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Micro and material climate monitoring in wooden buildings in sub-Alpine environments

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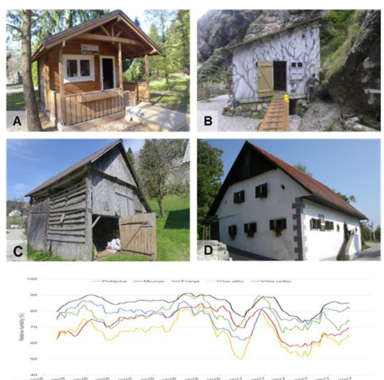
HIGHLIGHTS

- Service life of wood depends on the wood inherent durability and material climate.
- Material climate in real objects was determined in four different objects.
- There was 50.000 moisture measurements performed on 34 locations in four objects.
- The results indicates the correlation between wood moisture and fungal degradation.

GRAPHICAL ABSTRACT



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ABSTRACT

Wood is one of the most important construction materials and its use in building applications has further expanded in recent decades. In order to enable even more extensive and reliable use of wood in outdoor applications, factors affecting wood's service life need to be understood. It is well known that fungal degradation of wood is predominantly affected by temperature (T) and moisture content (MC). In order to elucidate the influence of these two factors, long term monitoring of T, relative humidity (RH) and MC at four locations was carried out: a model house made of thermally modified wood in Mozirje (1), the WWII partisan hospital Franja (2), a hayrack in Pokljuka (3) and a house in the north of Slovenia in Vrba (4). The results clearly showed that fungal degradation of wood is influenced by MC and T. In addition, the influence of micro-climatic conditions on fungal decay was shown.

1. Introduction

Hygrothermal measurements in test houses or real buildings have long been used to address building performance at full-scale in a real environment [17]. These monitoring were performed on various type of buildings, from wooden [22] to buildings made of straw [6]. Field measurements are useful primarily because they expose building components to the whole range of exposure conditions, that cannot be simulated in laboratory conditions. These data are of considerable importance. They can be used to validate the models and to correlate these data with service life data of wood.

The service life of wooden structures is one of the most important pieces of information for the selection of the appropriate construction or façade material. The time during which a particular

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wooden structure will perform its task depends on a variety of factors [8]. However, the service life of wood exposed outdoors is predominantly affected by wood decaying fungi (brown and white rot fungi) [19]. In addition to a material's inherent durability, the moisture conditions and temperature (T) are the most important factors influencing the ability of fungi to degrade wood [18]. These two factors are influenced by the design of the construction, exposure conditions and local climatic conditions (micro-climate). If moisture content (MC) and T are monitored, the severity of a particular location can be evaluated [22]. Based on the severity of the location, additional protection can be applied with design measures. However, if this is not sufficient, a more durable material should be selected. Durable materials can be chosen from the group of naturally durable wood species, wood species treated with biocides or modified wood [11].

One of the issues related to an assessment of micro-climate of a particular location is the question of the moisture limit for fungal decay. There are various data available in the literature. In the first reports authors describes moisture limits are stated to depend predominantly on the fungal species. For example, Schmidt [15] reported that the minimum MC of wood for the growth of *Fibriporia vaillantii* and *Gloeophyllum trabeum* is 30%, while slightly lower (26%) minimum MC are reported for *Coniophora puteana* and *Serpula lacrymans.* Similar values are reported in other references as well [3]. However, recent findings have shown that moisture limits for fungal growth and decay depend on the fungal species in question, and considerably differ among wood species investigated. For example, minimum MC for wood decay varied between 16.3% (*G. trabeum* in Scots pine sapwood) and 52.3% (*Donkioporia expansa* in Douglas fir) [12]. A common question is: how fast will decay occur in various wood based materials, and under what conditions (T and MC) will decay become established and cause structural damage. In buildings where moisture and temperature conditions are not precisely known and often fluctuate, and where the wood is exposed to spores of a wide variety of fungi (mold and decay) of unknown and varying quantities and viability, time for occurrence of decay is hard to be determined [3].

The aim of the present study was to determine the material climate, as defined by Brischke and co-workers [2] and Isaksson and Thelandersson [8], of wooden constructions of four different objects located in the sub-Alpine region at micro-locations with notably different micro-climates.

2. Material and methods

Monitoring was performed on four objects located in different locations with distinctive micro-climates (Fig. 1): a model house made of thermally modified wood in Mozirje (1), WWII partisan hospital Franja (2), a hayrack in Pokljuka (3), and a house in the north of Slovenia in Vrba (4). In Vrba, measurements were performed at two locations: cellar and attic. All of the objects are fairly close together from a geographical perspective. The longest distance between them is less than 100 km.

2.1. Description of the monitored objects

The model house in Mozirje (N 46.334802, E 14.961115) is a log house made of thermally modified (TM) 8 cm thick prefabricated spruce logs (*Picea abies*) (Fig. 1A). The house was constructed in 2009 for exhibition purposes by the company LogHouse (Nazarje, Slovenia). The logs are made of thermally modified wood according to the Silvapro® procedure (Silvaprodukt, Slovenia) at a T around 230 °C. The logs are not surface coated. The dimensions of the cabin are approximately 2 m × 3 m. The cabin is located in a park close to the river Savinja, approximately 340 m above sea level. Some minor parts of the cabin are made of untreated wood, which enabled a comparison between thermally modified wood and reference Norway spruce (*Picea abies*) (Table 1). The second object is a "cabin for the wounded" at the Franja partisan hospital (http://www.muzej-idrija-cerkno.si) (Fig. 1B). This hospital is situated in a remote location in Pasice gorge near Cerkno (N 46.154081, E 14.028197), approximately 600 m above sea level. Since the stream in the gorge is present in all seasons, the RH is always very high. The majority of the huts were completely renovated in 2010 after a disastrous flood in September 2007. The design of the hospital is the same as it was during WWII. It should be noted that the huts were designed as temporary shelters, and subsequently declared a cultural monument of national importance. All the huts are made primarily of Norway spruce wood (*P. abies*). Since the climatic conditions in the gorge are fairly harsh, all the Norway spruce wood was dip-treated with copper-ethanolamine based wood preservative (Cu-EA) (Silvanolin®, Silvaprodukt). The impregnation procedure was not performed correctly, so considerable decay has taken place in the most exposed wood.

The third object, a hayrack on Pokljuka (N 46.304674, E 13.984277), was built approximately 100 years ago and was used in the past for drying and storing hay and other agricultural products (Fig. 1C). The hayrack is made of larch (*Larix decidua*) and Norway spruce (*P. abies*). It is located approximately 1000 m above sea level on an alpine plateau. The last, fourth monitoring was performed in an old farmhouse in the village of Vrba (N 46.387899, E 14.147478) (Fig. 1D). The house has been declared a cultural monument, as an example of old architecture and because it was the birthplace of the Slovenian poet, France Prešeren. The house is located in a sunny exposure, approximately 500 m above sea level (Fig. 1D). In Vrba, measurements were performed in the cellar (humid, not hydro-insulated cellar) and in the attic (dry, ventilated conditions). Use classes of the wood were determined according to EN 335 [25]. All buildings were unheated.

2.2. Monitoring types and equipment

Monitoring of the microclimatic conditions at the various locations did not start at the same time, but they were performed for at least one year and the monitoring equipment and principle was the same at all locations. The durations and micro-locations of the relevant MC measurements are shown in Table 1. In addition, it should be noted that none of the objects are inhabited, although all of them are in use and are maintained. With exception of Vrba, objects are not heated. However, even in Vrba MC was monitored on unheated part of the object.

Three types of continuous monitoring were performed on all of the objects. T sensors Scanntronik (Mugrauer GmbH) were located close to the actual moisture measurement sensors in order to obtain exact values for conversion of electrical conductivity into wood MC [14]. In order to perform this conversion, all relevant wood species and treatments were conditioned at different temperatures and RH to obtain the wood with different MC. Electrical conductivity of the respective wood samples were determined. In parallel MC was determined gravimetrically as well to determine function between wood MC and electrical resistance at given temperature. These calibration curves considered the influence of impregnation applied on respective objects or thermal modification. In general, two T sensors were mounted on each object. T data were collected twice per day, at midnight and noon with Thermofox data loggers (Scanntronik Mugrauer GmbH, Germany). Most of the MC sensors were positioned 20 mm below surface, while temperature was monitored on the surface not to interfere with MC.

In addition, temperature and RH data were recorded hourly with a Thermofox hydrofox. RH and T were determined in the objects, close to the wood MC measurements. The MC was deter-