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Assessment of mould growth within elements of exterior constructions

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Abstract: The installation of external, internal or cavity wall insulation may be an efficient measure to reduce the energy consumption of a building. Applying internal wall insulation may be the only feasible solution for some cases. However, unintended consequences such as moisture accumulation within the building elements may occur. This study constitutes part of exploratory research which aimed to examine whether air sampling through impaction and culture-based analysis can be utilised for the assessment of mould growth within building elements. The present paper aims to determine whether the location of mould within confined spaces affects the sampling results. Towards this end, a CFD analysis was carried out and was complemented by two series of scale experiments. The results from both procedures were then compared and useful conclusions regarding the flow pattern and the potential relationship between the mould's location and the sampling results were extracted.

Keywords: Internal Wall Insulation, Air Sampling, Mould, Assessment, Location

1. Introduction

Uninsulated exterior walls may be responsible for more than one-third of the total heat loss of a building (Anderson and Robinson, 2011). As a result, applying insulation to exterior constructions is considered to be an effective solution for the improvement of the energy efficiency of old buildings. Internal Wall Insulation (IWI) may be the only solution when wall insulation interventions are considered —e.g. buildings where external wall insulation may alter the architectural character of the neighbourhood. However, implementation of IWI entails risks and might lead to unintended consequences.

Moisture accumulation and condensation are two major concerns when internal insulation is applied (Biseniece et al., 2018). Vapour-closed materials or reduced ventilation may lead to interstitial moisture (Alev and Kalamees, 2016). Poor installation and quality of materials and equipment may be reasons for moisture accumulation according to the Environmental Protection Agency (U.S. EPA, 2013). Chinazzo (2014) suggested the application of an air gap of at least 3 cm, between the applied insulation and the internal surface of the solid wall to prevent moisture penetration and condensation-related problems from occurring. However, the avoidance of mould growth and moisture accumulation cannot always be guaranteed (Klõšeiko et al., 2015).

2. Literature

2.1 Fungi and mould growth

The World Health Organization (WHO, 2011) inferred that dampness and mould growth in buildings is increasing. Thermal conditions, nutrients and humidity affect the growth of fungi in the indoor environment (WHO, 2011). Damage to the structural integrity of exterior constructions, e.g. decay of wood-based materials (BRE, 2014), can be caused by mould growth and dampness. Emission of bio-reactive agents and indoor material damage can be caused by mould growth (Andersson, 1999).

2.2 Mould Growth Assessment

Currently, mould growth assessment is covered by various sampling and analysis methods. Sampling refers to the collection of microorganisms, fragments, or spores and determines the analysis technique used. The selection of an appropriate combination of sampling and analysis technique is significant for the extraction of accurate results.

Many international standards and guides have described mould growth assessment procedures for the indoor environment (parts 16–20 of the BS ISO 16000 standard and ASTM D7338-14 standard). However, no international standards or guides were found in the literature for the identification of mould growth within building elements.

Currently, a variety of sampling methods exist for the assessment of mould growth in the built environment. These methods are often divided into two main categories, (a) air sampling, and (b) surface sampling. Aktas (2018) implies that air-sampling methods constitute robust strategies for determining the mould's characteristics and composition. Air sampling through impaction, spore trap sampling, liquid impingement, cyclone sampling or air filtration are the most common among air sampling techniques. Surface-sampling methods can assess fungal growth on surfaces. These methods are considered very useful for the determination of the effect of fungal growth on surfaces, to the background concentration of mould (Yang and Heinsohn, 2007). Surface-sampling techniques such as swab sampling, wipe, bulk, and tape lift sampling methods are widely used to identify the species and composition of mould growing on materials. It is important to mention that these techniques may also be used as indicators of contamination levels and often complement air sampling methods

The selection of an appropriate analysis technique is imperative for examining the characteristics of mould and determining the accuracy of the extracted results. Information regarding the decision-making process for the determination of the most appropriate technique and description of the procedures to obtain accurate results from the analysis of the collected data is provided by parts 16–20 of BS ISO 16000.

WHO (2011) divides the techniques into two main categories:

- Culture-based methods: involve the cultivation of culturable microorganisms that were recovered from a sampling process. It is important to underline that the term 'culturable' differs from 'viable'. While all culturable microorganisms can form colonies, viable microorganisms may not be able to be cultivated due to conditions that do not allow their reproduction (Aktas, 2018).
- Non-culture-based methods: rely on the analysis of data originating from sampling and the provision of information for both viable and non-viable spores, along with microscopic fragments.

Selection of an appropriate combination of culture-based and non-culture-based methods may prove to be of great importance for the accurate identification of both viable and non-viable mould species within the indoor space under examination.

3. Methodology

The present paper constitutes part of a study that aimed to determine a methodology for the assessment of mould growth within the building elements of exterior elements. The proposed method involved the recovery of culturable microorganisms on a sampling medium through impaction. The utilisation of a culture-based technique was then implemented as a means for the analysis of data.

The present study consisted of a Computational Fluid Dynamics (CFD) analysis and an experimental procedure. More specifically, a CFD analysis using ANSYS Fluent software was conducted to examine the airflow pattern when air sampling is carried out in a full-scale wall. The analysis was complemented by two series of scale experiments aimed at investigating whether the location of mould within a confined space will affect the results extracted from air sampling data analysed by culture-based techniques.

3.1 CFD experiments

A full-scale 3x3 m wall with an air gap of 3 cm was simulated through the ANSYS Fluent software. The geometry that was thought to describe the construction best was a 300x300x3 cm box. The thickness of all walls was considered to be 2 mm while the space within the box was deemed to be filled by still air at a pressure of 1 atm. The box included two ¼ inch holes that were placed on a bisector of the square and had a distance of 1 m between them. Initial and boundary conditions, along with assumptions, were essential to consider for the CFD analysis. The conditions above along with the assumptions, are listed below.

Assumptions
The effect of gravity was considered not to alter the flow pattern. The flow was considered to be turbulent; As a result, the model that was considered to describe the flow phenomena best was the k-epsilon. Transient flow phenomena were not taken into account Heat exchange phenomena were not taken into account The mesh created consisted of triangles and was considered to be of good quality for the present analysis The results were considered satisfactory if the convergence of the velocity residuals aimed dropped two orders of magnitude
Initial and boundary Conditions
Air, with a density of 1.225 kg/m3 and a viscosity 1.7894·10-5 kg/m-s was used as a fluid No slip effect was considered to occur while the sides of the box, were all considered to be stationary. The airflow rate was considered to be 20 l/min The pressure of the air at the inlet was considered to be 1atm. The temperature of the air was considered to be 15^{o}C Hybrid initialisation was utilised for the CFD analysis through the ANSYS Fluent software

3.2 Experimental procedure

Cultivation of *Aspergillus Versicolor* was achieved on a total of 25 potato dextrose agar plates. The growth rate of this mould specie is considered to be slow (Hocking, 2006), but its cultivation is thought to be achieved with ease in laboratories (Das et al., 2012). According to Smith and Hill (1982), the growth rate of *A. Versicolor* is maximised if temperature and water activity are 27^{o} C and 0.98, respectively. It is important to mention that *A. Versicolor* species may serve as a humidity indicator, as reported by BS ISO 16000-17:2008.

Optimum conditions for the cultivation of the mould were maintained for 14 days before conducting the experiments. Though full coverage of the Petri dishes' surface by the mould was not achieved, the growth level of the fungi after the 14 days was considered satisfactory for the purposes of the study.

An experimental setup was designed and built for the purpose of conducting the experiments under scale conditions. Figure 1 contains a schematic representation of the setup. An airstream, within the box, was created by operating the pump leading to the collection of spores, fragments, and microorganisms on the sampling medium (potato dextrose agar plate) within the sampler (BioStage® impactor by SKC Inc.). The volumetric flow rate was calibrated and measured during the sampling by a rotameter. After the completion of the procedure, the agar plate was removed from the sampler and placed in an environmental chamber where the cultivation of mould was accelerated. It is essential to mention that the dimension of the box was 45x45x5 cm, so that 25 Petri dishes could fit.

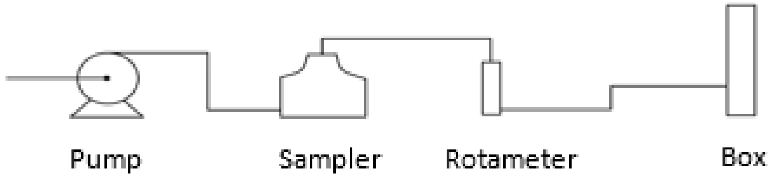
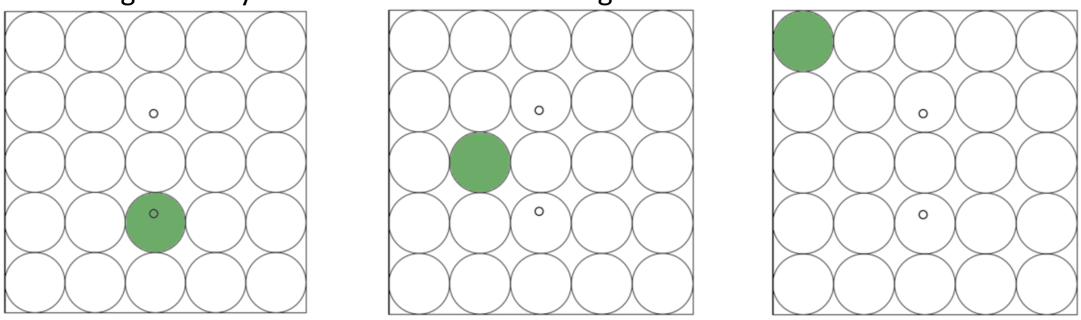


Figure 1. Schematic representation of the experimental setup

For the examination of the effect of the mould's location on the sampling results, two series of experiments were performed. The first series involved the operation of ventilation fans while in the second series the fans were turned off. As a result, the indoor air velocity in the first series was higher than the corresponding one in the second series. The aim of the two series was to examine whether the potential pattern describing the effect of mould location on the sampling results remained the same regardless of the environmental conditions. It is important to mention that the fans are placed on the ceiling of the environmental chamber where the experiments were conducted.

Three different cases were examined in each series of experiments. Each case referred to a different location of a plate with mould within the experimental box. The position of the plate with fungi in every case is demonstrated in Figure 2.



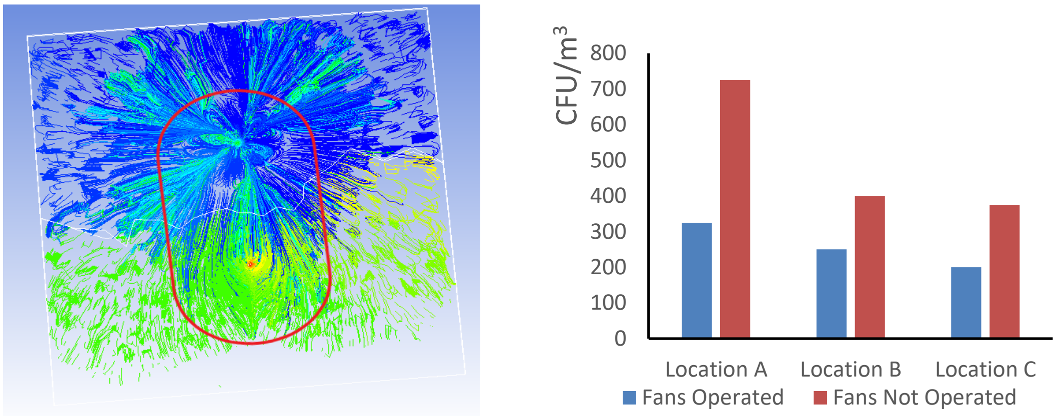
(a) (b) (c)

Figure 2. Illustration of the moulds location in the three cases examined – (a) Location A; (b) Location B; (c) Location C

4. Results and discussion

Figure 3 (a) below shows the simulated airflow pattern within the confined space. The Figure also indicates that both the surrounding space and the space between the holes will be affected by the airflow created. However, particles near the corners seem not to be affected by the airflow in a similar way to the particles that are closer to the two holes. The displacement of particles close to the edges of the wall seems to be reduced in comparison to the displacement of particles close to the inlet and outlet holes. This observation implies that identifying mould growing near the edges of the wall may be difficult. Each series of experiments involved placing one plate with mould in three different locations within the experimental box. During these experiments, the airflow rate and the sampling period remained constant. The sampling time was selected to be two minutes, while the airflow rate was 20 l/min. The results from the culture-based analysis of the sampling data are shown in Figure 3 (b).

As seen in Figure 3 (b), the highest concentration of Colony Forming Units (CFU) per cubic metre of sampled air was observed for both series of experiments when the mould plate was placed under the outlet hole. The concentration of CFU in the sampled air seemed to decrease as the distance between the mould and the outlet hole increased.



(a) (b)

Figure 3. (a) Representations of the airflow pattern for the case examined through CFD (b) Comparison of CFU concentration (CFU/m3) from the experimental box for three different locations.

It was also observed that the operation of the ventilation system had led to reduced values of CFU/m^3 in comparison to the corresponding ones when the system was turned off. The phenomenon may be related to changes in the airflow pattern caused by the operation of the ventilation system. Increased velocity of the indoor air may have led to an increase of the inertial impaction's frequency. The term inertial impaction describes the phenomenon where particles collide with walls and become attached potentially due to their inertia. More specifically, Haig et al. (2016) mention that the particles with a large mass and thus large inertia may not be able to follow the airflow streamlines, resulting in their collision and attachment to the wall.

The CFD analysis and results from the experiments imply that the sampling results may be affected by the location of mould within a confined space. Mould positioned at a considerable distance from the outlet hole may cause underestimation of the sampling results. Moreover, because the size of the mould inside the space may affect the results of the sampling, assessing the growth of mould may become impossible. However, performing more than one sampling procedure — using, at first, both holes as outlets and then moving to the creation of more holes (if needed) — may be an efficient solution to the underestimation concern.

5. Conclusions

Limitations: The CFD simulated the airflow pattern within a 300x300x3 cm box assuming a flow rate of 20 l/min and a steady-state flow. Because transient phenomena and the sampling period were not acknowledged in the CFD simulations, a limited understanding of the flow pattern may have been developed. At the same time, the existence of the agar plates inside the box for the experiments may have led to rapid changes in airflow streamlines. In real-life applications, the airflow will not have the same pattern with the airflow created in the experiments. As a consequence, some of the complexities of the phenomena taking place in full-scale applications may not have been incorporated in this study.

Discussion of findings: This study constitutes part of an exploratory and qualitative research. As a consequence, the results extracted from the experiments cannot be used for purposes of statistical analysis; however, they can indicate potential relationships and patterns.

Based on the results and discussion section, it can be inferred that the location of the mould within a confined space, such as an air gap between an external wall and internal wall insulation, may affect the results of sampling. The findings of the experiments indicated that the greater the distance between the sampling hole and the location of the mould, the greater the underestimation of the sampling results. Also, taking into account that the data from the CFD analysis imply that the created airflow may not significantly affect mould particles close to the edge, it can be inferred that in both scale and full-scale applications, the underestimation of sampling results may exist.

Future research: Conducting further CFD simulations for the examination of flow phenomena within an air gap or cavity wall, is recommended. The performance of CFD, assuming both transient and steady-state phenomena, may contribute towards the development of a better understanding of the flow pattern and its effect on sampling results.

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