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Fungal Growth On Concrete Surfaces Of Floors And Walls

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Abstract. Generally, a high pH-value (above 12) in building structures is considered to be an inhibitory factor against fungal growth. However, fungal growth can in some cases be detected on concrete surfaces in new buildings shortly after commissioning and in existing walls retrofitted with internal insulation installed using cement based adhesive mortars. This paper deals with two building envelope structures: newly casted concrete floors fitted with vapor membranes and existing walls fitted with internal insulation. In both fungal growth has been detected and linked to the decreasing pH-value and lingering moisture. For floors, several new buildings were investigated and the cleaning method, moisture content, concrete age after casting and fungal species were registered. Furthermore, the development in pH-value was measured on newly casted concrete to determine the decrease in pH-value. For walls, laboratory and field experiments were conducted both under realistic and worst-case condition. After 1-4½ years, samples of the internal insulation were taken to investigate fungal growth, fungal species, moisture content and pH-value behind the insulation. Moreover, the development in pH-value of fresh cement-based adhesive mortars was investigated. The results showed that the fungal species, *Aspergillus versicolor*, was common in both floors and walls and indicate that the *A. versicolor* spores can survive the high pH-value (above 12), and then later germinate and grow when pH-value decreases and moisture content increases. Furthermore, the results showed that the pH-value decreased faster, when the surface/interface has access to air and that only a totally clean surface would prevent later fungal growth in the interface, if the pH and moisture conditions change in favour of fungal growth.

INTRODUCTION

In the construction industry, there seems to be a widespread perception that inorganic materials are robust and therefore do not require special care in relation to the prevention of fungal growth. Cementitious products, for example, could be underestimated in terms of risk of fungal growth by consultant due to their alkaline conditions (especially during the initial period after casting). Whether it is habitual thinking, "business as usual", ignorance, or perhaps misleading claims in various experience-based documentation and best-practice guidelines is not known - perhaps a combination of these. The obsolete Danish guideline on fungal growth in buildings [1] (valid 2003-2020), stated that newly cast concrete provides great resistance to microbial growth due to its high alkalinity, whereas the current Danish guidelines on moisture [2] and fungal growth [3] in buildings state the critical moisture level of concrete to be 90-95% relative humidity (RH). Furthermore, concrete has been categorised as “medium resistant” in several mathematical models used to predict the risk of fungal growth [4-5]. However, in several recent cases, massive fungal growth has been detected on newly cast concrete floors, with a moisture membrane (PE-foil) and flooring [6]. The study concluded that the reason for growth was usually due to an inadequate drying period. In addition, fungal growth has been found in solid masonry walls fitted internally with insulation systems installed using cement-based adhesive mortars. The purpose of this paper is to present a study investigating fungal growth on concrete surfaces and how high alkalinity affects the risk of fungal growth, and to review and synthesize findings from other recent studies on the topic. Focus is on newly cast concrete floors and solid masonry walls with internal insulation applied using cement-based adhesive mortars.

FUNGAL GROWTH, PH-LEVEL AND CARBONATION OF CONCRETE

Fungal spores are everywhere and will germinate and grow in the built environment if suitable conditions are present. Many fungal species can grow in extremely nutrient-poor environments, which is why dust and dirt particles that bind or settle on inorganic surfaces, such as concrete, can provide sufficient nutrients for growth [7]. In general, there is a risk of fungal infestation in buildings when RH is higher than 75%. Most fungal species thrive best at 80-95% RH. Once the fungal spores have begun to germinate and produced a mycelium, the fungus can continue growing under less optimal conditions. Fungal mycelium and spores can survive / hibernate at RH levels of 45% or lower [8]. In addition to RH, several other abiotic and biotic environmental factors affect fungal growth, which include temperature, pH, oxygen availability, nutrient availability, illumination [9-10]. Previous studies [4-5] have investigate the temperature and RH conditions required for fungal growth on several building materials. However, the effect of pH on fungal spore germination and growth on buildings materials is not yet well established.

Acidity and alkalinity are stress factors for most fungal species. In nature, the pH of most environments is between 4 and 9, which is typically the optimum pH for most fungal species. Very high or low pH may have an inhibitory effect on the growth [11]. However, there are several fungal species that can grow or survive exposures to high pH-levels, which are defines as alkali-tolerant. *Aspergillus* spp. are generally more tolerant to high pH environments, while *Penicillium* spp. are tolerant to low pH [12]. Correspondingly, Sedlbauer [5] observed that *A. parasiticus*, *A. ochraceus*, *A. niger* and *A. flavus* were tolerant to high pH, while Bakshaliyeva et al. [9] found that *A. fumigatus* and *Mucor* spp. were able to grow at pH 9. In a study by Andersen et al. [8], the authors investigated 5353 cultivation samples (V8-agar) from 18 different building materials and found that especially *M. spinosus*, *M. racemosus*, *A. ochraceus*, *A. versicolor* and *A. niger* and some *Penicillium* and *Chaetomium* spp. had strong associations with concrete. Furthermore, many fungal species can reduce the pH-level of the immediate environment, through production of metabolites that are chemically aggressive for building materials, especially concrete (organic and mineral acids, CO_2, sulphur compounds etc.) [7]. This was observed in [13], where growth occurred on alkaline substrates with pH 9.7-10.3.

Concrete is very alkaline and newly cast concrete will typically have pH >12, and concrete made from highly alkaline cement can have pH >13. Concrete with pH >11.5 is defined as non-carbonated, while the pH range 9-11.5 is defined as partially carbonated (i.e. 0-50%), the pH range 7.5-9.0 is predominantly carbonated (i.e. 50-100%) and pH <7.5 are considered thoroughly carbonated [14]. Carbonation occurs very slowly in water saturated or dried-out concrete, but somewhat faster in medium-moist concrete. It is also required that the concrete has a certain porosity which allows the carbon dioxide of the air to penetrate into the concrete [15]. The rate of carbonation generally increases with temperature. Field measurements of 28.9 MPa concrete have shown that a carbonation depth of 3.1 mm after 12 months [16], and laboratory tests found that pH decreased relatively fast to pH 9, thereby increasing the risk of fungal growth [17]. A large part of the risk assessment for fungal growth on concrete follows the assumption that pH decreases very slowly and therefore has a significant fungal-inhibiting effect that will last till the concrete is dry.

FIELD STUDY: FUNGAL GROWTH ON NEW CONCRETE TERRAIN AND INTERMEDIATE FLOORS

The following are results from a Master project conducted at the Department of the Built Environment at Aalborg University, Copenhagen, Denmark [18] and are based on industry field measurements from the period 2017-2020. The purpose of the study was to investigate the risk of fungal growth on cast concrete floors and if the moisture in the concrete would reach non-critical levels before moisture membrane and flooring were installed. The study comprised three parts: 1) Calculation of drying time for the concrete floors, 2) fungal growth investigations on concrete floors (on terrain and intermediate floors) in 21 anonymised case buildings, and 3) pH measurements of concrete floors on terrain in several anonymous single-family houses.

Drying Time for the Concrete Floors

Drying time for built-in moisture was investigated using three different calculation methods. Drying was investigated for a typical single-family house construction phase, with around 3 months of drying in three phases: 1) 1 month with weather exposure, 2) 1 month with cover unheated, and 3) 1 month dehumidification at 40% RH and 20

°C. Calculations were carried out with construction start in summer and winter, and four different types of concretes were investigated (different water to cement ratios).

Fungal Growth Investigation

Fungal growth was investigated using three methods: 1) Mycometer method [19], 2) Contact V8 agar plate sampling, and 3) transparent Scotch or Sellotape sampling [10]. In terms of sampling, the Mycometer surface method was used in 5 of the 21 case buildings (2-5 samples per case), while a total of 68 samples were carried out using the contact plates and tape preparations in the remaining 16 case buildings. Samples were taken during the period 2017 to 2020. Tape preparations were examined for fungal structures using a light microscope, while the contact plates were examined in a stereo microscope [10] and colony forming units (CFU) were counted. The Mycometer test measures the fluorescent product released from the enzyme-substrate complex relating to the N-acetylhexosaminidase activity found in fungal growth to determine the extent of the growth [19]. Sampling and analysis were performed according to [20], and the Mycometer Values (MV) were evaluated as:

- Category A (green), normal background level: MV ≤ 25 (surface) or MV ≤ 150 (material test)
- Category B (yellow), above background level: 25 < MV < 450 (surface) or 150 < MV < 450 (material test)
- Category C (red), a high level of fungi: MV > 450
- Below Detection Level: BDL

pH Measurements

The pH-level of concrete floors on terrain in several single-family houses was measured on-site, using a pH-meter (LAQUA Pocketmeter PH22 from HORIBA). Measurements were carried out by grinding the concrete surface with coarse sandpaper (40 grit), followed by mixing 0.05-0.1 g of concrete dust with 10-20 drops of deionized water and then left for 60 seconds. The mixture was then transfer to the sensor electrode of the pH-meter using a pipette for direct measurement. Measurement uncertainty was ± 0.01 pH.

Results

Calculations of the drying time showed that in many cases RH levels did not get below the recommended 85% within the 3 months of drying, before the moisture membrane and flooring were installed. The net drying time for ordinary P20-MPa concrete to moisture criterion 85% RH, was found to far exceed 3 months, reaching up to 22 month or almost 2 years, depending on the type of concrete, climate conditions, etc. [18]. Meanwhile, 21 pH-spot measurements (Fig. 1) showed that pH decreased from around 12.5 to pH 9-10 within 12 weeks after casting the concrete floors. This indicate that at the time of installation of the moisture membrane and flooring, the conditions on the surface of the concrete floors could be suitable for fungal growth. In terms of the fungal testing, the Mycometer tests showed high fungal biomass in 9 of 15 sampling locations and above normal background in the remaining 6 samples, indicating active growth. Meanwhile, the tape preparation samples found growth in 65 of 68 sampling locations. The CFU counts for the contact plates are shown in Fig. 2. The CFU counts showed that the six most prevailing fungi were: *A. versicolor* (62.2%), *Penicillium* spp. (24.6%), *A. sydowii* (4.9%), *Chaetomium* spp. (1.8%), *A. flavus* (1.2%), and *Sarocladium strictum* (1.1%). Where the literature has shown that former five fungi have a concrete preference [8], several of them are able to grow in alkaline environments. From the CFU counts several tendencies were observed for fungal growth on cast concrete floors:

- Concrete surfaces which have undergone special cleaning (i.e. chemical or dry-steam) showed significantly lower CFU counts compared with surfaces with were cleaned normally. Indicating that soiling of the concrete surfaces is of significant importance.
- The CFU counts decrease with age of the concrete before installation of the moisture membrane and flooring, with 64% of samples on 4-6 months old concrete detecting fungal growth, compared with 23% on 7-9 months old concrete and 13% on 10-12 months old concrete. This indicate that later installation of membrane and flooring is crucial to minimise the risk of fungal growth, as the concrete require sufficient time for drying. Alternatively, self-drying concrete could be used for more rapid drying.
- CFU counts were higher for concrete floors on terrain compared with intermediate concrete floors. Probably due to a higher degree of soiling, from traffic closer to the ground compared with floors higher up in the building.

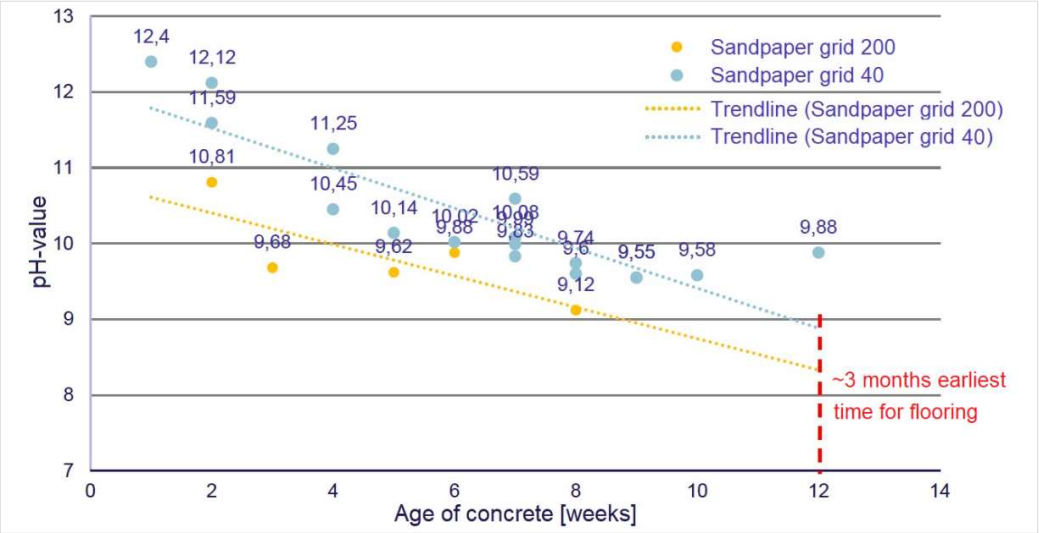

FIGURE 1. pH spot measurements on concrete floors on terrain. Shown in red, the earliest time for laying of moisture membrane and flooring according to standard Danish building practice [18].

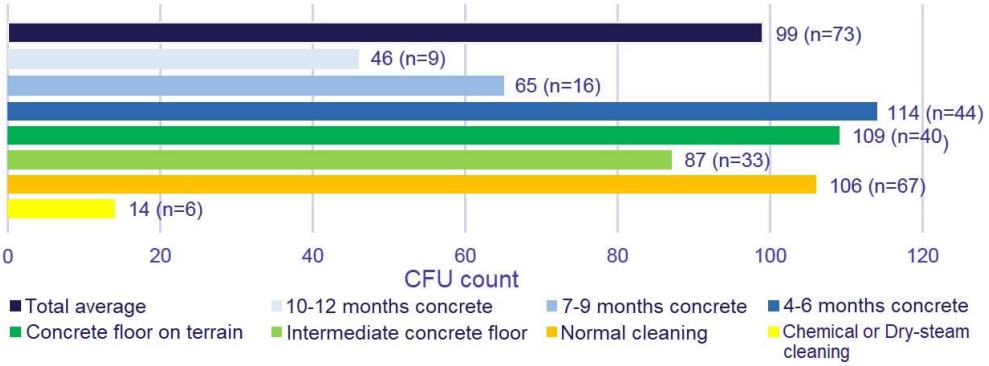

FIGURE 2. Average CFU count across all found fungal species. Comparison between concrete age, construction element and cleaning level. Confidence: (n = number of samples from case study) [18].

DISCUSSION

In a study by Kristensen et al. [6], six randomly picked apartments in a newly built apartment complex were investigated for fungal growth and moisture on newly cast concrete floors, with a moisture barrier and floating flooring. Floors were made with hollow core decks, 100 mm EPS insulation, 60 mm wear layer, moisture membrane and wooden flooring. The tests were carried out 1½ year after casting of the concrete floors. The fungal growth tests were carried out using tape preparation sampling (6.25 cm^2) for direct microscopy and contact plate sampling (V8-agar, 24 cm^2) for cultivation, identification and counting of fungi. A total of 62 contact agar plate samplings (6-22 in each apartment) and 16 corresponding tape preparation samplings were carried out.

The moisture measurements showed that in 22 of 62 sampling points RH was above 90%; in 27 sampling points RH was between 75% and 90%; and in 13 sampling points RH was below 75%. In terms of fungal growth, the contact plate samplings showed 41 of 62 samplings had substantial growth, 14 had moderate growth, and 7 had low growth (based on CFU counts). In contrast, the tape preparation tests showed no sign of fungal growth in 15 of 16 samplings. The authors concluded that the project demonstrates that at least some fungal species could grow very well on the newly casted concrete if the surface was dusty and moist. In addition, the authors pointed out the general assumption that fungal growth is unable to establish on newly cast concrete due to the high pH, but that the concrete might already be carbonated a few months after construction and state that further research is needed on this area.

In a series of study by Jensen et al. [20-23], a large experimental setup was constructed, comprising two insulated shipping containers. The purpose of the project was to investigate the hygrothermal performance of several large-scale internally insulated solid masonry walls. Five insulation systems were investigated, which included: polyurethane foam with calcium silicate channels (PUR-CS), phenolic foam (PF), calcium silicate (CaSi), autoclaved aerated concrete (AAC), and cork-lime plaster (CL). All systems, except for the cork-lime, were applied using cement based adhesive mortar. Drilled-out core samples were taken out after 3½, 4 and 4½ years, and investigated for fungal growth and pH in the masonry/adhesive interface. Fungal growth was investigated using the Mycometer method [19] (surface and material tests) and incubation of swab samples streaked out agar media were analysed under stereo and light microscopes [10]. pH-level was determined for the interface materials by crushing the samples into powder, and a mixture was made with 5 g of powder and 12.5 ml demineralized water. Samples were shaken for 60 minutes at 260-270 rpm, followed by a 10-minute settling period before testing. pH measurements were carried out using a Sension+ MM374 (accuracy: ≤0.002 pH). The results of the study are presented in Table 1.

TABLE 1. Measured Mycometer and pH for the large test walls with internal insulation [21,24].

	Mycometer Value (MV) [-] in masonry/adhesive interface								pH measurements						
Sample	A	B	A	B	A	B	A	B	Lime render**			Adhesive mortars			
Insulation system and orientation	Nov. 2018		Mar. 2019		Sep. 2019		Dec. 2019		Nov. 2018	Sep. 2019	Dec. 2019	Fresh mix	Nov. 2018	Sep. 2019	Dec. 2019
Uninsulated ref1_SW									9.2	9.3	9.3				
Uninsulated ref2_SW										9.1					
Uninsulated ref3_NE										9.2	9.2				
PUR-CS+H_SW	BDL	BDL			3	3			12.6	12		12	12.6	12.5	
PUR-CS_SW	BDL	BDL			23	23			12.7	12.1		12	12.5	12.2	
PUR-CS_NE	BDL	BDL			12	9			9.7	12.4		12	12.6	12.2	
PUR-CS+H_NE	BDL	BDL			8	5			12.8	12.5		12	12.6	12.3	
PF_SW	BDL	BDL					17	4			12.6	12.4			12.5
PF+H_SW	BDL	BDL					12	12			12.7	12.4			12.6
PF+H_NE	BDL	BDL					12	18			12.7	12.4			12.6
PF_NE	BDL	BDL					37	6			11.9	12.4			12.5
CaSi_SW	BDL	BDL			4	6			9.5	9.4		12.7	10.2	9	
CaSi_NE	BDL	BDL			5	5			9.5	9.3		12.7	10.8	9.2	
AAC+R_SW	BDL	BDL	227	159	42	32			9.5	9.5		12	9.4	9.2	
AAC_SW[1,2,3,4,5,6]	BDL	41	220	196	140	137			9.4	9.4		12	9.7	9.2	
AAC+H_SW[1,2,4,5,6]	26	37	120	307	195	227			9.4	9.1		12	9.5	9.5	
AAC+H+TB_SW					235	255				9.3		12		9	
CL_SW							12	31			11.7	12.7*			12.0*
CL+H_SW							30	26			10.9	12.7*			12.1*

*No adhesive mortar, pH in outermost 10 mm of insulating plaster; **pH of freshly mixed lime render 12.7; SW: walls facing southwest; NE: walls facing northeast; +H indicate walls with exterior hydrophobisation; +R indicate walls with exterior rendering; +TB indicate walls with thermal bridge installed in front of wooden wall plate. A and B indicate the two samplings done in each location. Evaluation of Mycometer results is described above. The numbers in superscript indicate what fungal species were found, which are described in the subsequent paragraph.

The results showed high initial pH-levels (>12) in the internal lime render and the adhesive mortars, which decreased over time. It is seen that the pH decreased slower in the more diffusion-tight insulation systems (PUR-CM and PF) in comparison with the highly diffusion-open insulation systems (CaSi and AAC). In terms of fungal growth, it was observed that in the insulation systems which had high pH-levels (the more diffusion-tight systems and the diffusion-open cork-lime), the levels of fungal biomass (spores and mycelia) were low, indicating no active growth after up to 4½ years despite hygrothermal conditions favourable for growth in most walls. In addition, the swab test found no colony forming spores in the masonry/adhesive interface. In contrast to the findings for the more diffusion-tight systems and the calcium silicate, findings for the walls with AAC insulation showed lower pH-level (<10) and high levels of fungal biomass. Further investigations showed high levels of fungal biomass in the outermost parts of

the AAC insulation, which were in contact with the adhesive mortar. Here, 11 of 30 samples had high levels of fungal biomass, ranging from 450 to 1459 (i.e. Mycometer Value, MV), indicating active growth. Thermogravimetric analysis of the AAC system found organic additives. No growth was observed in the cork-lime system, despite the presence of cork, probably due to the high pH. Cultivation of the swab samples on V8 and DG18 media [10] resulted in the following fungal species being identified in the AAC test walls: 1) *A. versicolor*; 2) *P. chrysogenum*; 3) *Parengyodontium album*; 4) *S. strictum*, 5) *Pseudogymnoascus pannorum*; 6) *Cladosporium sphaerospermum*. In the literature [8,10,25-26], the latter three species have been described as able to grow in alkaline conditions and have been isolated from materials such as limestone and plaster.

A laboratory experiment comprising 17 small-scale test walls were constructed and fitted with different insulation systems: PUR-CS, PF, CaSi, AAC, and CL [23,27]. The purpose of the study was to assess fungal growth conditions in artificially contaminated masonry/adhesive interfaces, and if high alkalinity of the adhesive would prevent growth. The small-scale test walls were placed over a water reservoir, inside plastic boxes serving as small climate zones and to avoid cross contamination between test walls. Drilled-out core samples were taken out after 6 and 12 months and investigated for fungal growth and pH in the interface materials. Fungal growth was investigated using the Mycometer method (surface and material tests) and incubation of agar imprint samples, analysed under stereo and light microscopes [10]. pH measurements were carried out as presented for the large-scale test walls. The results of the study are presented in Table 2.

TABLE 2. Measured temperature, RH, Mycometer, and Colony Forming Units (CFU) for the small test walls [23,27].

Insulation system	Average Temp. [°C]	Relative humidity [%]		Mycometer Value (MV) [-] in masonry/adhesive interface						Total CFU from V8 and DG18	
				Results after 6 months			Results after 12 months				
				Masonry/ adhesive interface		Adhesive mortar (Material test)	Masonry/ adhesive interface		Adhesive mortar (Material test)	6 months	12 months
		Average	Final	A	B		A	B			
PUR-CS 1	18.4	99.6	99.9	46	11	6	11	15	16	3	154
PUR-CS 2	19	99.9	99.9	17	5	3	13	12	BDL	1	0
PUR-CS 3	19	99.6	99.9	14	14	5	15	16	30	2	301
PUR-CS 4	18.9	99.7	99.9	7	7	4	11	11	2	75	4
PF 1	20.6	86.3	97.2	5	8	6	11	12	5	2	1200
PF 2	20.8	96.4	99.9	1	3	8	34	41	19	634	611
PF 3	22.7	86.3	93.5	26	6	4	9	18	21	112	1214
PF 4	20.8	88.2	93.4	3	1	2	18	19	19	216	359
CaSi 1	18.6	95.9	99.5	7	12	6	10	9	10	0	100
CaSi 2	19.3	98.5	99.9	4	9	5	7	11	42	2	28
CaSi 3	19.2	99.2	99.9	20	7	6	3	13	6	228	8
CaSi 4	19.5	99.7	99.9	5	5	13	9	10	9	5	168
AAC 1	18.8	99.8	99.9	7	7	4	10	8	9	58	475
AAC 2	19.1	99.8	99.9	BDL	0	6	5	5	2	7	3
AAC 3	19	99.8	99.9	32	14	19	8	15	6	0	4
AAC 4	19.3	99.6	99.9	3	2	2	6	5	4	5	13
CL	19	99.8	99.9	19	26	Not tested	12	13	Not tested	1	3

A and B indicate the two samplings done in each location. Evaluation of Mycometer results is described above.

Drilled-out core samples examined one year after application showed high pH levels (>12) in the internal renders and adhesive mortars. It was observed that the hygrothermal conditions in the masonry/adhesive interface were very favourable for fungal growth to occur, at both the 6- and 12-month samplings. However, on-site Mycometer tests found low levels of fungal biomass (spores and mycelia) in all 17 test walls, indicating no active growth. In contrast to the Mycometer tests, the agar imprint tests found a large number of CFUs indicating high numbers of viable spores in many of the test walls. This indicated that while no active growth was detected, some types of fungal spores were able to survive the highly alkaline conditions but were not able to start germination and begin vegetative growth, probably due to high pH. Analysis of agar imprints showed that *A. versicolor* and *P. chrysogenum* were the first and

second most prevailing fungal species, respectively. Despite rather similar pH-levels, the type of adhesive mortar was also found to be of importance. A broader variety of fungal species were found in walls insulated with the phenolic foam system.

In a study by Morelli and Møller [28], several apartments in two three-storey residential buildings were insulated internally using different combinations of capillary active insulation measures (PUR-CS, CaSi, and AAC). The purpose was to investigate the energy savings and hygrothermal performance of the applied insulation systems, and over a 2-year period, heating, temperature, and RH were measured. After completion of the measurement campaign, the insulation was dismantled in two test apartments fitted fit PUR-CS insulation, to investigate fungal growth in the masonry/adhesive interface. Fungal growth was not detected using the Mycometer method [20] and through visual inspection. pH in the interface was examined using phenolphthalein, an indicator that changes from colourless to purple if the pH-value is higher than 9 [14].

The test with phenolphthalein showed that interface materials were very alkaline with high pH (>9), and the Mycometer tests showed low fungal biomass (spores and mycelia) levels. Indicating no active growth in the interface two years after installation, despite high interface RH in one of the apartments (85-90% for extended periods).

SUMMARY AND CONCLUSION

The two construction types described in this paper deals with two very different scenarios in relation to the risk of fungal growth on cementitious materials. Adhering to traditional building principles, increased time pressure, lack of attention to moisture and increased focus on indoor climate have also made problems with hidden fungal growth on newly cast concrete floors visible. For example, in a typical construction process of a single-family house (uncomplicated construction process), there is often only 3 months from casting the concrete floor on terrain till installation of membrane and flooring. A typically used moisture criterion for concrete floor is 85% or 90% RH (for most flooring types, even down below 65% for wooden flooring), according to requirements from flooring suppliers. However, as shown in this paper, the drying time of cast concrete floor were found to generally exceed the 3 months. The high alkalinity, which inhibits fungal growth in the concrete surface, decreases during the construction period to a level that allows for fungal growth at the time of installation of the moisture membrane and flooring. High levels of soiling will worsen the damage picture in cases where both moisture and pH allow fungal growth. Furthermore, as shown in this paper and in the literature, there are several fungal species with a preference for concrete and the ability to grow in high pH environments. This indicate that a pH of 9-10 does not eliminate the possibility of fungal growth. Based on the results of these case studies and the knowledge that many fungal species can change the pH-level of the immediate environment through production of acidic metabolites, it cannot be ruled out that certain species can thrive at even higher pH-levels, probably pH >10.

For existing masonry walls fitted with internal insulation installed using cement-based adhesive mortars, it was found that in the case of high pH (>12) in the immediate surroundings, no fungal growth was detected in the masonry/adhesive interface despite extended periods with optimal hygrothermal conditions for fungal growth. However, growth was detected only in some test walls with lower pH (<10), which also contained organic additives. Organic additives would in part be comparable to the findings for soiled concrete floors, increasing the risk of fungal growth. Organic residue or additives should be avoided as much as possible due to the rather critical nature of internal insulation in terms of moisture exposure. High pH (>11) could be maintained for more than 4-5 years, when using insulation systems with a large water vapour diffusion resistance, slowing carbonation of the adhesive mortars and ensuring longer protection. However, in agreement with the literature, one wall study found that certain species, i.e. *A. versicolor,* were rather resilient against high pH, even after long-term exposure.

RESEARCH GAPS IN THE LITERATURE

For more precise risk assessment in relation to specific fungal species, there is need for research into the abiotic factors, in particular the effect of pH on growth of the individual fungal species and on various building materials, which is generally lacking in the literature. Especially, for prominent species such as *A. versicolor*. Furthermore, it is also unknown for how long fungal spores can survive highly alkaline environments, and whether it would be possible in certain construction element to maintain high pH long enough to prevent growth.

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