Topic B6: Prediction & measurement

INDOOR DAMPNESS AND MOLD AS INDICATORS OF RESPIRATORY HEALTH RISKS, PART 7: A REVIEW OF MICROBIAL VOLATILE ORGANIC COMPOUNDS (MVOCS) OBSERVED UNDER DAMP CONDITIONS

Makoto KAWAGUCHI[1,2], Mark MENDELL[1], George CHRYSOCHOU[1], Dennis SHUSTERMAN[3,4], Justine HUTCHINSON[3], Kazukiyo KUMAGAI[1,*]

[1]Indoor Air Quality Section, California Department of Public Health, USA
[2]Department of Science Division 1, Tokyo University of Science, Tokyo, Japan
[3]Occupational Health Branch, California Department of Public Health, USA
[4]Department of Population Medicine, University of Guelph, Canada

[*]*Corresponding email: kazukiyo.kumagai@cdph.ca.gov*

Keywords: Microbial VOC, MVOC, Dampness, Mold, Odor

SUMMARY

This paper describes one part of a multi-component, on-going effort at the Indoor Air Quality Section of the California Department of Public Health to develop evidence to support *quantitative*, health-protective guidelines for indoor dampness and dampness-related agents. A literature search was performed on microbial volatile organic compounds (MVOCs) and their associations with dampness and mold indicators (DMIs) in the built environment, and the chemical properties of the MVOCs were determined. Results indicated positive associations between the presence of DMIs and the concentrations of some MVOCs. In addition, it may be possible to identify chemicals released by microorganisms by their boiling points and chemical structures. The study provides a perspective on selected MVOCs as potential dampness indicators and suggests that measurement of specific MVOCs may improve detection of dampness or mold quantitatively and objectively.

INTRODUCTION

Previous reviews of epidemiologic studies reported that the only dampness and mold indicators (DMIs) that were correlated consistently with health effects were: (1) observed mold growth; (2) observed dampness/water damage; and (3) mold odor (Institute of Medicine, 2004; World Health Organization, 2009; Mendell et al., 2011). Unfortunately, these indicators are subjective and are not readily quantified for use in evidence-based, health-protective guidelines for indoor dampness/mold.

Measurement of the moisture content (MC) of building materials is a quantitative indicator of damp conditions (Macher et al., 2014; Chen et al., 2014). However, moisture may be localized or episodic and not detected by moisture measurements. In addition, moisture meters measure dampness to a limited depth and may not detect interior dampness or dampness on the opposite side of a wall. Moisture meters also are not suitable for difficult to reach locations, e.g., inside ductwork.

Therefore, we considered the possibility of regarding microbial volatile organic compounds (MVOCs) as a more objective DMI, one that may be more stable than possibly fluctuating MC, and one that could complement measurements made with moisture meters. In this paper, we conducted a literature review of MVOCs that have been detected in actual buildings and related them to observations of DMIs. We discussed the consistency of observed correlations between the concentrations of MVOCs and the presence of DMIs, and we identified MVOCs with statistically significant positive correlations with dampness, visible mold, mold odor, or water leaks. Finally, we investigated the chemical properties of these MVOCs to determine the specifications that would be needed to detect them with portable monitors that could be used in field investigations of DMIs in built environments.

METHODS

A literature search was performed in PubMed using the keywords "MVOC," "microbial VOC," "microbial volatile organic compound," "indoor," and "building." We selected field studies that identified specific VOCs and their concentrations as well as papers that compared observed DMIs to VOC concentrations. We identified chemicals with consistently, statistically significant positive relationships with DMIs. The selected chemicals were tabulated, along with their properties, i.e., boiling points and characteristic chemical structures as determined from SciFinder and the NIST Chemistry WebBook.

RESULTS AND DISCUSSION

Comparison of Chemical Concentration by Dampness Evidence

Seventy-three articles were identified with the target keywords of which five papers included indoor DMIs. In these five studies, 30 compounds were reported. Within each study, we compared MVOC concentrations in buildings with and without each DMI and calculated the relative differences. The concentrations of 23 of the 30 chemicals were higher when a DMI was present (Table 1a–c).

Table 1. Comparison of MVOC concentrations (μg/m^3) in buildings without and with DMIs. (Blank cells represent unreported compounds rather than concentrations below a detection limit.) MVOCs are arranged in ascending order of their boiling points, which are discussed later.

Key	
Difference Level	Abbreviation
X < 0%	FID = flame ionization detector
X = 0%	GC = gas chromatography
0% < X ≤ 33%	GM = geometric mean
33% < X ≤ 66%	MS = mass spectroscopy
66% < X ≤ 100%	TD = thermal desorption
X > 100%	

1a. Comparison of MVOC concentrations by presence of dampness

Author	B. Sahlberg (2013)			G. Wieslander (2007)		
Source and Description	Households in three major cities in Iceland, Sweden, and Estonia			Office buildings in a major city in Sweden		
Sample collection, Analysis	Charcoal tubes, GC/MS			Charcoal tubes, GC/MS		
DMI	Not damp	Damp	Total	Not damp	Damp	Total
Sample Size	92	64	156	1	1	2
MVOC	GM	GM	Difference	N/A	N/A	Difference
Dimethyl sulfide						
2-Methylfuran						
3-Methylfuran*	0.018	0.029	61%	0.005	0.014	180%
Dimethyl disulfide*				0.003	0.019	533%
Ethyl isobutyrate	0.0013	0.002	54%			
3-Methyl-2-butanol						
Isobutyl acetate*	0.053	0.061	15%	0.01	0.024	140%
1-butanol	6.02	5.6	-7%	1.56	2.37	52%
2-Pentanol*	0.011	0.012	9%	<0.001	0.015	1400%
2-Hexanone*	0.059	0.053	-10%	0.024	0.027	13%
2-Methyl-1-butanol*	0.067	0.08	19%			
3-Methyl-1-butanol*	0.26	0.3	15%			
Ethyl-2-methybutyrate	0.022	0.04	82%			
1-Pentanol*						
2-Heptanone*	0.31	0.33	6%	0.031	0.026	-16%
1-Octen-3-ol*	0.046	0.06	30%	<0.001	0.003	300%
3-Octanol						
2-Pentylfuran	0.041	0.044	7%	0.024	0.018	-25%
3-Octanone*	0.039	0.041	5%	<0.001	0.005	400%
Fenchone						
2-Nonanone						
α-Terpineol						
Geosmin	0.025	0.046	84%			

* Some positive association with DMI

1b. Comparison of MVOC concentrations by presence of visible mold

Author	H. Schleibinger (2005)	K. Elke (1999)	A. Araki (2012)

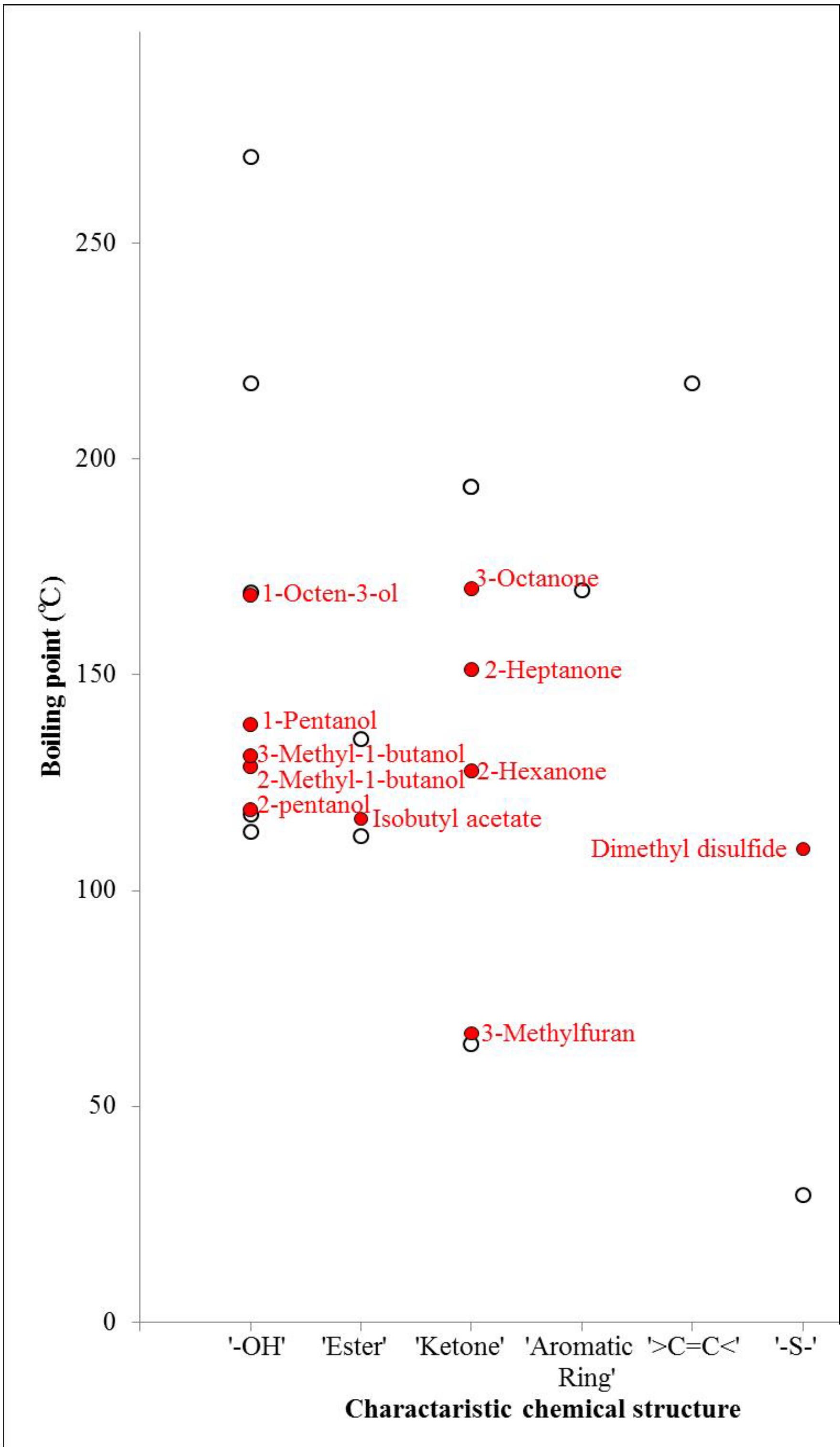
Source and Description	Apartment in Germany			Children's rooms in one rural and two industrialized areas of Germany			Households less than seven years old in six regions of Japan		
Sample collection, Analysis	Tenax TA® + activated charcoal tubes, TD-GC/MS			Diffusive air sampling w/ charcoal tube, GC/FID			Diffusive sampling w/ carbon molecular sieves, GC/MS		
DMI	No mold	Visible mold	Total	No mold	Mold found	Total	No mold	Visible mold	Total
Sample Size	44	40	84	117	15	132	42	140	182
MVOC	GM	GM	Differ-ence	GM	GM	Differ-ence	GM	GM	Differ-ence
Dimethyl sulfide	0.08	0.15	88%						
2-Methylfuran	0.65	1.21	86%						
3-Methylfuran*	0.17	0.32	88%						
Dimethyl disulfide*	0.07	0.15	114%						
Ethyl isobutyrate									
3-Methyl-2-butanol				0.5	0.7	40%			
Isobutyl acetate*									
1-butanol									
2-Pentanol*	0.07	0.06	-14%	0.2	0.3	50%	0.29		-100%
2-Hexanone*	0.47	0.57	21%	0.1	0.2	100%	0.31	0.32	3%
2-Methyl-1-butanol*	0.08	0.16	100%						
3-Methyl-1-butanol*	0.22	0.41	86%	0.7	1.3	86%	0.43	0.48	12%
Ethyl-2-methybutyrate									
1-Pentanol*							0.48	0.64	33%
2-Heptanone*	0.96	1.21	26%	0.2	0.3	50%	0.19	0.19	0%
1-Octen-3-ol*	0.06	0.13	117%				0.18	0.19	6%
3-Octanol	nd	nd		1.8	4.6	156%			
2-Pentylfuran	0.73	1.09	49%						
3-Octanone*	0.05	0.05	0%	1.4	2.0	43%	0.15	0.14	-7%
Fenchone				0.3	0.4	33%			
2-Nonanone				0.4	0.8	100%			
α-Terpineol				0.5	0.9	80%			
Geosmin									

* Some positive association with DMI

1c. Comparison of MVOC by presence of moldy odor and water leak

Author	A. Araki (2012)					
Source and Description	Households less than seven years old in six regions of Japan					
Sample collection, Analysis	Diffusive sampling w/ carbon molecular sieves, GC/MS					
DMI	No moldy odor	Moldy odor	Total	No water leakage	Water leakage	Total
Sample Size	144	37	181	161	20	181
MVOC	GM	GM	Difference	GM	GM	Difference
Dimethyl sulfide						
2-Methylfuran						
3-Methylfuran*						
Dimethyl disulfide*						
Ethyl isobutyrate						
3-Methyl-2-butanol						
Isobutyl acetate*						
1-butanol						
2-Pentanol*	0.31	0.25	-19%	0.30	0.25	-17%
2-Hexanone*	0.32	0.33	3%	0.32	0.32	0%
2-Methyl-1-butanol*						
3-Methyl-1-butanol*	0.45	0.53	18%	0.48	0.41	-15%
Ethyl-2-methybutyrate						
1-Pentanol*	0.60	0.60	0%	0.58	0.79	36%
2-Heptanone*	0.19	0.19	0%	0.19	0.21	11%
1-Octen-3-ol*	0.19	0.17	-11%	0.19	0.18	-5%
3-Octanol						
2-Pentylfuran						
3-Octanone*	0.15	0.13	-13%	0.14	0.13	-7%
Fenchone						
2-Nonanone						
α-Terpineol						
Geosmin						

* Some positive association with DMI



Name	BP (°C)
Dimethyl sulfide	29.5
2-Methylfuran	64.5
3-Methylfuran	66.9
Dimethyl disulfide	109.7
Ethyl isobutyrate	112.6
3-Methyl-2-butanol	113.6
Isobutyl acetate	116.6
1-butanol	117.7
2-Pentanol	118.8
2-Hexanone	127.8
2-Methyl-1-butanol	128.7
3-Methyl-1-butanol	131.2
Ethyl 2-methyl butyrate	135.1
1-Pentanol	138.5
2-Heptanone	151.2
1-Octen-3-ol	168.4
3-Octanol	169.0
2-Pentylfuran	169.7
3-Octanone	169.9
Fenchone	193.5
2-Nonanone	193.5
α-Terpineol	217.5
Geosmin	270.0

Figure 1. Boiling points and characteristic chemical structures of 23 selected MVOCs. The left half of the figure shows the distribution of MVOCs by their boiling points and chemical structures. Chemicals with consistent relationships with DMIs are shown in red.

Chemical Properties of Microbial Volatile Organic Compounds

From the five studies in Table 1, we identified 23 MVOCs that had consistent positive associations with DMIs.

1) Five chemicals at higher concentrations in damp building in both papers in Table 1a:
2-pentanol, 1-octen-3-ol, 3-methylfuran, 3-octanone, and isobutyl acetate;
2) Four chemicals at higher concentrations in buildings with visible mold in at least two of three papers in Table 1b:
3-methyl-1-butanol, 1-octen-3-ol, 2-hexanone, and 2-heptanone;
3) Three chemicals not suggested in (1) or (2) above but positively correlated with two or more of the following DMIs: dampness, visible mold, moldy odor, or water leakage:
dimethyl disulphide, 2-methyl-1-butanol and 1-pentanol;

This left 11 chemicals that were fairly consistently associated with DMIs:
3-methyl-1-butanol, 2-pentanol, 1-octen-3-ol, 3-methylfuran, 2-hexanone, 2-heptanone, 3-octanone, dimethyl disulfide, 2-methyl-1-butanol, isobutyl acetate and 1-pentanol.

The MVOCs in Table 1 are listed by their boiling points (BP) on the right of Figure 1 (the 11 selected MVOCs are shown in bold.). The left half of the figure shows the 23 MVOCs arranged according to their BPs and chemical structures. Seven of the 11 chemicals were in a BP range of approximately 30°C, i.e., 109.7−138.5°C. These 11 chemicals also included examples of all MVOC chemical structures other than aromatic rings and double carbon bonds. This characteristic distribution in Figure 1 may indicate the possibility to identify MVOCs and estimate dampness or mold quantitatively.

CONCLUSIONS

A PubMed search yielded five studies that compared the concentrations of 30 MVOCs in buildings without and with the presence of dampness or mold indicators. Of there, the concentrations of 23 MVOCs were positively associated with dampness or mold in at least one investigation. Eleven of these 23 chemicals showed stronger and more consistent associations with the presence of dampness or mold indicators. In addition, the boiling points of seven of these 11 chemicals fell within a narrow range although they did not share a common chemical structure. These results suggest that measurement of specific MVOCs may improve detection of dampness or mold in a quantitative and objective manner as compared with subjective visual or olfactory evidence. Additional field studies on MVOCs, qualitative and quantitative dampness indicators, and health are needed to verify these results. Future work also could guide development of methods and instruments to measure MVOCs in field investigations.

REFERENCES

Araki, A., Kishi, R., et al (2012). “The relationship between exposure to microbial volatile organic compound and allergy prevalence in single-family homes” *Science of the Total Environment*, 423, 18-26.

Chen W., Macher, J. M., et al (2014), “Indoor Dampness and Mold as Indicators of Respiratory Health Risks, Part 5: Comparison of a Moisture Meter and Water Activity Sensor to De-termine the Dampness of Gypsum Wallboard”, Accepted for Indoor Air 2014.

Elke, K., Dunemann, L. (1999). “Determination of selected microbial volatile organic compounds by diffusive sampling and dual-column capillary GC-FID—a new feasible approach for the detection of an exposure to indoor mould fungi?” *Journal of Environmental Monitoring*, 1, 445-452.

Institute of Medicine (2004). *Damp Indoor Space and Health*. Washington, DC, National Academy of Sciences.

Macher, J. M., Chen W., et al (2014). “Indoor Dampness and Mold as Indicators of Respiratory Health Risks, Part 5: Comparison of a Moisture Meter and Water Activity Sensor to Determine the Dampness of Gypsum Wallboard” Accepted for Indoor Air 2014.

Mendell, M. J., Mirer, A. G., et al (2011). “Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence” *Environmental Health Perspectives*, 119(6) 748-756.

NIST Chemistry WebBook, URL: http://webbook.nist.gov/chemistry/.

Sahlberg, B., Norback, D., et al (2013). “Airborne molds and bacteria, microbial volatile organic compounds (MVOC), plasticizers and formaldehyde in dwellings in three North European cities in relation to sick building syndrome (SBS)” *Science of the Total Environment*, 444, 433-440.

Schleibinger, H., Ruden, H. (2005), “Emission patterns and emission rates of MVOC and the possibility for predicting hidden mold damage?” *Indoor Air*, 15 Supplement s9, 98-104

SciFinder, URL: https://scifinder.cas.org/.

Wieslander, G., Norback, D., Venge, P. (2007) “Changes of symptoms, tear film stability and eosinophilic cationic protein in nasal lavage fluid after re-exposure to a damp office building with a history of flooding” *Indoor Air*, 17(1) 19-27.

World Health Organization (2009). *WHO guidelines for indoor air quality: Dampness and mould*. Copenhagen: World Health Organization.