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Agricultural buildings with timber structure – Preventative chemical wood preservation inevitably required?

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ABSTRACT: Wood preservation is an important issue for agricultural buildings with timber structure. This is among others due to the largely open façade system, high level of moisture release from livestock or storing goods. The possibly high moisture content in the building structure and the potential threat caused by wood-destroying organisms, necessitates more in-depth research. The latest results of a research project carried out at the Technical University of Munich, in cooperation with the Bavarian State Research Center for Agriculture, show that, for the most agricultural buildings built from spruce, no preventative chemical wood preservation is necessary to ensure a durable construction.

KEYWORDS: agricultural building, timber structure, wood moisture content, constructive wood preservation, chemical wood preservation

1 INTRODUCTION

Wood plays an important role in the construction of agricultural buildings. Especially in rural areas, this natural and renewable raw material is widely available. As a building material, wood is preferred by many farmers. That is because they themselves are often forest owners and this material can be used for a variety of construction types and different building utilisations. As an organic material, however, wood must be protected against harmful organisms (fungi, insects). Thus, in order to ensure the stability and durability of agricultural timber buildings an effective wood preservation is of great importance.

In order to avoid fungal attack, wood moisture content (MC) of 20 % is usually set as general upper limit among experts. According to the current German standard for wood preservation DIN 68800-1:2012 [1] the ambient conditions around timber elements lead to their assignment into different Use Classes (GK), which range from GK 0 (with MC "constantly" < 20 %) to GK 5 (with MC "constantly" > 20 %). Although timber could also be attacked by insects at a lower level of wood moisture content, the risk of such an attack is decreasing. The reason for this is that, nowadays the majority of structural timber products are applied after going through technical drying process.

Based on the present state of knowledge, agricultural buildings with timber structure, e.g. stables or storage buildings, should be classified into GK 2 or GK 3 (with MC "occasionally" to "frequently" > 20 %), as a result of their construction design und building use. Spruce, however, the primarily used wood species for the construction of agricultural buildings, is only allowed in GK 0 due to its limited durability - if no additional wood preservation measures are applied. The additional wood preservation measures include in particular: preventive constructional measures and chemical preservatives [2, 3].

In the DIN 68800 series, agricultural buildings have not yet been explicitly dealt with. In particular, there is a lack of statements towards the so-called "special constructional measures", i.e. constructive wood preservation measures which allow a classification of the timber elements into Use Classes GK 0. Theoretically, chemical wood preservation offers one possible solution, but in areas with direct contact with animals and stored goods the use of chemical preservatives must be excluded. In consulting practice, the application of chemical wood preservatives is not recommended concerning the possible accumulation of hazardous substances in the food chain. The fact that no chemical preservative is desired for reasons of food safety, but neither clear rules for the classification of agricultural buildings nor special constructional measures are available, is posing a challenge for building owners, planers and expert engineers.

2 METHODS

In a current research project funded by the Bavarian state institute of forestry (LWF), agricultural timber buildings in typical types of construction and application are systematically studied and assessed by means of monitoring of climate and wood moisture content.

For the long-term measurements, a total of thirteen agricultural buildings, more explicitly stables and

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storage buildings, located in southern Bavaria (Germany) are investigated (Figure 1). Depending on the size, the internal layout and the use of the building, an individual monitoring concept was created for each building. Various climate conditions are recorded across the building area. These are e.g. sections with unusual climate conditions due to local moisture ingress or accumulation of moist air in narrow spaces.

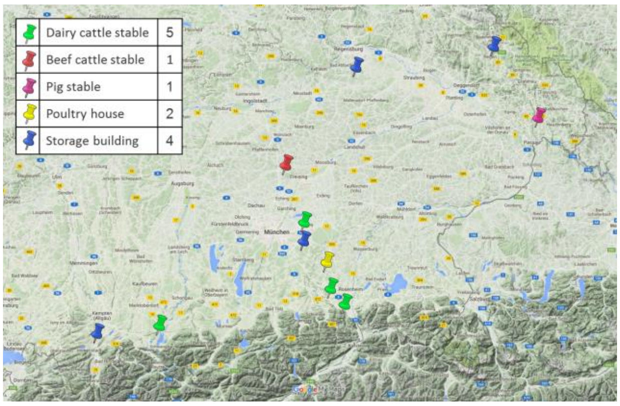

Figure 1: *Locations of all selected monitoring objects*

For the measurement of wood moisture content, the method of electrical resistance measurement was chosen. The measuring system illustrated in Figure 2 was used, which has been successfully applied in prior research projects [4, 5]. Depending on the situation, each measuring system comprises two to four measuring points, at which the wood moisture content and the material temperature are measured at defined depths. The building indoor climate is recorded via an external sensor unit. In addition, a weather station is installed in the near of the measuring objects.

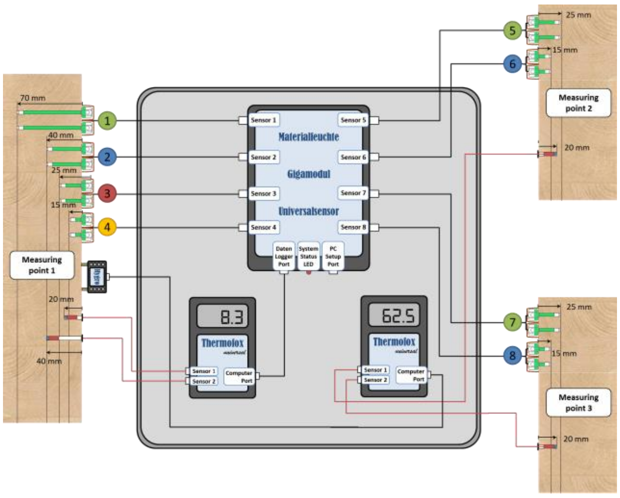

Figure 2: *Schematic illustration of the measuring system*

3 INDOOR VS. OUTDOOR CLIMATE

The measuring were installed in the period from December 2014 to December 2015. At the time of writing this article, the measuring period of all thirteen objects was more than two years. In order to make the results of the measuring objects comparable, the measured data are evaluated for a continuous period of one year.

In Figure 3, the indoor and outdoor climate of the investigated objects are summarized. As additional information, the upper limit of relative humidity according to DIN 68800-1 is drawn. This limit indicates that, with an average relative humidity of up to 85 % and no other moisture load, the wood equilibrium moisture content of 20 % should not be exceeded. It can be clearly seen that, depending on the use and constructive design of the building, the objects differ in their climatic conditions, sometimes only slightly, but sometimes significantly.

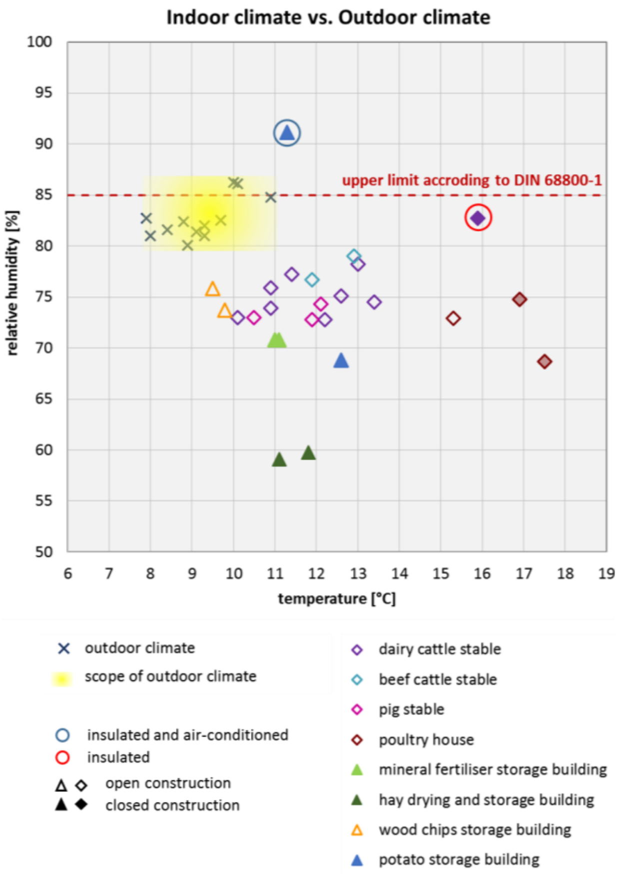

Figure 3: *Climatic conditions in monitored objects*

STABLES

In the cattle stables, the temperatures are above and the relative humidity below the values of the outdoor climate. The outlier is the only closed, warm stable, in which the livestock are kept tethered (red circle in Figure 3). Compared to cold, open stables, higher average temperatures and relative humidity are measured. The stable with tethering systems, in which the animals cannot move freely, were widespread until the 1970s and are characterized by the principle of closed construction. Recent studies on performance and animal welfare of dairy cattle prioritize the open-spaced stables with good ventilation through open construction [6].

The relative humidity in the pig stables is slightly lower than that of the cattle stables. Timber, as building material in pig stables, is usually applied in the roof construction. Load-bearing outer walls are normally form solid martial. The evacuation and ventilation takes place via small windows, outlet flaps which could be opened while the animals are going in and out, open roofs or chimneys with support of direct mechanical ventilation.

The poultry houses are a little bit warmer compared to the other stables. In poultry farming, ventilation is usually achieved by means of an appropriate ventilation system. The lower temperature among all three measuring points is achieved by the climate sensor, which is positioned at an open window of the stable.

STORAGE BUILDINGS

In the mostly closed storage buildings for mineral fertilizers, the climate tends to be drier than in the stables. That is because mineral fertilizer is a highly hygroscopic material that can absorb moisture from the air.

In the hay drying and storage building, high temperatures of about 30 °C and relative humidity of around 80 % were achieved at the time of drying. During the remaining periods of storage, the temperature is strongly dependent on the outdoor temperature, i.e. comparatively low on average. Also the average humidity is lower than those of the other warehouses.

Due to the open construction, in the storage house for wood chips prevails an almost external climate with slightly reduced air humidity.

An interesting object is the potato storage building. In this building, expected temperatures and relatively low relative humidity were measured in the uninsulated roof area, constructively separated by a false ceiling from the storage room. In the closed and structurally insulated storage room (Figure 4), however, an average of 25% higher relative humidity was recorded. This is a result of the cool and moist storage conditions that are essential for the potatoes and the necessary air conditioning of the building area.

Figure 4: *Storage room of potato storage building*

4 WOOD MOISTURE CONTENT

As an important part of the monitoring, wood moisture contents are measured at different depths of the structural components. However, in order to assess the potential risk of wood-destroying fungi, the following chapters will focus on the wood moisture content that is measured near the surface (at 15 mm).

The wood moisture contents reflect mostly quite well the indoor climate. In all stables, with the exception of the warm stable, wood moisture contents permanently below 20 % were measured at the majority of measuring points. Wood moisture contents above 20 % occur mainly in the area of local particularities (e.g. under an open roof, over manure passage or directly in the milking parlor). In the storage buildings, wood moisture contents of lower the 20 % were also measured. On average they are slightly below the wood moisture contents abstained in the stables. Exceptions are the timber components in the storage room for potatoes and those in the woodchip storage house that are in direct contact with the wood chips.

At 60 out of a total of 78 measuring points, the wood moisture contents were permanently below 20 %. For 10 out of the remaining 18 measuring points, the period, in which the upper limit is exceeded, was no longer than 1/5 of the total measuring period; for 4 of the remaining 8 measuring points this period was between 20 % and 40 % of the total measuring period; for the last four measuring points wood moisture contents of over 20 % were measured in more than 40 % of the total measuring period.

5 u > 20% AS INDICATOR IS NOT ENOUGH

During an extensive visual inspection of all monitored objects, including interviews with the building owners, no fungal attack was detected. In order to elucidate this positive, however at first glance not conclusive result, the wood-decaying model derived by Viitanen and Ritschkoff [7] is used. This model takes into account that a fungus attack and fungal growth depends - in addition to the wood moisture content - also on the duration of the surrounding air humidity and temperature.

The wood-decaying model applied here is divided into two parts. On the one hand, it has to be examined which surrounding conditions have to be reached and maintained over which period of time so that the fungal spores could be "activated". In the case of the potato storage building, about 7 °C and 95 % relative humidity prevail during storage. According to the wood-decaying model, these climatic conditions should be maintained for at least 120 days before the germination of fungal spores, see Figure 5.

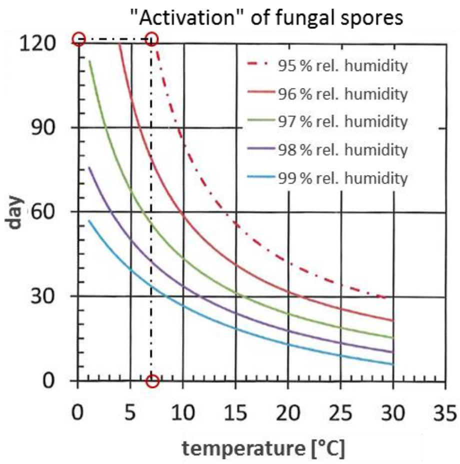

Figure 5: *wood-decaying model of Viitanen [8] – phase I: "Activation" of fungal spores*

The second phase is the "starting" of the fungal growth or the beginning of the wood decay. Again, certain climatic conditions are necessary, and the necessary time is again dependent on the surrounding climatic conditions. In the same case of the potato storage building, the climatic conditions mentioned above have to be maintained over a period of almost 90 days until the fungi start to grow, see Figure 6. With a reduction of the relative humidity to 90 % (t = 20 °C), a period of more than 12 months would be required.

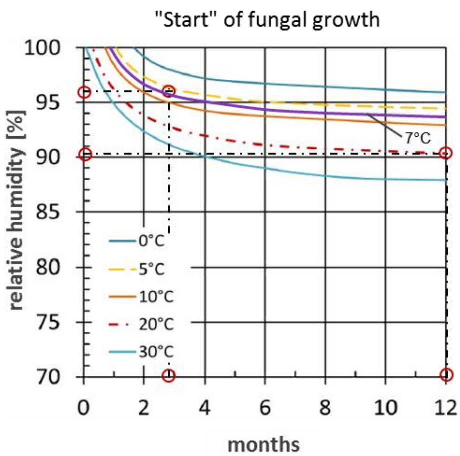

Figure 6: *wood-decaying model of Viitanen [8] – phase II: "Start" of fungal growth*

Kehl [8] derived a simplified engineering approach from the detailed wood-decaying model of Viitanen. In this approach, a boundary line is set for the surrounding climate condition, below which no wood decay would take place, even after 12 months. With help of sorption isotherms, this temperature-dependent boundary line of relative humidity was transferred to wood moisture content. Figure 7 shows that, in contrast to the upper limit according to DIN 68800-1, a temperature-dependent boundary curve for the maximum permissible wood moisture content can be derived, below which fungal attack can be avoided. The gray area represents the fluctuation range, taking into account the different wood moisture contents that occur during adsorption and desorption.

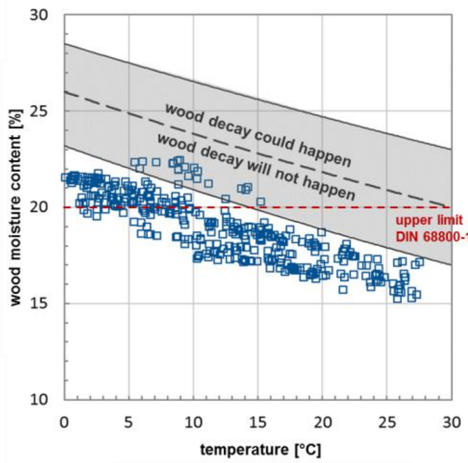

Figure 7: *Temperature-dependent boundary for the assessment of the potential of wood decay*

In order to assess the potential risk of fungi attack, a closer inspection of the coupled influences of wood moisture content and surrounding temperature is carried out on all building components with wood moisture content above 20 % with the aid of this model. The wood moisture contents and their associated temperatures are plotted as point cloud in the diagram derived from the wood-decaying model, see Figure 7. These values are compared to the temperature-dependent boundary line. By means of this representation, it can be shown that the high wood moisture contents (over 20 %) measured in winter would not lead to wood decay. Due to the prevailing low temperatures at that time, no fungal infestation is possible.

6 EXAMPLES

In the following, three exemplary measuring points are discussed in more detail using the approach explained previously. The amount of the days, on which the average wood moisture content at 15 mm depth exceeded 20 %, is shown additionally as curve of cumulative sum.

The first example is a calves stable (Figure 8), in which wood moisture contents above 20 % were measured on a column on the side of the open eaves for 47 almost consecutive days. Considering only the upper limit according to DIN 68800, several data points fall above the 20 %-limit, which would result in a classification of this specific building component in Use Classes other than GK 0 or 1. If one compares the measuring data with the previously presented, engineering approach [8], in which the temperature is taken into account, none of the data points lie within the gray fluctuation range, i.e. fungal growth on the building component can be avoided.

In the second example, a dairy cattle stable (Figure 9), measurements were taken on a column which lies directly in the area of a milking parlor. This area is frequently cleaned with a water jet. Near the surface of this column, the wood moisture content is constantly over 20 %. Also when combined with the temperature, all data points fall into the grey area, indicating a risk of fungal growth. However, despite this, no fungal attack was detected on this building component. This could be due to the fact that the fungal spores were not "activated", since the required relative humidity of at least 95 % was not reached. On the other hand, a "wash out effect" is also possible, as a result of the cleaning process.

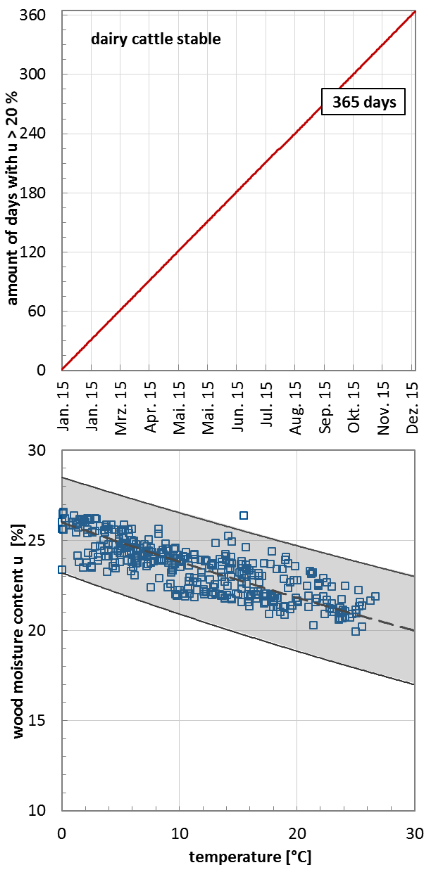

Figure 9: *Evaluation of data from stable for dairy cattle*

Finally, the storage room of the potato storage building is analyzed (Figure 10). During the storage, wood moisture contents of over 20 % were recorded for a long period. At least half of the data points fall into the grey area, in which fungal growth is possible. However, also here, no fungal attack on the building component was detected. A closer inspection of the climate data shows that in the potato storage room prevailed a climate of around 7 °C and 95 % relative humidity from the end of November to the beginning of April. The relative humidity decreased thereafter to about 90 % and remained at this level for the next 4 to 5 months, with temperatures ranging between 7 and 15 °C. This leads to the conclusion that, despite a possible "activation" of the fungal spores, the necessary climatic conditions after germination for "starting" fungal growth were not fulfilled for a sufficient period of time.

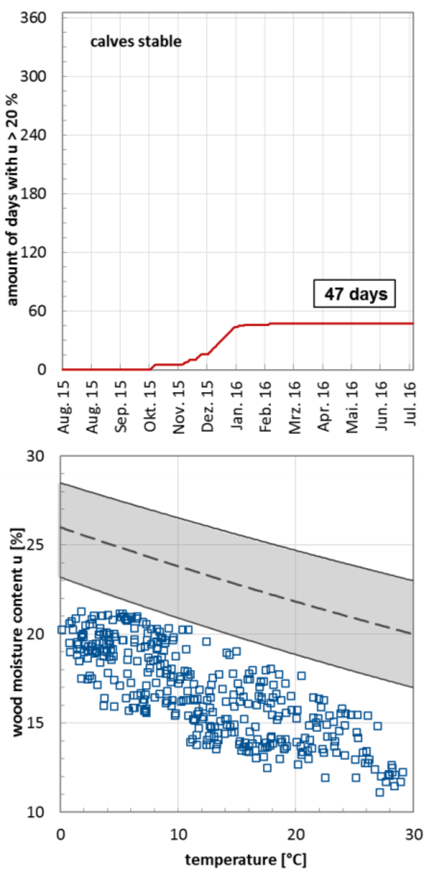

Figure 8: *Evaluation of data from calves stable*

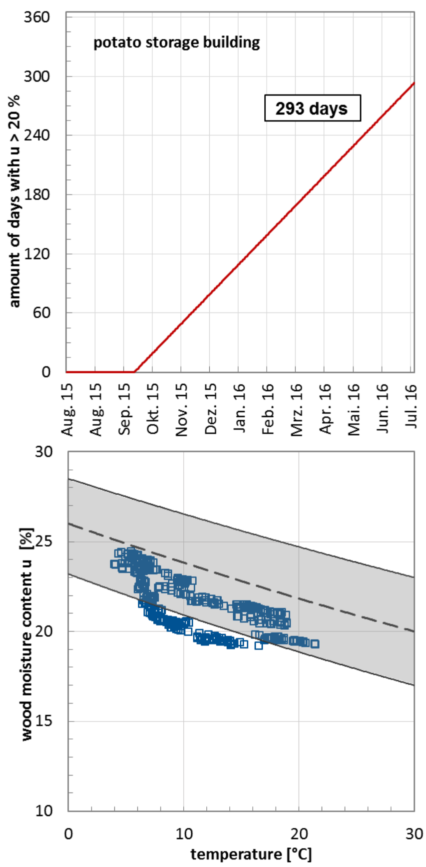

Figure 10: *Evaluation of data from potato storage building*

7 CONCLUSIONS

Until March 2017, more than twelve million data sets were collected and evaluated. Diagrams of the wood moisture content, the in- and outdoor climate were plotted over time. Wood moisture content over 20 % was documented at 18 of a total of 78 measuring points. By applying the wood-decaying model of Viitanen [7], i.e. taking the influence of temperature into account, the risk of fungal growth can be excluded in 13 of the 18 measuring points. In an extensive visual inspection of the investigated objects, including interviewing with the building owners, no wood decay was detected.

The positive results obtained from those 13 agricultural buildings does not mean that no wood preservation measure is necessary. In the planning of constructional wood preservation measures, one should distinguish between local influences, which require only local measures, and global influences, for which global solutions are necessary. An example of local influence are the columns in frequently washed areas. A possible solution for this would be the protection of timber columns from direct humidification by means of ventilated board cladding. For new constructions of such area, the use of more durable wood species should be taken into consideration. As an alternative to this, reinforced concrete elements could be applied in these area up to a height of e.g. 1.5 m. An example of global influences is the air-conditioning in the potato storage building. In this case, the use of wood species of higher durability, e.g. Larch and Douglas fir heartwood, should be considered.

In March 2018 the measurements in 10 out of 13 objects, in which the risk of fungal attack could be excluded, have been terminated. The over twelve million data sets are going to be further evaluated. The measurements in the objects with potential risk of fungal growth will be continued. This is done to, for example, prove the effectiveness of local wood preservation measures, which have already been applied on the building components. For projects with global influences leading to moist conditions, visual inspection is going to be carried out regularly.

In addition to the monitoring campaign mentioned above, preventive constructive measures are going to be established, which should ensure a durable protection of timber constructions in agricultural buildings. It is aimed to, either define constructive measures that allow the classification of construction elements into Use Class 0 (no preventive chemical wood protection for spruce required) or lower the resulting Use Class so far that, by applying wood species with increased natural resistance, the use of chemical wood preservatives could be waived. Such a construction catalogue would be comparable with the “special constructive measures” given in the standard DIN 68800-2 [2]. Those guidelines could possibly be introduced to complement DIN 68800-2, Appendix A, allowing its application also in terms of an approval by building-authorities. This work on creating such a catalog has recently been finalised by the project partner, the Bavarian State Research Center for Agriculture (LfL).

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