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Radon, fungal spores and MVOCs reduction in crawl space house: A case study and crawl space development by hygrothermal modelling

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ABSTRACT

In this case study was to investigate how ventilation of the crawl space will influence on concentrations of radon, fungal spores and MVOCs in the crawl space and indoors of detached house. The crawl space pressurisation by exhaust air from indoors was successful to prevent the convective flow of radon from the soil, but it increased microbial growth in the crawl space. After installation of the supply and exhaust ventilation in the crawl-space and in the living space, the concentrations of fungal spores in the crawl space and also entry of radon and MVOCs into a house decreased.

A microbiologically safe crawl space was determined with hygrothermal simulation utilizing the Finnish Mould Growth Model and a two year examination period. The optional structures of the crawl space being depressurised with exhaust ventilation included an open base uncovered ground and various air-sealed closed structures. When mould growth of building materials was at medium resistant sensitivity class, mould was not observed during different air change rates in any of the examined structures. Open base uncovered gravel ground is a functional solution of a crawl space, only when there are no organic materials. The air-sealed ground structure is recommended build with concrete + insulation and when air exchange rate (ach) varied from 0.2 to 1 h^{-1}. A concrete ground in the crawl space having ach from 0.2 to 0.6 h^{-1} is also very effective. XPS insulation and plastic sheet covered ground are not recommendable due to their high mould index.

1. Introduction

In the Nordic countries, crawl spaces are typically outdoor air-ventilated. In older buildings, ventilation is often natural, but mechanical ventilation is quite common in newer buildings.

If the crawl space less than 0.8 m height, which is typical nowadays, the operation of the natural ventilation is often unsatisfactory. The flow of radon-bearing soil gas and entry of mould-like odours (MVOCs) from the crawl space depend on the difference in crawl space-indoor pressure and the leakage area between the crawl space and the house. According to the studies, a significant fraction of infiltration air can enter into the house via the crawl space [1–4], but the correlation between microbial concentrations in crawl space and indoors depends on the microbial species [3] and pressure difference across the structure [4]. Natural ventilation of crawl space has not been found to give greater than about 50% reduction of indoor radon in most cases [1].

Infiltration of airborne particles such as fungal spores and microbial metabolites from the crawl space is a more complex and less known process than radon and MVOCs. Secondary metabolites are expected to be present in airborne spores, and may thus occur in airborne dust and bioaerosols. The penetration of fungal spores is expected by Liu and Nazaroff to be a function of particle diameter, crack geometry, and pressure difference across the crack [5]. They have modelled particle penetration through uncomplicated cracks. Further studies are needed in real buildings, where exist cracks having different kind of surface and geometry. In addition, the size of spores varies a lot according to the species being between 1 μm–100 μm and the mean size of microbial spores increases during the activities [6,7].

In buildings with mechanical ventilation the pressure difference between indoor and outdoor is often in a range of 0–10 Pa, but pressures of up to several tens of pascals are possible for building with mere exhaust ventilation [8–10]. In general, the exhaust ventilation in crawl space with opening vents, maintains slight under pressure relative outdoor. Improving ventilation in the crawl space reduces the indoor radon concentration by less 60% on average [11].

In mechanical crawl space depressurisation systems, a fan is installed to exhaust crawl space air and to reduce its entry into the house. However, crawl space depressurisation increases the convective flow of

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radon-bearing or other soil gas, moisture from the soil and outdoor air into the crawl space. In addition to avoid mould growth in the crawl space structures the efficient disturbance of fresh air in the whole sphere of crawl space is important and often defective. Crawl space depressurisation has been found to give reduction of indoor radon in the range of 70%–96% [1].

In crawl space pressurisation systems, a fan is installed to blow outdoor air or indoor air into the crawl space. If pressurisation is successful, it prevents the most of the convective flow of radon-bearing and other gas from the soil. In addition, reduction of radon depends on the leakage area between the crawl space and the living space. If indoor air is used it raises the relative moisture and temperature of the crawl space and thus, promotes the microbial growth in structures of the crawl space. Crawl space pressurisation also increases air infiltration from the crawl space into the living space. Crawl space pressurisation has been found to give reduction of indoor radon in the range of 30%–80% [1].

Concentrations of the fungal spores and identifying genus level of fungal colonies are used to confirm or exclude the presence of possible mould growth and damages inside building structure and on a surface of the structure. Air sampling, building material or surface sampling methods have been used for the microbial analyses. However, the result of the microbiological analyse depends on the activity of the mould growth and on ambient conditions (nutrients, pH, humidity and temperature) [12].

The moisture output in the crawl space comes mostly from ground moisture evaporation and high moisture contents of ventilation air brought in from outside. Outdoor air-ventilated crawl spaces can prove problematic in the Nordic countries during summer, when outdoor air is warm and humid, and thus the absolute humidity of outdoor air is higher than that of the crawl space. In numerous studies of crawl spaces, long-term 70–90% relative humidity has been observed [13–17]. Different countries and region vary in climate, which should consider in design of the crawl space. The temperature in the crawl space is considerably lower than that of outdoor air due to cool earth and massive foundations cooling the crawl space. Thus, the warm and humid air from outside used for ventilation is cooled in the crawl space and the relative humidity increases. According to Matilainen and Kurnitski [13,22], humidity problems in crawl spaces can be reduced by heat insulation the cold ground in the crawl space and by arranging basic ventilation 0.5–1 h-1. In cases where the bottom of the crawl space is covered by a layer of crushed gravel as a form of evaporation insulation, it is recommended that in summer ventilation should increase to the value of (2-5 h-1) [13]. Because there is always enough organic material in a crawl space for mould to feed on, the conditions are favorable for the start of mould growth [18,19]. Of used construction materials only freshly made concrete has a high pH level that makes it less likely to mould, but as it ages its resistance to mould reduces. Moulds are able to grow in broad temperature ranges, and only the relative humidity in crawl space conditions is the limiting factor for mould growth. At low temperature (5 °C) mould growth is limited and mould does not growth at temperature below 0 °C [21].

Generally, 75–80% can be considered a safe limit value for relative humidity in crawl spaces [14,20]. Some moulds can tolerate very low humidity, which from a microbiology perspective means that it is not possible to build a completely microbial clean crawl space. Mould growth on and the risk of moulding for structures in a crawl space can be assessed with a calculation by observing the building materials' temperature and humidity data over the examination period and using a developed calculation models that includes a classification that describes the mould growth sensitivity of typical building materials [19,20]. For the purpose of this calculation, materials have been divided into classes on the basis of their mould growth sensitivity. The models are a tool to simulate the progress of mould and decline development under different conditions on the surfaces of structures.

The microbial volatile organic compounds (MVOCs) are formed due to the primary and secondary metabolism of fungi and bacteria [23]. More than 200 compounds have been considered to be released by the microbes according to the literature [23]. However, those compounds can be released from the other sources as well. For example from the building and decoration materials, plants, chemicals and detergents. Nonetheless, many alcohols and ketones have a mould-like odour and are considered to be release from the microbes [24–26]. MVOCs can be analysed accurately, but the result of the analysis also depends on the activity variation of the mould growth and on availability of nutrients in a substrate. Furthermore, it is proposed that the different microbial species produce specific MVOCs, which could be used as an indicator of the microbial growth [24,26]. Korpi et al. [27] recently reported that some alcohols, ketones, and terpenes can be regarded as MVOC. On the other hand, the various VOCs accompany microbial activity but no single VOC is reliable indicator of biocontamination in building materials. Pasanen et al. [28] calculated theoretically indoor air concentration of selected VOCs for rooms with and without microbial contamination. The results revealed that microbial growth in construction seems to have only a marginal effect on the total VOC load in indoor air.

Aim of this case study was to investigate how ventilation parameters of the crawl space will influence on concentrations of radon, fungal spores and MVOCs in the crawl space and indoors. In addition to this, simulations were used to study the temperature and humidity conditions and mould growth sensitivity of crawl spaces. The open and closed ground structures were modelled during period consisting of consecutive building physically critical test years. The optimal ventilation rate of mechanical exhaust was determined in the crawl space for different structural options. The goal of mechanical ventilation is to maintain a sufficient pressure difference between the crawl space and living space.

2. Materials and methods

2.1. The studied building

The research building is a single storey one-family house (floor area 129 m^2) which was located in Tampere on the low-lying clayey soil. Under the floor, which was constructed from low density aerated concrete, there was a crawl space. There was a plastic membrane on the surface of bearing soil and a layer of sand (Fig. 1).

The house had an exhaust ventilation system that was used also for radon mitigation. In this ventilation system, indoor air was blown to the crawl space (volume 52 m^3) by the exhaust fan and air was then let to escape outdoors through an open duct through the roof. During the monitored periods, the house was inhabited by two adults and two children. Inhabitants did not use ventilation through the windows during the measuring periods.

2.2. Method for mitigation

The original pressurisation system was removed and the house was

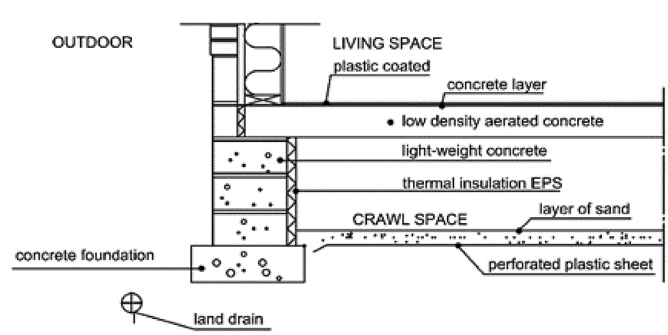

Fig. 1. The sectional drawing of the crawl space foundation in the studied building.

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