Bulcke et al. (2009), k_r is in the range of 0.6 to 1.0, and the value 0.8 is used here.

$$u_1(t_i) = u_{01}(t_i)[1 + k_r] \tag{7}$$

At the end of each rain period, the parameters t_r and $t_d = a \cdot t_r$ are determined as well as the difference Δu_{1r} between the total moisture content (Equation 6) and the relative humidity-induced moisture content (Equation 5), i.e.

$$\Delta u_{1r} = u_1(t_e) - u_{01}(t_e) = k_r \cdot u_{01}(t_e) \tag{8}$$

where t_e denotes the last day of the rain period. For day k after a rain period the moisture content is determined by:

$$u_1(t_k) = \max[(u_1(t_{k-1}) - \frac{k}{t_d}\Delta u_{1r}), u_{01}(t_k)] \tag{9}$$

Note that as soon as a new day with rain occurs the moisture content is again determined by Equation 6. It is further assumed that the daily average wood temperature T_1 is equal to the daily average surrounding (global) temperature given by Meteonorm. Having interconnected values of daily average moisture content u_1 and temperature T_1 for one year the daily dose can be calculated according to Equations 5 and 6.

By calculating the daily dose and accumulating the dose for one year a measure of the risk of decay is obtained. This is made for several sites, and the result in terms of dosedays can be compared between the different sites. To be able to compare different sites, the dose was transferred to a relative dose by dividing it by the dose for the "base-station" Helsinki.

By this methodology, basic exposure indices I_{so} were calculated for various geographical locations. Figure 24 shows calculated values for a number of European sites. Due to the variation of climate across Europe, relative doses between 0.6 (northern Scandinavia) and 2.1 (Atlantic coast in Southern Europe) were obtained. For sites not shown in Figure 24 the (relative) base value of the exposure can be estimated with the help of the methods described above based on climate data from Meteoronorm. Note that the values describe the relative climate effect on a horizontal board of spruce sapwood (exposed to rain but without moisture traps). The results have been partly verified against another type of model; see e.g. Viitanen et al. (2010). However, it should be kept in mind that local variation of climate conditions may lead to different relative doses than shown in the map. Examples could be sites near large lakes – experiencing higher relative humidity, sites at high altitude with lower temperature or with extremely high relative humidity and large rainfalls.

A detailed climate characterization for the whole Europe is very difficult to make and would be very rough and uncertain (see Figure 24). A more detailed mapping on the national level should be made with the same methodology.

Table 2. Basic exposure index for different climate zones at altitudes lower than 500 m above sea level.

Climate Zones	I_{so}	Description
Continental Europe	1.4	All Europe except the following zones
Nordic Climate zone	1.0	Northern Europe
Atlantic Climate zones: • South of latitude 50 • Latitude 50–55 • North of latitude 55	 2.0 1.7 1.4	Coastal regions, higher values in southern parts, lower in northern parts
Mediterranean climate zone	1.5	Mediterranean regions south of the alps. Dry climate areas are not included.
Altitude effect: altitudes above 500 m, reduce factor by 0.3		

Figure 24. Climate zones in Europe. Relative numbers given are results obtained based on Thelandersson et al. (2011a, b).

This climate characterization for the whole Europe is very rough and uncertain. A more detailed mapping on the national level can be made with the same methodology. A more precise characterization for a given location should be made by using climate data from Meteonorm as input evaluating the dose according to the method described by Thelandersson et al. (2011a, b).

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