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Indoor Air Chemistry – Olfaction and Sensory Irritation – An Overview

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The most common health and comfort effects reported in indoor environments are olfaction and eye and airway irritation symptoms regarding the classic "sick building syndrome" [1–3]. The common denominator about the role of indoor air chemistry (IAC) is the question about its biological relevance, i.e. have cause-effect (exposure-response) relationships been identified to play a role at typical IAC concentrations for the majority of the population. The reported symptom rates of, in particular, eye and upper airway irritation cannot be explained by our present knowledge of common chemically non-reactive VOCs measured indoors [4;5].

The increase of a given complaint(s) (i.e. symptom(s) or sign(s)) as a result of exposure (and dose) to a given pollutant(s) is essential for the discussion about how and which VOCs or hitherto unknown species should be measured and assessed. For example, do we know what the symptom 'eye irritation' in offices really means? Have cause-effect relationship(s) been established for specific compounds? For an answer to this question, see [6]. Another important question is "Can we measure what should be measured or do we miss important species by available standard sampling and analytical methods?", cf. [7].

Olfaction

Odor perception is omnipresent in our daily life and work. The perception as opposed to sensory irritation is immediate with steep dose-response curves. The character of odors represents a large variety from pleasantness (e.g. perfumes, flowers) to unpleasant ones (malodors, like dried fish), but the relationship(s) between olfaction and emotion/mood is complex, and cultural difference may even exist. Although, no cause-effect relationship exists between olfaction and objectively observed health effects, malodors (as perceived in the Western part of the world) are generally undesirable in indoor environments. There is no evidence, however, that (mal)odors *per se* are associated with objective adverse health effects [8;9]; except for certain "vulnerable" subjects for reasons still unknown [10]. Environmental awareness and belief through warning about both pleasant odors and malodors facilitates learning about subjective health symptoms such as airway irritation [11−13]. At VOC concentrations that are well below their airway irritation thresholds, but above their corresponding odor thresholds [14], reports of perceived sensory irritation most likely signify odor annoyance, and possibly accompanied by concern of toxicity. These reactions are probably psychological in nature [15], possibly a reaction to an "unknown" airborne chemical [16]. It is plausible that similar mechanisms also exist for indoor levels. However, it is uncertain if odors as encountered in typical indoor environments (e.g. emitted from building materials, office equipment) can be distinguished from other internal sources of odors and elicit specific effects of significance.

Olfaction is associated with a number of phenomena, which includes adaptation, habituation, exposure history, expectation and beliefs of health risk (i.e. informational bias), personal variables, and social factors (i.e. personal bias) [17]. Especially, belief has a strong influence, because "it creates a context through which perception is filtered". Some odors appear to influence the pattern of reporting symptoms, e.g. self-reported health and productivity.

Reduced air quality by emission of organic compounds from an old carpet and office equipment in climate chambers, respectively, has been associated with productivity deterioration, e.g. slower text typing speed and more typing errors [18;19]. Two hypotheses have been suggested by the same research group: i) Reduction of the perceived air quality caused headache (in the carpet study) which exerted less effort among the subjects thus lowering the speed of typing, ii) Although, expected to be present in low concentrations (i.e. less than a few μg/m^3), unidentified organic compounds was suggested in the second study to cause the decrements. The headache itself could have been the result of depression of breathing (cf. [20]. However, a more general explanation could be that nearly perceptible odors of the emitted organic compounds cause a mental and cognitive distraction of the subjects (e.g. by extension of the reaction time) which results in deteriorated performance, however, only briefly and especially if the odor is perceived as unpleasant or unrecognizable [20].

Olfaction and sensory irritation may be experienced as a unitary phenomenon and possibly result in biased reporting [16]. Although, the effects can be indistinguishable, it is important to understand the characteristics of the two types of effects and their contributions to the overall perception and reporting of the indoor air quality as a result of IAC.

Sensory irritation

The irritation effects are generally temporary in nature and disappear after leaving the building. However, irritation is a health effect and can be strongly annoying. Sensory irritation is characterized by a latency of effect, i.e. the symptom is experienced with delay (a built-up period) in contrast to odor perception. This has been reported from studies of city halls and libraries where reported "irritation" increased during a working day [21;22]. In a climate chamber study, subjects that were exposed to the emission of butanol and formaldehyde emitted from an acid-curing lacquer reported sensory irritation with considerably delay in contrast to the immediately perceived odor assessed by a panel of subjects for which sensory irritation was absent [23]. These and similar observations [24;25] indicate the importance of the time necessary for the development and perception of irritation symptoms.

Measurements

It is difficult to explain the complaints of "pure" sensory irritation by the measured IAC, cf. [5;26], nor by measured MVOCs [27], partly because the concentrations are far below thresholds for estimated eye/airway irritation, cf. [5;14]. In addition, some epidemiological studies have indicated that the sum of VOCs may be higher in an office building "classified" as "sick" as compared to a similar building classified as "healthy". This indicates that certain chemical reactions between certain VOCs and oxidants like O_3 may produce new irritants that could explain the increase of the complaints. This is referred to as "*the reactive chemistry*" hypothesis [5], for further discussion, see below.

It now appears salient to distinguish between four types of organic compounds in indoor air according to their expected influence on health and comfort effects. These groups are:

- Non-chemically reactive (stable) organic compounds, e.g. toluene and butyl acetate.
- Chemically "reactive" organic compounds like styrene or limonene (e.g. reacting with ozone [28]).
- Organic compounds that form a chemical bond to receptor-sites, i.e. biologically reactive (e.g. formaldehyde and acrolein).

- Organic compounds with known toxic properties, e.g. fungicides (e.g. pentachlorophenol).

Material emission testing

Identification of the odorous organic compounds is difficult, because information about the link between the sensory assessment and the "measured" emitted organic compounds is limited (cf. [29]. Odor thresholds can vary by orders of magnitude depending on the chemical structure and for some organic compounds the best analytical performance is inadequate for low odor threshold compounds. There are two reasons for this observation: First, many materials continue to release VOCs by secondary emissions [30], in particularly those materials that are based on linseed oils [14]. Although the corresponding VOC concentrations are in the low μg/m^3 range or less, the latest reported odor thresholds of many VOCs, in particularly aldehydes appear to be considerably lower than previously reported (e.g. [31]). Second, probably many organic compounds are not captured in sufficient amounts to be analyzed, because of their exceptionally low odor thresholds; nevertheless they are contributing to the overall odor intensity.

Why indoor air chemistry?

It is well known that unsaturated organic compounds, like terpenes (i.e. chemically reactive) react with ozone and the hydroxyl radical. Terpenes are common compounds indoors emitted from wood, plant, and fruit based products (e.g. citrus and pine oils). In addition, terpenes and terpene derivatives are common fragrances used in cleaning agents, household products, including personal care products [32]. Ozone oxidizes terpenes under typical indoor conditions producing a number of acids, diacids, aldehydes, ketones, and mixed aldehyde-keto-carboxylic acids (e.g. [33]). The results from a mouse bioassay [34] and recent human exposure studies [35;36] infer that oxidized terpenes produce eye/airway irritants that cannot be readily identified by conventional sampling techniques, partly because the stable reaction products, inter alia formaldehyde, methacrolein, methyl vinylketone, including formic and acetic acid cannot alone explain the bioresponse. On this basis, it is concluded that certain, not yet identified, species, like radicals and other analytically unstable products (e.g. hydroperoxides, nitrates), are responsible for the observed effect. For example, peroxy benzoyl nitrate, formed in the presence of benzaldehyde (or styrene), ozone and nitrogen dioxide, has an irritation threshold significantly lower than that for formaldehyde [37].

It is concluded in a recent review about eye irritation symptoms that "Rather than chemically stable indoor organic pollutants are causing eye complaints, it appears more plausible that work-related factors like computer work, including high temperature, low relative humidity, demands of visual and cognitive tasking, and psychological fatigue enhance the water loss from the eye tear film leading to dehydration, thus facilitating a chemical attack. Unsaturated VOCs in the indoor environment that undergo oxidation reactions with ozone should be considered sources of irritation, in particular in environments of low relative humidity" [38]. The interplay of relative humidity and indoor air should be explored.

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