Development of a performance indicator for mould growth risk avoidance in buildings

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ABSTRACT

Microbial growth has been known as one of the major problems related to IAQ in residential and commercial buildings. International and local standards define the upper limits of indoor relative humidity in order to avoid moisture related problems. However, setting limits on indoor relative humidity does not guarantee a mould-free environment. The intention of this ongoing research is to develop a performance indicator (PI) that can be used to monitor and test the performance of existing buildings, in terms of the risk of fungal growth.

This PI for mould growth risk should be based on a mix of 'building component' characteristics and 'usage factors' as they implicitly determine mould growth conditions. The building components include building envelop systems, HVAC components, furniture, occupants and so on. This paper describes the development of the PI that is composed of five sub-elements (one for the physical states at interior surfaces and four for building situation factors). Each of them may be an aggregated value, not just a measurable simple property.

INDEX TERMS

Mould growth; Performance indicator; Hygrothermal simulation

INTRODUCTION

Despite intensive research efforts on preventing mould growth in buildings for decades, the relationships between the probability of mould growth and certain values of building parameters have not been fully discovered yet. It is not obvious how such causalities can be expressed in a measure that quantifies the building's systems performance to avoid mould growth. Such performance measure will be influenced by a multitude of parameters with complex physical interactions. The set of relevant building 'parameters' will include physical properties or type-parameters of building components, building usage, building materials, occupants' behaviour, HVAC system components, weather data, and so on. Previous researches have tried to solve the mould growth problems in buildings within an 'idealized' scope, e.g., based on the simulation of local surface conditions or moisture content in the building envelope. However, physical properties of building systems are not the sole determinant of mould growth problems in buildings.

This paper intends to develop a performance indicator (PI) for mould growth that combines knowledge of aggregated physical states at interior building surfaces and a set * of building specific situation factors. In order to accomplish this goal, a literature review was conducted to find common causes of mould problems in existing buildings. The paper will conclude with a discussion on the establishment of a PI that additionally accounts four situation factors.

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CAUSES OF MOULD PROBLEMS: LITERATURE REVIEW

Moisture related problems in existing buildings are caused by complex thermo-hygric-biological phenomena, which involves studies in biology, heat and mass transfer resulting from the physical interaction of a variety of building systems. Many researches have reported the possible causalities between building parameters and mould occurrences. We conducted a literature review to find common causes in residential buildings (Merrill, 1989; Pasanen, 1992; TenWolde, 2000; Moyer, 2001), in commercial buildings (Shakun, 1992; Parat, 1997) and in school buildings (Meklin, 2002). Baughman reported that interior dampness problems are usually related to construction faults, such as inadequate insulation, thermal bridges, inadequate ventilation, certain patterns of building use, interior sources of humidity, improperly weatherproofed outside walls, or inadequate drainage (Baughman, 1996). This and the other sources were used in the literature review to categorize the causalities. It was found that common causes of moisture problems in different type of buildings can be attributed to a set of common causes. The results were summarized in Table 1. We categorized the causes found in existing buildings into five main categories. The main target of the survey study was to find the major causes of the occurring mould problem, as indicated in Table 1.

Table 1 Causes of mould growth

Causes	Real building examples from literature review	Cause category	Buildings*
HVAC defect	Direct infiltration of humid air	PI*	1,2,3
	Negative pressures across the envelope	PI*	1,2
	Inadequate moisture removal (return duct)	N/A	1
	Inadequate ventilation	PI*	1,2,3
Design defect	Low permeance of the exterior weather barrier	PI*	1
	Vapor retarder in the wrong location	PI*	1,2
	Leakage of precipitation	PI*	3
	Defective drainage	N/A	1,2,3
	Impermeable surfaces (vinyl flooring, vinyl wall paper)	PI*	1,2
	Inadequate insulation, thermal bridges	d	1,2
Building usage	High occupant density	PI*	1
	Pattern of use, cooking habits	PI*	1,2
	Low air conditioner thermostat setting	PI*	1
	Stock of wood, papers, books	a	1
Maintenance/ operation	Inadequate maintenance and operation of equipment	c	1
	Cleaning	c	2
	Aging of construction materials	c	3
Construction defect	Poor site drainage	N/A	1
	Location and orientation	N/A	1, 2
	Water leakage from piping, roof, basement.	N/A	1, 3

*1, residential; 2, commercial; 3, school.

Cause categories: PI*: mould can be explained from idealized simulation of surface conditions, leading to an idealized PI. a, b, c, d: mould growth cannot be explained from idealized simulation but can be related to case specific situation factors which will be introduced below.

POSTULATED MOULD GROWTH PERFORMANCE INDICATOR

Mould growth is dominated by the relative humidity (or moisture content) at building material surfaces, not the ambient relative humidity. In order to acquire accurate surface conditions (temperature and RH), it is required to (1) calculate the moisture flow between porous building materials and adjacent air, (2) calculate moisture flow within multi-layered building materials. For this purpose, many first principles based energy and mass transport models have been developed (Hens, 1996). Having full knowledge of the physical state at the material surfaces over time should, in principle, be sufficient to predict mould occurrences, but accurate mould growth models as function of temperature, relative humidity and length of time that certain conditions are maintained, are lacking.

Moon and Augenbroe demonstrated how a result derived from the first principles based virtual experiment (i.e., an idealized simulation) can be aggregated through post-processing into a mould growth analysis (Moon, 2003). The result of the mould growth analysis can be regarded as the idealized PI* , purely based on comparison of the physical environmental states of the interior surface with known favourable conditions for mould germination.

It must be acknowledged though that simulation based on idealized situations and physical properties of building systems alone cannot predict mould growth in existing buildings in all circumstances. TenWolde claimed that service conditions, including building design and operation, should be considered in mould growth analysis (TenWolde, 2000). Hens combined substrate nutrient values with the threshold relative humidity and incubation time (Hens, 1999). The basic conjecture of our research is that, although the idealized measure (PI*) cannot predict all mould growth occurrences, it can be used as the foundation of a ‘practical’ PI by adding a set of additional building related factors (case specific situation factors).

From the conducted literature review on building pathology of mould occurrences in existing buildings, four situation factors were derived which could ‘explain’ each studied example as shown in Table 1. The suggested situation factors are building usage(a), substrate corrections(b), maintenance/operation(c) and building details(d).

A broadly applicable and practical PI can now be put in a formula combining the idealized PI* with the situation factors as follows:

$$\boxed{\text{Mould growth PI} = a \times (b \times \text{PI*}) \times c \times d, \quad (0 < a,b,c,d < 1)}$$

where

PI*: Idealized performance based on aggregated surface environmental conditions using a hygrothermal simulation and a mould growth post-analysis (i.e., germination graph method, discussed in Moon and Augenbroe, 2003)

The relevance and situational dependence of the four factors are discussed below:

Building Usage Factor (*a*)

This situation factor considers the building usage or storage of favourable materials for mould growth in a building zone. For example, a load of wood, paper or books in a room increases the mould growth risk. In the next stage of the research a measure for the availability of certain material in a space will be introduced leading to the quantification of ‘a’.

Substrate Correction Factor (*b*)

The suggested PI* is based on the isopleths for mould spores (mould germination graph), which is developed from experiments to find the relationships among temperature, relative humidity and required exposure time. Since the experiments were not conducted on building materials, appropriate correction factors need to be developed. The relationship between different building materials and mould occurrences could be found from literature, such as in the following.

Adan found that each building material has different threshold levels of temperature, RH and exposure time to initiate the germination of mould (Adan, 1994). Hens considered three types of building materials in terms of nutrient for mould growth, i.e., porous substrate with a clear nutrient value, clean non-porous material and non-porous materials with enough organic dust or fat. He used different threshold RHs and incubation time according to the building material type (Hens, 1999). Typical construction materials that can support the mould growth include wood, cellulose, hemicellulose, wallpaper, organic insulation materials, glues, paints, mortars, textiles, insulation materials in duct. Typical materials that are not degraded by mould include mineral wool, metal, polyvinyl chloride, synthetic polymers, bricks, tile, mineral products (Ahearn *et al.*, 1995, 1996 [as cited by (Bayer 2000)], Baughman, 1996). This information will be used to quantify the substrate correction factor 'b' in the next stage of the project.

Maintenance/Operation Factor (*c*)

Some researchers have reported that the maintenance and operation of the HVAC system contribute to mould occurrences in buildings. Although air filtration can eliminate a part of airborne particulates, some dust containing microorganisms can settle on duct insulation materials or enter into a room (Baughman, 1996; Parat, 1997; Ginestet, 2002). It is also reported that air movement near interior surfaces affects to moisture transfer rate, supported by findings that show how sufficient ventilation can decrease the risk of mould growth.. This supports the suggestion that maintenance and cleaning policies as well as HVAC operation factors should be taken into account in the quantification of the maintenance/operation factor 'c'.

Building Detail Factor (*d*)

Mould prefers to grow where insulation materials are improperly designed or installed, causing condensation problems due to thermal bridge effects. Possible places for condensation include windowsills, corners between ceiling and exterior walls, behind impermeable wallpaper or under vinyl flooring. Table 2 summarizes the reported places of mould problems and type of buildings. This situation factor takes into account of building details where actual condensation or mould growth may occur, faster than predicted by the idealized simulation.

Table 2 Mould growth locations

Locations	Buildings*
Sheathing	1
Interior walls	1, 2, 3
Interior furnishing	3
Window frames, sills	1, 2, 3
Gable ends	1
Ceiling	1, 3
Shoes	1

Wood fittings	1
Back of furniture	1
Behind impermeable surfaces	1, 3
Fixture	2
Building construction	1, 2
Under carpet	1, 3
Fan-coil units	3
Papers, books	1, 3
Duct insulation	1, 3

*1, residential; 2, commercial; 3, school.

CONCLUSION AND IMPLICATIONS

Because mould growth in existing buildings is such a complex phenomenon, there is no single mechanism or measure that explains all cases. One has to consider the physical properties of the building system as well as case specific building factors in order to understand and predict mould growth in a specific case. In this ongoing research project, we have suggested a mould growth performance indicator that consists of five elements. It is based on an idealized performance indicator, i.e., the calculation of physical states of interior surfaces, multiplied by four situation factors. A literature review underlined the relevance of PI* and each of the four factors to 'explain' case-specific mould growth. The quantification of the four situation factors will be the subject of research in the next stage of the project. A database of known mould growth occurrences in existing buildings will be used to find the correlations between building parameters (categorized in the four categories represented by a, b, c and d) and PI values related to actual mould occurrences. Once the correlations are established, the next step is to calibrate the four factors in the postulated PI for mould growth, i.e., quantify the four factors as a function of observable building and use parameters. The resulting PI will consequently be used in the design prediction and/or early diagnosis of moisture problems. It is expected that the number of *in situ* diagnosis of mould problems be reduced using the resulting PI.

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