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ScienceDirect
Atmospheric Environment 41 (2007) 1230–1236
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

The effects of evaporating essential oils on indoor air quality

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Received 8 May 2006; received in revised form 19 September 2006; accepted 22 September 2006

Abstract

Essential oils, predominantly comprised of a group of aromatic chemicals, have attracted increasing attention as they are introduced into indoor environments through various forms of consumer products via different venues. Our study aimed to characterize the profiles and concentrations of emitted volatile organic compounds (VOCs) when evaporating essential oils indoors. Three popular essential oils in the market, lavender, eucalyptus, and tea tree, based on a nation-wide questionnaire survey, were tested. Specific aromatic compounds of interest were sampled during evaporating the essential oils, and analyzed by GC-MS. Indoor carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compounds (TVOCs), and particulate matters (PM_{10}) were measured by real-time, continuous monitors, and duplicate samples for airborne fungi and bacteria were collected in different periods of the evaporation. Indoor CO (average concentration 1.48 vs. 0.47 ppm at test vs. background), CO_2 (543.21 vs. 435.47 ppm), and TVOCs (0.74 vs. 0.48 ppm) levels have increased significantly after evaporating essential oils, but not the PM_{10} (2.45 vs. 2.42 ppm). The anti-microbial activity on airborne microbes, an effect claimed by the use of many essential oils, could only be found at the first 30–60 min after the evaporation began as the highest levels of volatile components in these essential oils appeared to emit into the air, especially in the case of tea tree oil. High emissions of linalool (0.092–0.787 mg m^{-3}), eucalyptol (0.007–0.856 mg m^{-3}), D-limonene (0.004–0.153 mg m^{-3}), ρ-cymene (0.019–0.141 mg m^{-3}), and terpinene-4-ol-1 (0.029–0.978 mg m^{-3}), all from the family of terpenes, were observed, and warranted for further examination for their health implications, especially for their potential contribution to the increasing indoor levels of secondary pollutants such as formaldehyde and secondary organic aerosols (SOAs) in the presence of ozone.

Keywords: Essential oils; Indoor air quality; Airborne microbes; Terpenes; Formaldehyde; Secondary organic aerosols

1. Introduction

Essential oils and some extracted fragrance compounds are widely adopted into modern society for their capacity, at least reportedly, in generating pleasant odors, and providing anti-bioactivity benefits regardless of lacking sufficient scientific evidence to elucidating the specific effects and their corresponding mechanisms (Lahlou, 2004). Meanwhile, it is only natural that use of essential oils and products containing fragrances will release mixed volatile organic compounds (VOCs) into the indoor air, and many of these, such as terpenes and D-limonene, have demonstrated a significant role in the formation of secondary organic aerosols (SOA), often more irritating or allergenic than the original substance,

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1352-2310/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2006.09.044

after oxidation (Wainman et al., 2000). Yet, whether emission from evaporating or heating essential oils can affect the profiles of indoor air quality has not been investigated comprehensively thus far. We therefore began by examining the emission patterns of evaporating essential oils with burning candles underneath incense evaporator in typical office and residential environment to further characterize the effects of evaporating essential oils on typical indoor air pollutants (CO, CO_2, and PM_{10}) and airborne microbes in these environments.

2. Research methods

Three best-sold essential oils, together comprising more than 50% of total sale volume, were selected for the field study based on market survey, including lavender (*Lavandula angustifolis*), eucalyptus (*Eucalyptus globules*), and tea tree (*Melaleuca alternifolia*). Bulk samples of these essential oils were analyzed in our own laboratory by GC-MS to characterize the chemical compositions following the procedures reported previously (Chaintreau et al., 2003), and 300 μl of each essential oil were diluted with 50 ml water for use in incense evaporator with burning candle.

Two different types of indoor environments, one bedroom (space volume: 21.6 m^3; air change rate (ACH): 1.8 h^{-1}) and one small office (space volume: 28.2 m^3; ACH: 1.3 h^{-1}) were chosen for the experiment. Before evaporating, 30 min background sampling was performed to measure background levels of various indoor air pollutants, including CO, CO_2, total volatile organic compound (TVOCs), and PM_{10}, using continuous monitor. Carbon dioxide (CO_2) and carbon monoxide (CO) were measured by using Q-track monitor (Model-8550, TSI Inc., USA) with detection ranges within 0.04–1000 ppm for CO and 0–5000 ppm for CO_2. PM_{10} was measured by Dust-track monitor (TSI Inc., USA) with the detection range within 0.06–5000 μg m^{-3}. TVOCs was measured by using ppbRAE air monitor (PGM-7240, RAE system Inc., USA) with the detection range within 0–200 ppm. All real-time data were recorded by one data per minute during the sampling period. Airborne microbes were also collected before study. Monitoring during evaporating essential oils began after background profiles had been established, and were continuously recorded for at least 3 h for each round of test with triplicate tests completed for each essential oil in each testing space. All real-time data were recorded with the frequency of one data point per minute during the sampling period. Duplicate samples of airborne fungi and bacteria were collected using Burkard sampler (Rickmansworth, UK) with malt extract agar plates (MEA) and tryptic soy agar (TSA) at a flow rate of 10 LPM (Macher et al., 1995; Su et al., 2001). Airborne fungi and bacteria were collected at 0, 30, 60, 120, and 180 min within the period of evaporating essential oils. Fungi were cultured, incubated, and identified before average concentrations of duplicated samples, as colony forming unit per cubic meter (CFU m^{-3}), were calculated for the sampling site (Wu et al., 2005).

Stainless-steel tubes filled with Tanex-TA and Carboxen for absorbing VOCs (EPA-TO-17) were equipped with a sample pump (SKC 223-3, U.S.A.), and sampling at flow rate of 70 ml min^{-1} during the period of evaporating each essential oils in the testing space for VOCs sampling. Air samples were sealed by stainless-steel cap and sent to laboratory to be desorbed by automatic thermal desorption system (ATD-400, PerkinElmer Inc., USA), and directly transferred to GC-MS (Hewlett-Packard GC-5890; Hewlett-Packard MS-5972)(Rastogi et al., 2001). All procedures were completed within 30 min in our own laboratory. Specific VOCs, including two monoterpene hydrocarbons (D-limonene and ρ-cymene), one monoterpene ether (eucalyptol), and two monoterpene alcohols (linalool and terpinene-4-ol) were chosen as indicators. They were thermally extracted, analyzed, and quantified by standard curve using GC-MS set at the identical condition as for bulk sample analysis.

Wicoxon signed rank test was applied to compare the indoor pollutants' concentrations before and after evaporating essential oils, and Friedman test to examine whether the change of fungal or bacterial concentrations at different sampling periods.

3. Results

The effects of evaporating essential oils on indoor TVOCs concentrations in the testing spaces are shown in Fig. 1. The emissions of VOCs mostly occurred, both at home and office environment, during the first 20 min of initial evaporation of eucalyptus and tea tree oil. The emissions of TVOCs of lavender oil seemed to be slower than eucalyptus and tea tree oils, yet, also reaching steady state within 30–45 min, either at home or at office space.

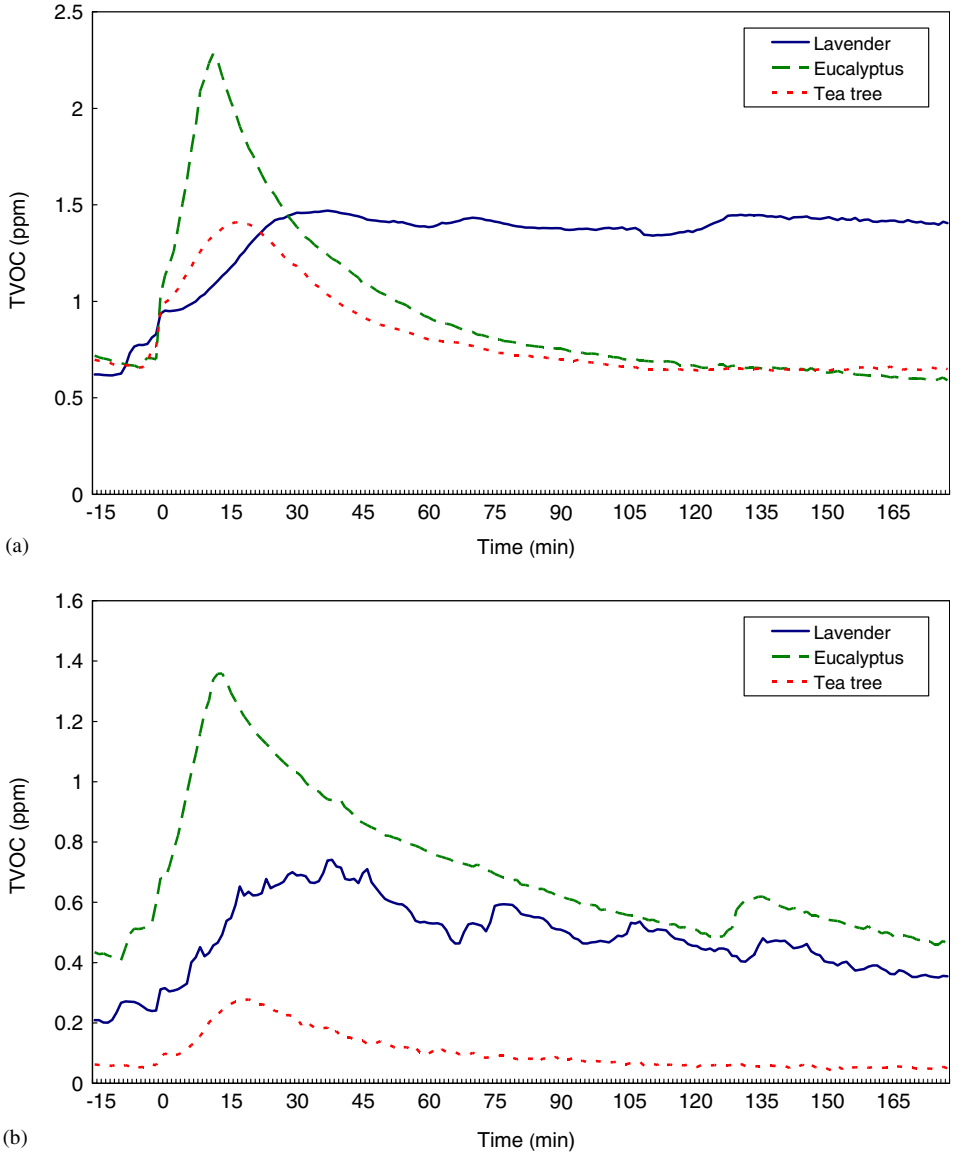

Fig. 1. The effects of evaporating essential oils on the indoor TVOCs concentrations in the testing spaces ((a) homes and (b) office).

The average concentrations of CO_2 and CO were significantly higher (CO_2: 543.21 ppm and CO: 1.48 ppm) in the testing periods, compared to background levels (CO_2: 435.47 and CO: 0.47 ppm) (Table 1). The levels of PM_{10} were observed to have a minor increase during the evaporating test, yet without statistical significance ($p = 0.053$). Indoor concentrations of total airborne bacteria appeared to decrease after evaporating lavender, eucalyptus, and tea tree oils regardless of being in office or home environment, and the lowest level was found at 30 min after evaporating when the highest levels of volatile components of these essential oils appeared to have emitted into the air (Fig. 2). Unfortunately, their effects on airborne bacteria did not seem to persist through time especially in the naturally ventilated home. Similar phenomenon was also observed with airborne fungi when airborne fungal levels began to decrease after the first 30 min.

The levels of indicator VOCs during the testing periods (180 min) were shown in Table 2. The level of linalool, a major composition of lavender oil, was between 496.04 and 986.90 $\mu g\,m^{-3}$, when evaporating lavender oil in the testing space. D-limonene was

Table 1
Levels of indoor air pollutants during background and evaporating periods

Pollutants (unit)	Cycles of testing	Average concentrations (SD)		*p*-value
		Background (30 min)	Evaporating period (180 min)	
CO (ppm)	15	0.47 (0.87)	1.48 (1.13)	<0.01
CO_2 (ppm)	18	435.47 (109.14)	543.21 (71.65)	<0.01
PM_{10} ($\mu g\,m^{-3}$)	17	2.42 (1.44)	2.45 (1.42)	0.05
TVOCs (ppm)	18	0.48 (0.30)	0.74 (0.45)	<0.01

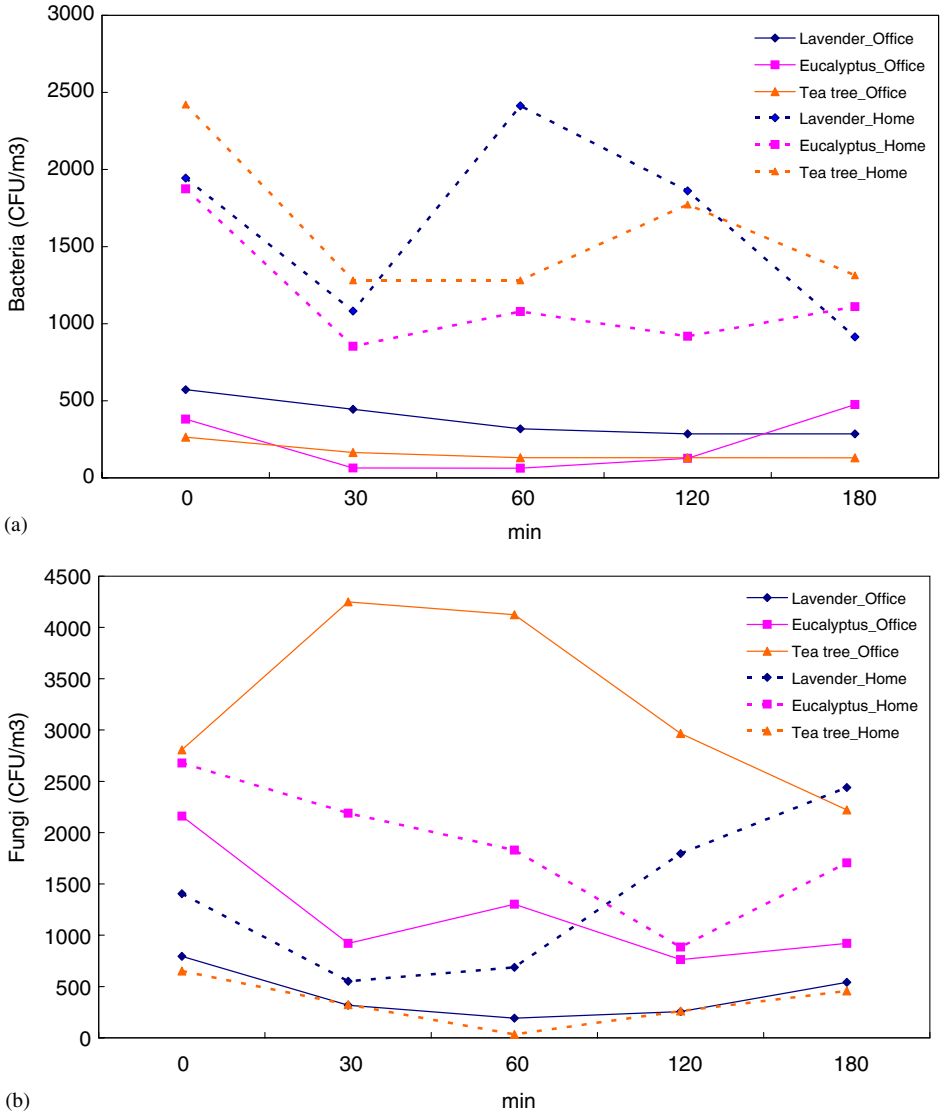

Fig. 2. The effects of evaporating essential oils on airborne bacteria (a) and fungi (b).

released from all three essential oils, and the concentrations were between 2.37 and 69.32 $\mu g\,m^{-3}$ in testing office and home, respectively. Terpinene-4-ol was also found in three essential oils, showing highest levels when evaporating tea tree oils (467.68–954.18 $\mu g\,m^{-3}$). Eucalyptol (1,8-cineole) was

Table 2
Levels of indicative volatile organic compounds during the testing periods (180 min)

Compounds ($\mu g\,m^{-3}$)	Office			Home		
	1st	2nd	3rd	1st	2nd	3rd
Lavender						
Linalool	533	496	604	987	779	594
D-limonene	12	6	2	32	21	28
Terpinene-4-ol	100	74	56	198	89	48
Eucalyptus						
Eucalyptol	523	1541	503	263	203	522
D-limonene	69	36	34	13	13	32
ρ-Cymene	58	46	—	14	16	28
Terpinene-4-ol	71	77	33	31	27	—
Tea tree						
Eucalyptol	94	97	42	80	53	34
D-limonene	23	19	6	3	5	—
ρ-Cymene	132	119	72	173	157	91
Terpinene-4-ol	882	903	623	954	840	468

a major compound in eucalyptus and tea tree oils, and the higher levels were observed when evaporating eucalyptus oils ($203.09–1540.62\,\mu g\,m^{-3}$). ρ-Cymene showed a strong presence both in eucalyptus and tea tree oils, and higher levels were found when evaporating the latter ($72.25–173.23\,\mu g\,m^{-3}$).

4. Discussion

Our finding suggests that most VOCs in the essential oils would emit into the air within the first 30 min, while the emission patterns varied in each evaporating test. The most likely rationale to justify these variations might be attributable to various burning temperatures associated with different candles. Combustion-related emissions products, including CO_2 and CO also significantly increased during the evaporating period as expected. Such a phenomenon might suggest the need of fresh air intake when evaporating essential oils using an incense evaporator with a burning candle. Compared to other claims, the anti-microbial activity of essential oils has been the one with more scientific evidences, and documentations for bioactivity of lavender, tea tree, and eucalyptus oils under diffusion or contact study-setting were available (Viljoen et al., 2003; Lis-Balchin and Hart, 1999; Hammer et al., 1999; Inouye et al., 2001; Pattnaik et al., 1997). Our study is, thus far, the first to demonstrate the effects of using essential oils on reducing airborne microbial levels. These results implied that the reduction of airborne microbes when evaporating essential oils could only be observed during the first 30–60 min when the highest levels of volatile components in these essential oils appeared to emit into the air. The effect, yet, did not seem to persist through, and was easily disturbed by outdoor sources and other contributions of fugal levels from indoor human activities. While benefits of using various essential oils have been advocated for commercial purpose, only a few studies in the literature have aimed to elucidate the specific effects of these essential oils, and the mechanisms of their bioactivities. The reported bioactivities of essential oils have included insecticidal activity, anti-microbial activity, effects on musculoskeletal system, neurological effects, blood pressure action, gastroprotective effect, sedative, and antispasmolytic actions (Lahlou, 2004). Yet, with increasing usage and exposure to essential oils and related fragrant compounds, concerns on clarifying more specifically their potential health and environmental impacts have arisen in recent decades. Meanwhile, a large quantity of VOCs with complex mixture is also likely to be emitted into indoor air when using essential oils and products containing rich fragrance. The major constituents of these three testing oils often include linalool, eucalyptol (1,8-cineole), D-limonene, ρ-cymene, γ-terpinene, and terpinene-4-ol-1 belong to the family of terpenes. Terpennoids are a group of unsaturated hydrocarbons and oxygen-containing compounds mainly emitting from plants in nature. Previous studies have indicated that these monoterpenes (hydrocarbons, alcohols, and ethers) with one or more unsaturated carbon–carbon bonds may easily interact with oxidants, such as ozone, hydroxyl and nitrate radicals, in general environments, and generate consequently a variety of secondary organic pollutants in gas and particle phase (Weschler, 2000). The oxidation products of terpenes, such as D-limonene, α-pinene, and linalool, have been characterized by atmospheric chemists to include a number of higher molecular weight oxidation products include aldehydes, ketones, organic aicds, and diacids (Grosjean et al., 1992; Reissell et al., 1999; Grosjean et al., 1993; Shu et al., 1997; Hakola et al., 1994). One major product derived from reaction between oxidants and terpenes is formaldehyde, and serial studies have shown O_3/terpene reactions are important sources of secondary indoor air pollutants including secondary hydroscopic organic aerosols (SOAs) which are mainly of sub-micron

particles (Sarwar et al., 2004; Iinuma et al., 2004). These oxidation products have attracted rising concerns as many of them seem to be more irritating than their precursors (Karlberg and Dooms-Goossens, 1997; Wolkoff et al., 1999; Wolkoff et al., 2000), and fine to ultra-fine particles are known to penetrate into lower respiratory system more easily. The concentration levels reported in this investigation can be of great importance as they may well be the first set of field concentrations for various terpenes measured during the evaporation of essential oils in general indoor environments. These data indicate that evaporating essential oils could be another hidden source of indoor terpenes, and deserve more attention for its potential impacts on indoor air quality, especially on the levels of secondary pollutants such as formaldehyde and SOAs.

Although, the scientific evidence regarding the effects of these aromatic compounds remains limited, they have been at least suggested to be sensitization agents (Buckley et al., 2003). Exposure to fragrance and essential oils from the air has also induced or worsened respiratory problems including decrease of pulmonary function and increase of chest tightness, wheezing and exacerbates asthma in susceptible subjects (Kumar et al., 1995; Millqvist et al., 1999; Millqvist and Lowhagen, 1996; Galdi et al., 2004). In addition, fragrances are also accounted for the cause to occupational asthma (Baur et al., 1999; Lessenger, 2001), and respiratory symptoms and other nonspecific symptoms in susceptible subjects triggered by exposure via airway and other sensory pathway (Millqvist et al., 1999), with many of them being similar to those described in multiple chemical sensitivity and sick building syndromes (Millqvist et al., 1999; Opiekun et al., 2003). Our investigation illustrates the range of concentrations that may potentially result from evaporating essential oils in a manner commonly employed by a great proportion of Taiwanese population. The findings warrant a need for further evaluation on health consequences of applying essentials in the above-discussed fashion.

Acknowledgments

The authors are in great debt to the building owners for their understanding and cooperation during the long process and sampling activities. We also thank our colleagues participating in the field investigations, and helping in the laboratory task. Taiwan National Science Council (NSC 93-2320-B-006-070) grants have in part, supported this study. It is to be noted that partial data reported in this work have appeared as preliminary results and were published in the proceedings of indoor air 2005.

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