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Dominant microbial volatile organic compounds in 23 US homes

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HIGHLIGHTS

- Only low microgram m^{-3} concentrations of MVOCs prevail in basements generally.
- "C8" MVOCs were generally elevated in homes with detectable MVOCs.
- 2-Octen-1-ol was significantly elevated in non-problematic basements.
- C8 alcohols and ketones were found with molds known to predominate in wet locations.
- A semi-quantitative predictor of mold termed "MOW" can aid in applied mold studies.

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ABSTRACT

Associating Microbial Volatile Organic Compounds (MVOCs) with the species producing them may open the path to more rapid and reliable chemical methods to detect mold problems, especially for mold hidden in wall cavities or small enclosed spaces. This study associated the dominant MVOCs in a convenience sample of 23 homes with the mold species present. Three semi-quantitative predictors of mold growth ("MOW scores") were assessed in the homes through a comparison of basement to main floor areas. MVOC samples were collected and analyzed by GC/MS. Aerotek N-6 samplers were co-located with the MVOC samplers to collect bioaerosols. Concentration and prevalence data for 19 definitive MVOCs were compared with the bioaerosol data. Mold predictor scores were elevated in basement locations as compared with main floor areas. Of the 23 mold genera identified, the predominant genera (ranked occurrences) were *Cladosporium*, *Penicillium*, *Basidiomycetes*, and *Aspergilli*. The MVOCs 2-octen-1-ol, 3-octenone, 2-heptanone, 1-octen-3-ol, and 1-butanol showed the highest average concentrations (11–37 $\mu g\ m^{-3}$), but no single MVOC was significantly elevated in basement locations as compared with main floor living areas in these non-problematic homes. Using a less conservative one-tail test of significance, average 2-octen-1-ol concentrations in basements were higher ($p < 0.040$), and both 3-octenone and 1-octen-3-ol were elevated ($p < 0.095$). Differences in MVOC occurrence were greatest between homes, with MVOCs found in basement locations typically detected in living areas at similar concentrations and frequencies. Based on these findings, the C_8 MVOCs show promise as gross indicators of fungal growth related to the most frequently found mold genera.

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1. Introduction

Available evidence has demonstrated that a multitude of factors are associated with poor indoor air quality, including temperature, humidity, lighting and noise; social/psychological stressors; and microbiological causes such as fungal allergens or other growth byproducts like Microbial Volatile Organic Compounds (MVOCs) (Dillon et al., 1996). The Institute of Medicine has concluded that there is "sufficient evidence of an association" between exacerbation of asthma and exposure to mold allergens (Pope et al., 1993).

Multiple federal funding priorities demonstrate an interest in the root causes of poor indoor air quality and in the techniques for their early detection and elimination (U.S. Department of Health and Human Services, 2001; U.S. Department of Housing and Urban Development (HUD) and Office of Healthy Homes and Lead Hazard Control, 2004). The use of MVOCs as a rapid and reliable method to detect mold problems holds promise in this regard, since MVOCs can serve as important indicators for the presence of molds in indoor air pollution (Fiedler et al., 2001). At present, however, the relevance of fungal metabolites in indoor air remains insufficiently studied (Fischer and Dott, 2003).

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Despite the availability of highly sophisticated laboratory-based methods for trace chemical detection, most routine assessment of indoor fungal contamination problems is presently performed by visualizing large-scale fungal growth (e.g., the "New York City Guidelines") and by environmental wipe or air sampling (New York City Department of Health and Mental Hygiene, 2002). In addition, comparative measures of moisture, such as the output of a properly used moisture meter, can be taken to predict locations at which hidden mold growth is probable. However, these relative moisture methods cannot detect excessive mold growth or the causative species, and the intuition and experience of the investigator must be relied upon to identify and sample suspect growth locations. Services of dubious value have emerged offering qualitative inspection services that capitalize on fears of "black mold" or "toxic mold" contamination where resources directed toward such analyses are unlikely to produce scientifically meaningful results (Blackmold.awardspace.com, 2011; Home Air Check, 2011). For these reasons, advances toward more objectively characterizing indoor mold contamination are of real interest to practicing professionals and the IH profession as a whole.

Competently performed field studies of suspected microbially affected indoor environments rely heavily on sometimes subjective, semi-quantitative visual inspections, spore trapping, dust cultures, or bioaerosol collection. Well recognized deficiencies of such viable airborne mold sampling techniques include high seasonal, geographic, temporal, and analytical variability, as well as comparatively long turnaround times. For this reason, the documentation of one or more validated correlations between MVOCs and the molds producing them may open the path to more economical and precise chemically-based quantification methods. Given the extensive commercial volatile organic compound analysis infrastructure in the US today, mold assessments based on MVOCs would be significantly quicker than culture-based analyses.

Delays in obtaining sampling results can greatly inconvenience building residents and clients, and often add significantly to the construction-related costs of mold-issue resolution at affected buildings. Although existing methods are passable for some needs, all mold assessment surveys could benefit greatly from a method capable of providing a more immediate turnaround, with results requiring less interpretation by the professional. Recent work with portable ion-mobility spectrometry has resulted in a promising field application of real-time MVOC detection with the lower limit of detection necessary for most MVOCs (Tiebe et al., 2009). Interpretation of conventional culture results, whether bioaerosol or solid surface in nature, is often of questionable scientific merit. In fact there is presently no definitive, widely accepted statement as to the meaning of most cultured fungal concentration data. Correlating MVOCs to known mold genera and colonization extent, moisture content, and related environmental factors, will serve to create an investigative tool that is commercially feasible now, as well as highly cost-effective.

A number of studies have been conducted on the utility of MVOCs as indicators of fungal growth. Possible advantages to the use of MVOCs for fungal contamination quantification include (a) rapid analysis as no culture is needed, and (b) indication of not only visible but also hidden microbial growth, since MVOCs are known to permeate building structures (Gao and Martin, 2002; Matysik et al., 2008). All culture-based methods suffer from an inability to non-destructively detect mold hidden in wall cavities or small enclosed spaces. A key characteristic of MVOCS—their ability to diffuse from enclosed spaces, from behind vinyl wallpaper or vapor barriers, or off heating, ventilation, air conditioning (HVAC) filters free of visible contamination—has been of interest to investigators seeking to employ MVOCs as indicators of latent mold growth (Strom et al., 1994; Ahearn et al., 1997; Elke et al., 1999; Hachem et al., 2009). It is this property, in part, that makes MVOCs so attractive as a mold assessment tool. However, as noted by the US Environmental Protection Agency, a definitive determination on how to use MVOC data remains lacking and "Research on MVOCs is still in the early phase." (USEPA, 2011).

Finally, information about the prevalence of specific MVOCs is significant to basic research for several reasons. MVOCs in indoor air present a group of compounds worthy of additional study both because of their innate toxicological properties, or as precursors for more toxic mycotoxins. For almost two decades now there have been suggestions that such volatiles, and the mycotoxins for which they may act as precursors (Borjesson et al., 1992; Zeringue et al., 1993; Jelen et al., 1995; Pasanen et al., 1996) could be partially to blame for indoor air quality (IAQ) problems caused by fungal growth (Land et al., 1987; Tobin et al., 1987; Burge, 1989; Sorenson, 1989; Flannigan et al., 1991; Miller, 1992; Samson, 1992). Thus the prevalence of MVOCs is a basic public health question of potential merit.

In one of the most frequently cited early works on MVOCs a total of 23 compounds (grouped into Classes A and B) were labeled by Wessen and Schoeps (1996) as arising uniquely from microbial sources. According to them, Class A MVOC occurrence is usually of higher frequency than Class B but Class B compounds are necessary to correlate microbial impact with the indoor environment. With the publication of additional studies since Wessen and Schoeps, it is possible to compile a more definitive list of presumptive MVOCs. A single grouping of fourteen (14) empirically derived MVOCs has been compiled by the authors in Table 1 (Ryan, 2011). The definitive criterion for this listing is the independent quantification of an MVOC in three or more separate field-based investigations (Hung et al., 2005).

Compared to other areas of IAQ research, there exist comparatively few field studies of MVOC occurrence patterns. The often cited work done in Swedish houses is based on only three houses (one of which was a control dwelling) (Stom et al., 1994). The significance of those findings must be guarded given the lack of a statistically valid number of observations. With respect to other field studies of MVOCs there are relatively few reports ($n \sim 7$) in the peer-reviewed literature (Miller et al., 1988; McJilton et al., 1990; Bayer and Crow, 1992; Wessen and Schoeps, 1996; Schleibinger et al., 1997; Elke et al., 1999; Matysik et al., 2009) and no recent surveys of US housing stock. All studies which attempted to correlate mold species with predominant MVOCs have yet to be repeated. The great majority of published studies to date have in fact investigated mold genera and specific MVOCs only under laboratory conditions (not discussed here), where a great diversity of compounds is reported. Perhaps because of the complexity presented by this diversity there exists in the literature at present a dearth of studies that examine the nature of the mold-MVOC relationship under field conditions. Recent work with artificial neural

Table 1
Fourteen MVOCs as suggested by consistent isolation in $\geqslant 3$ field surveys (AIHA, 2005).

3-Methyl furan
1-Butanol
3-Methyl-1-butanol
3-Methyl-2-butanol
2-Pentanol
2-Hexanone
2-Heptanone
3-Octanone
3-Octanol
1-Octen-3-ol
2-Octen-1-ol
2-Nonanone
Borneol
Geosmin

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