Chemosphere 103 (2014) 205–211

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Impact of operating wood-burning fireplace ovens on indoor air quality

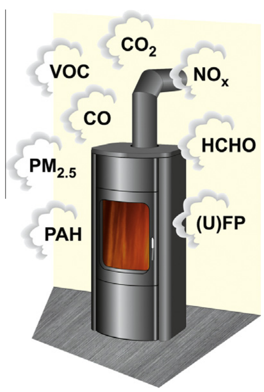
Tunga Salthammer *, Tobias Schripp, Sebastian Wientzek, Michael Wensing

Fraunhofer WKI, Department of Material Analysis and Indoor Chemistry, Bienroder Weg 54 E, 38108 Braunschweig, Germany

HIGHLIGHTS

- Wood-burning fireplaces are potential sources of indoor air contaminants.
- Especially the concentration of ultrafine particles increases during operation.
- The effects of NO_x, CO and CO_2 were comparatively small.
- In addition to the combustion process itself firelighters are a potential source for benzene.
- In some case increased concentrations of benzo[a]pyrene were measured.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 August 2013
Received in revised form 16 November 2013
Accepted 26 November 2013
Available online 22 December 2013

Keywords:
Fireplace oven
Wood combustion
Indoor air quality
Particles
Gaseous emissions
Guideline values

ABSTRACT

The use of combustion heat sources like wood-burning fireplaces has regained popularity in the past years due to increasing energy costs. While the outdoor emissions from wood ovens are strictly regulated in Germany, the indoor release of combustion products is rarely considered. Seven wood burning fireplaces were tested in private homes between November 2012 and March 2013. The indoor air quality was monitored before, during and after operation. The following parameters were measured: ultra-fine particles (5.6–560 nm), fine particles (0.3–20 μm), $PM_{2.5}$, NO_x, CO, CO_2, formaldehyde, acetaldehyde, volatile organic compounds (VOCs) and benzo[a]pyrene (BaP). Most ovens were significant sources of particulate matter. In some cases, an increase of benzene and BaP concentrations was observed in the indoor air.

The results illustrate that wood-burning fireplaces are potential sources of indoor air contaminants, especially ultra-fine particles. Under the aspect of lowering indoor air exchange rates and increasing the use of fuels with a net zero-carbon footprint, indoor combustion sources are an important topic for the future. With regards to consumer safety, product development and inspection should consider indoor air quality in addition to the present fire protection requirements.

1. Introduction

Wood-burning fireplaces have regained popularity in homes over the past years. These ovens create a cozy, warm ambience while offering an attractive lower cost, ecological alternative to other forms of heating. In times of increasing energy prices, wood-burning ovens can be competitive on running costs and conserve resources when compared to fossil fuels. Combustion of wood as a renewable resource is also close to climate-neutral in terms of carbon dioxide (CO_2), since in the ideal case only the CO_2 which was drawn in during the tree's growth and stored in the wood is released into the atmosphere again.

It is, however, natural that combustion takes place more or less incompletely and causes undesirable by-products to form. The more complex the combustion material is, the more difficult

* Corresponding author. Tel.: +49 531 2155 213; fax: +49 531 2155 200.
E-mail address: tunga.salthammer@wki.fraunhofer.de (T. Salthammer).

0045-6535/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.chemosphere.2013.11.067

the reaction process is. Natural gas can relatively easily be burned to produce carbon dioxide and water, but burning oil and coal in an environmentally friendly manner requires much more effort (Lackner et al., 2013). Wood and other kinds of biomass are among the oldest combustion materials but are also some of the most problematic. From a chemical standpoint, wood is a polymer of celluloses, polyoses and lignin with proportions of other minerals and extracts depending on the wood species (Fengel and Wegener, 1989). The heat energy from firewood (beech, oak, birch) is around 17–19 MJ kg^{-1}. Depending on how the oven is operated, set up and maintained, and the firewood itself, a wide range of other combustion products are released besides carbon dioxide and carbon monoxide (McDonald et al., 2000; Schauer et al., 2001; Hedberg et al., 2002; Shen and Gu, 2009). These particularly include the usual combustion products of the cellulose (Shen and Gu, 2009), aldehyde (Cerqueira et al., 2013) and particulate matter (Hedberg et al., 2002; Tissari et al., 2008). At high burn-off temperatures (<1200 °C), which however rarely occur in wood combustion, NO_x can form from atmospheric nitrogen. Low temperatures (<500 °C), in contrast, lead to de novo synthesis of aromatic compounds (Choudry and Hutzinger, 1983) and the formation of poly chlorinated dioxins/furans when chlorine is present (Salthammer et al., 1995).

It has generally always been the case that fire sources in rooms cause an elevated level of indoor air pollution. Moreover, a heat source might influence the air movement in a room (Ardkapan et al., 2014). Reports in the past have looked closely at the effects of sources such as gas burners (Wallace et al., 2008; Wallace and Ott, 2011), candles (Glytsos et al., 2010), incense sticks (Wang et al., 2007), kerosene ovens (Carteret et al., 2012), pizza ovens (Buonanno et al., 2010) and especially open fireplaces in homes (Lahiri and Ray, 2010). Publications were made 30 years ago concerning the influence of wood combustion on indoor air quality (Sexton et al., 1984). In more recent times, Noonan and colleagues have paid particular attention to the formation of $PM_{2.5}$ in indoor air when operating wood-burning fireplace ovens (Ward and Noonan, 2008; Noonan et al., 2012; McNamara et al., 2013). Carvalho et al. (2013) have studied the formation of ultrafine particles from wood-burning stoves.

With fine and ultra-fine particulate matter being increasingly in the focus of public discussion recently, the German Federal Environment Agency published a guidance value for evaluating fine particulate matter ($PM_{2.5}$ fraction) in indoor air of 25 μg m^{-3} (Salthammer, 2011). This directly concerns wood-burning fireplace ovens as potential sources of particles (Jalava et al., 2010). Consequently, WKI carried out a study with a total of seven test series in living rooms with wood-burning fireplace ovens. The results are presented in this paper and discussed with regard to current indoor air hygiene criteria. Another paper reports the effects of ethanol fireplaces on indoor air quality (Schripp et al., 2013).

2. Materials and methods

2.1. Selection of fireplaces

The effects of wood-burning fireplace ovens on indoor air quality were investigated on-site in private homes with such an oven. Seven households in detached houses in the greater Braunschweig area were involved in the investigations. Braunschweig is located in the south east part of Lower Saxony (52°23′N, 10°56′E). Table 1 shows details of the rooms and ovens examined. The air intake was from the air in the room in each case except for oven 3, which had an intake from the outdoor air. The investigations began in the 2012/2013 heating period. The test samples were taken right though into March 2013. In order to detect whether the fireplace was affecting the indoor air quality, it was necessary to take air samples before the oven was used as well as during use. Fine particulate matter ($PM_{2.5}$) and polycyclic aromatic hydrocarbons (PAH) are typical products of wood combustion, but they are also present in the outdoor air and can enter the building during ventilation. These parameters were therefore also measured in the outdoor air close to the building in order to make a comparison.

2.2. Instrumentation

Temperature (*T*) *and relative humidity* (*r.h.*)*:* Rotronic Hygrolog-D data logger at intervals of 60 s.

Air exchange rate (*ACH*)*:* Tracer gas method. The air was spiked with dinitrogen oxide (N_2O) and the concentration vs. time curve was recorded with a photoacoustic detector (INNOVA 1312) at 4.5 μm (2215 cm^{-1}). The air exchange was then determined as described in (VDI 4300-7, 2001).

Volatile organic compounds (VOCs): Collected on Carbotrap spiked with internal standards (6 l total volume with 150 ml min^{-1}). The sorbent tubes were preconditioned with nitrogen. Analysis was carried out on a J&W Scientific DB-5MS column (L = 60 m; I.D. = 0.25 mm; film = 0.25 μm) using a GC/MS system (Agilent 7890/5975C) equipped with a thermal desorption system (Markes Unity + Ultra 2 auto sampler). Identification was based on a probability-based matching (PBM) library search and analysis of retention data versus internal standards. Moreover, mass spectra

Table 1
Overview of the wood-burning ovens used in this study.

Name	Type	Operation	Nominal performance (kW)	Room volume (m^3)	ACH (h^{-1})	Type of wood	Ignition with
Oven 1	Wood-burning oven Dependent on room air	Closed	~6	~150	0.21	Birch/beech	Wood-burning oven firelighters
Oven 2	Wood-burning oven insert Dependent on room air	Closed	8.0	100	n.d.	Ash/oak	Waxed straw, pine soaked in turpentine
Oven 3	Wood-burning oven Independent of room air	Closed	6.0	110	0.27	Birch	Wood-burning oven firelighters
Oven 4	Wood-burning oven Dependent on room air	Closed	~6	140	n.d.	Beech/oak	Waxed wood shavings
Oven 5	Wood-burning oven Dependent on room air	Open	n.d.	110	n.d.	Beech	Waxed wood shavings
Oven 6	Wood-burning oven Dependent on room air	Closed	9.0	~200	n.d.	Beech	Wood chips
Oven 7	Wood-burning oven Dependent on room air	Closed	4.9	108	n.d.	Beech	Wood-burning oven firelighters

n.d. = not determined.