Literature review of fungi in buildings and their ability to methylate chlorophenols into malodorous chloroanisoles.

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Abstract. A source of indoor malodor in older buildings are chloroanisoles, a methylation from chlorophenols. Chlorophenols were commonly used in wood preservatives 50 years ago which were used to treat construction details exposed to high moisture loads. The methylation process requires a methylator in the form of fungi or bacteria in conjunction with adequate growth conditions for said fungi. The food industry has a history of issues with chloroanisoles contaminating different food items. There have been studies made on fungi species found in the packaging materials or surfaces in proximity and their ability to methylate various chlorophenols. Different species of fungi are present in many places, not only packaging materials but also various building materials. A literature review has been made in this study to compare fungi species able to methylate chlorophenols and their potential occurrence in wooden construction details in buildings. Two species were found to be considered strong methylators and also commonly found in wooden constructions, Aspergillus versicolor and Paecilomyces variotii. The properties of these fungi will be used for future studies of the conditions achievable in wooden constructions where the historic wood preservatives were likely used.

1. Introduction
Many types of mold spores and fungi are ubiquitous in our natural environment. For fungal growth to appear on building materials, a certain water activity (a_w) is required. Water activity is defined as the equilibrium between the relative humidity of the air and the growth medium, in this case building materials [1]. The mold growth is also determined by the temperature, properties of the building material, and the properties of the fungi itself. In general, for visible mold growth to occur, there need to be adequate growth conditions for a considerable amount of time [2]. There have been studies of which species of fungi that are common in water-damaged building materials and which species are more likely to be found in certain materials [3].

There are other issues besides mold growth that are connected to the a_w in building materials, one of which is the methylation of chlorophenols into odorous chloroanisoles. The issue with chloroanisoles is that they have a mold-like odor with very low odor thresholds [4]. In the 1960s and 1970s, Sweden experienced a large building boom driven by a political goal of building a million new homes as well as other non-resident buildings. During this era, many new construction methods were introduced on a large scale, including the use of wood preservatives containing chlorophenols in indoor wooden constructions exposed to high moisture loads [5]. These wood preservatives have since then been a problem for the indoor environment due to the methylated chloroanisoles.

The methylation process occurs when the chlorophenols are exposed to a methylator, in many cases naturally occurring fungi and bacteria, and the proper growth conditions for said fungi [6]. This is the
reason why mold is often perceived to lie behind the presence of the observed odor as the conditions for mold growth and methylation of chlorophenols are similar [7]. The low odor threshold of chloroanisoles means that the odor is much more noticeable at low amounts of chloroanisoles compared to the amounts of mold growth that would have to be present to emit a similar odor intensity. Such mold growth would indicate severe moisture damage or long-lasting high moisture loads due to construction design flaws. It has been shown that the malodor from these construction details can still be present even though there is no significant mold growth, indicating that growth conditions for visible mold might not be necessary, only for the methylation process to begin [8].

Another field that has a history of problems with chloroanisoles is the food industry. Studies have been made on identifying which type of fungi that methylate chlorophenol, which moisture content is needed, and how much chloroanisole each type of fungi would methylate [6], [9]–[12]. This research has not been done in the building industry and could be used for identifying construction details where the conditions for methylation of chlorophenols could occur. The source of chloroanisoles in the studied contaminated food items were often from corresponding chlorophenols which were present in the packaging materials, such as fiberboard cartons. The reason the chlorophenols would methylate was the natural presence of mold fungi in the fiberboard and the increased humidity during transportation [6], [9]. The minimum growth conditions for the fungi would be achieved in this climate and trigger the methylation process of the chlorophenols.

The aim of this literature review was to find fungi species found in wooden constructions in buildings that can methylate chlorophenols into chloroanisoles. The properties of these fungi will be used for future studies, mainly focused on the $a_w$ required for minimum growth. The $a_w$ is of interest due to reports of malodor from the wooden construction details treated with wood preservatives containing chlorophenols is connected to moisture content and not the presence of significant mold growth [8].

2. Method

Literature regarding chloroanisole methylation was first found through references from relevant papers and this led to information regarding different types of fungi which had caused issues in various types of food industries. This information was then matched to reports and academic papers from the building industry about common types of moisture damage and mold growth. The aim was to search for fungi found in wooden constructions in buildings, which were able to methylate chlorophenol. The properties of these fungi were sought out to be used for future studies, mainly focused on the $a_w$ required for minimum growth.

3. Results

*Aspergillus versicolor* is common in buildings and can be found in many places, but is mostly associated with concrete, plaster, and wood. *Paecilomyces variotii* is mostly associated with wood and plywood [3]. Both of these species have been shown to be considered strong methylators of chlorophenols [6], [13]. The $a_w$ required for minimum growth for both fungi is 0.79 at 25°C with higher $a_w$ at lower temperatures [2], [14].

4. Discussion

The compilation made by Hill *et al* [9] based on a variety of methylation studies list several types of fungi which are able to methylate chlorophenols into chloroanisoles. These fungi have different origins and might not all be commonly found in wooden construction details in buildings. Therefore, fungi such as *Aspergillus versicolor* and *Paecilomyces variotii*, which are commonly found in these constructions, are the most interesting.

The water activity needed for the methylation process is reasonable to achieve in construction details treated with wood preservatives containing chlorophenols, such as the rough sill in windows or the sill plate of a curtain wall. The results from this review will be the base for WUFI-simulations of these
construction details and the different conditions and events which could satisfy the $a_v$ needed to enable the methylation process.

5. References

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