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# EFFECTS OF SMOKING LOCATIONS AND ROOM VENTILATION ON OCCUPANT EXPOSURE TO ENVIRONMENTAL TOBACCO SMOKE

# ผลของตำแหน่งสูบบุหรี่และการระบายอากาศของห้องต่อการได้รับควันบุหรี่จากสิ่งแวดล้อมของผู้อาศัย

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## Abstract

Non smoker exposure to second hand smoke is still of concern even though smoking free environments have been implemented in public places in Thailand. Thus, smokers have changed their behavior to smoke in their dwellings instead which could cause pollutant transfers from a smoking area to an adjacent non smoking area by air flows between zones. The objective of this study was to investigate relative magnitudes of environmental tobacco smoke (ETS) in a non smoking area that is adjacent to a smoking residential area. The study was also to demonstrate the effect of room ventilation rates on exposure levels of ETS. All experiments were conducted in a 4.5x3 $m^2$, studio-type apartment room with one bathroom. Smoking was occurred in either the bedroom or bathroom with the same rate of 10 cigarettes per day. There were 6 target pollutants under study included nicotine, phenol, 1-hexanol, nonanal, benzoic acid, and hexadecane. Pollutant monitoring using sorbent tubes was conducted for 24 hr in both the bedroom and bathroom simultaneously. Ventilation rates and air flows between zones were measured using tracer gas technique. Results show that smoking in the bathroom led to the increased concentration of nicotine of 0.54±0.76 $g/m^3$ in the bedroom without air conditioning and 1.78±0.30 $g/m^3$ with air conditioning. However, levels of the other organic pollutants were not varied in the same tendency due to emissions from the use of personal care products containing these compounds. An increase of the room ventilation rate by approximately 10 times resulted in reduction of the nicotine concentration in the smoking room.

**Keywords:** environmental tobacco smoke, nicotine, ventilation

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**บทคัดย่อ**

การได้รับควันบุหรี่มือสองของผู้ไม่สูบบุหรี่ยังคงเป็นปัญหาที่น่ากังวลอยู่ แม้ว่าประเทศไทยมีการบังคับใช้กฎหมายการห้ามสูบบุหรี่ในที่สาธารณะ ทำให้ผู้สูบบุหรี่จำนวนหนึ่งปรับเปลี่ยนพฤติกรรมเป็นการสูบบุหรี่ภายในที่พักอาศัยแทน ซึ่งทำให้มลพิษถูกพาจากพื้นที่สูบบุหรี่ไปยังห้องที่ไม่มีการสูบบุหรี่ซึ่งอยู่ติดกันได้เนื่องจากการไหลของอากาศระหว่างพื้นที่ งานวิจัยนี้จึงทำการตรวจวัดและเปรียบเทียบความเข้มข้นของมลพิษควันบุหรี่ในห้องพักอาศัยที่มีการสูบบุหรี่ในห้องหรือในบริเวณที่ติดกัน นอกจากนี้ ยังได้ศึกษาถึงผลของอัตราการระบายอากาศของห้องต่อระดับมลพิษควันบุหรี่ด้วย โดยทำการทดลองในอพาร์ทเมนต์ห้องสตูดิโอขนาด 4.5x3 ตร.ม. ที่มีห้องน้ำ 1 ห้องในตัว การสูบบุหรี่เกิดขึ้นในห้องนอน หรือในห้องน้ำด้วยอัตราการสูบที่เท่ากัน คือ 10 มวนต่อวัน สารมลพิษที่ศึกษา 6 ชนิด ได้แก่ นิโคติน ฟีนอล 1-เฮกซะนอล โนนานาล กรดเบนโซอิก และ เฮกซะเดเคน ทำการตรวจติดตามมลพิษโดยใช้หลอดดูดซับเป็นเวลา 24 ชม. ทั้งในห้องนอนและห้องน้ำพร้อมกัน ส่วนวิธีการวัดการระบายอากาศและการไหลของอากาศระหว่างพื้นที่ใช้เทคนิคก๊าซตามรอย ผลการทดลองพบว่า การสูบบุหรี่ในห้องน้ำทำให้ความเข้มข้นของนิโคตินในห้องนอนที่อยู่ติดกันเพิ่มขึ้นเป็น 0.54±0.76 มค.ก./ลบ.ม. เมื่อไม่เปิดเครื่องปรับอากาศ และเป็น 1.78±0.30 มค.ก./ลบ.ม. เมื่อเปิดเครื่องปรับอากาศ อย่างไรก็ดี แนวโน้มการเปลี่ยนแปลงความเข้มข้นของสารมลพิษอินทรีย์ชนิดอื่นไม่เป็นไปในทางเดียวกัน เนื่องจากการใช้ผลิตภัณฑ์ส่วนตัวที่มีส่วนประกอบของสารเคมีเหล่านี้ การเพิ่มอัตราการระบายอากาศของห้องประมาณ 10 เท่า มีผลให้ระดับของนิโคตินในห้องพักสูบบุหรี่ลดลง

**คำสำคัญ**: ควันบุหรี่จากสิ่งแวดล้อม, นิโคติน, การระบายอากาศ

## Introduction

World Health Organization reports that tobacco causes more than 5 million deaths worldwide each year[1]. The causing deaths are due to exposure to mainstream and sidestream cigarette smoke. Mainstream cigarette smoke is defined as "the material drawn from the mouth end of a cigarette during a puff", while sidestream smoke is "the material released directly into the air from the burning tip of the cigarette plus that which diffuses through the cigarette paper"[2]. Both mainstream smoke and sidestream smoke are described as environmental tobacco smoke (ETS). ETS consists several thousand chemical compounds, including inorganic gases, organic gases, and particulate matters. Thus, ETS can be a major contributor to indoor air quality problems. Some of the important constituents are CO, $CO_2$, $NO_x$, nicotine, phenol, nitrosamines, polycyclic aromatic hydrocarbons (PAHs), formaldehyde, acrolein, and hydrogen cyanide[3].

To prevent the morbidity and mortality, tobacco control policies have been implementing in many cities in the world. One of the control policies is smoke-free environments, which can help protecting non smokers from exposure to ETS. In Thailand, smoking has been banned in public places since 2006[4]. As a consequence, smokers are indirectly forced to smoke only in their dwellings such as houses or apartment rooms. Low- and middle-income people living in apartments or condominiums would prefer to smoke

in a bathroom rather than in a bedroom or main living area of where a smoking detector is normally installed. In a case of small indoor surface sinks for sorption of ETS constituents, air flows between zones could lead to migration of ETS from a smoking area, likes a bathroom, into a non smoking area, likes an adjacent bedroom. A degree of air transfers to the levels of ETS in the non smoking room is mainly dependent on air flow rates, which in turns are induced by natural or mechanical ventilation. Natural ventilation may result from infiltration through unintentional openings in the building envelope as well as opened windows or doors. Mechanical ventilation is provided by heating, ventilation, and air conditioning systems (HVAC) for non residential buildings, or by mechanical fans or air conditioning systems for residential buildings in tropical countries. However, no studies have been conducted to investigate the effects of smoking locations and air transfers between rooms on occupant exposure to ETS.

Thus, the objective of this study was to measure levels of ETS in an apartment room as smoking is occurred in different areas of the room. The air flow rates between room zones are also measured for analysis of their contribution to the ETS levels.

## Materials and Methods

### Field protocols

All experiments were conducted in a studio-type room in an apartment located in Mahasarakham province. The 4.5x3 $m^2$ room is divided into two areas, including a bedroom (main living area) and a bathroom. Figure 1 shows the room layout, smoking points, and air sampling points. The room contained a queen-size bed, a bookshelf, a closet, and other furniture. This room is considered as a smoking room because the room owner usually smokes in the main living area.

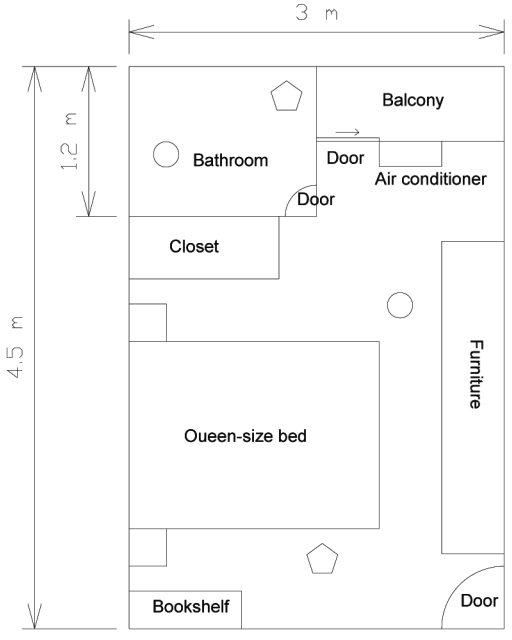


**Figure 1** A layout of the studied room showing placements of air samplers and ventilation-measuring device. Circle denotes a smoking point and pentagon denotes a air sampling point

This study was conducted with three settings. Firstly, the room had been vented for two days by leaving the back door opened and the wall-mount fan turned on. Smoking in the room had also been banned during this period (S1 = Venting period). Consequently, the occupant had started smoking in the bedroom consecutively for 10 cigarettes in 24 hr (S2= Bedroom-smoking period). Later, the room was vented for one day to remove the smoke residue. The last trial was conducted by the occupant smoking 10 cigarettes in the bathroom for another 24 hr (S3 = Bathroom-smoking period). For the bedroom- and bathroom-smoking periods, the glass back door of the room was kept opened, but the mosquito wire screen of the back door was closed at all times. All three setting were conducted with a room air conditioner turned off. The bathroom door was closed at all times, except when the occupant used the bathroom. The only room ventilation was due to a consequence of the infiltration through unintentional openings, the back door wire screen, and the opening frame of the bathroom. The room was occupied by one occupant

throughout the experiment. Air samples were collected simultaneously at two locations, i.e. the bedroom and bathroom, as shown in Figure 1. Sorbent tubes, containing two sections of 80/40 mg of XAD-4 resin (SKC Inc., USA) were used to collect ETS compounds for 24 hr for each setting. Personal sampling pumps (SKC Inc., USA) were used to draw air at a flow rate of 100 mL/min measured with a thermal mass flowmeter (TSI Inc., USA). The sorbent tubes were placed at ~1 m above the floor. Duplicate samples for each sampling point were collected to assure the reliability of sampling and analytical methods.

Later, the experiments for the three settings were repeated in the same room, but having the air conditioner turned on and the glass back door closed. In this scenario, the room ventilation was attributed mainly by the air conditioner. The field study was conducted during January to February 2011. The average room temperature and humidity were 22.8±1.3°C and 63.3±2.1% for the experiments without air conditioning and 24.1±0.1°C and 73.6±1.8% for the experiments with air conditioning. The outdoor temperature varied from 16 to 20°C for the experiments without air conditioning and from 17 to 36°C for the experiments with air conditioning.

### Air flow measurement and sampling analysis

The effective room ventilation and air flow rates between the bedroom and bathroom were measured using a constant injection technique with hexaflourobenzene (HFB) and octafluorotoluene (OFT) as tracer gases[5]. A Fickian diffusion model was used to design dimensions of the diffusion tubes. The tubes had the diffusion section of 4 mm-diameter and 40 mm-length. The diffusion tubes yielded the average emission rates of 6.97 mg/hr for HFB and 5.08 mg/hr for OFT at the room temperature of 24°C. For field sampling, diffusion tubes were weighed, and then installed in 250-mL flasks containing foam packaging peanuts. Two tubes of OFT were placed at two locations in the bedroom and one tube of HFB was placed in the bathroom at least 24 hr prior to sampling. Assuming that the room is well-mixed spaces at steady state, the effective room ventilation flow rate, $Q_{bed}$ ($m^3$/hr), is given by Equation (1):

$$Q_{bed} = \frac{F_{bed,OFT}}{C_{bed,OFT}} \quad (1)$$

Where $F_{bed,OFT}$ is OFT emission rate of the diffusion tubes placed in the bedroom (mg/hr) which was determined from weight

loss over the study interval; and $C_{bed,OFT}$ is OFT concentration in the bedroom (mg/m$^3$). A room ventilation flow rate can also be represented in terms of air exchange rate (AER). It is outdoor air flow entering the room envelope divided by the room volume (V, m$^3$), typically expressed in units of hr$^{-1}$. AER is given by Equation (2):

$$Q_{bath-bed} = (\frac{F_{bed,OFT}}{C_{bed,OFT}}) \times (\frac{C_{bed,HFB}}{C_{bath,HFB}}) \quad (2)$$

The air flow rate from the bathroom to the bedroom, $Q_{bath-bed}$ (m$^3$/hr), is given by Equation (3)[5]:

$$Q_{bath-bed} = (\frac{F_{bed,OFT}}{C_{bed,OFT}}) \times (\frac{C_{bed,HFB}}{C_{bath,HFB}}) \quad (3)$$

where $C_{bed,HFB}$ and $C_{bath,HFB}$ are HFB concentrations in the bedroom and bathroom, respectively (mg/m$^3$).

Sorbent tubes, containing two sections of 100/50 mg of 20/40 mesh size charcoal carbon (SKC Inc., USA), were used to collected HFB and OFT in the room air for ventilation measurements. HFB and OFT adsorbed in the charcoal tubes were desorbed with 1 mL of carbon disulfide (Merck & Co., Inc., USA). The vials were then sealed immediately and horizontally shaken for 24 hr. A 1-μL aliquot was then in jected on a gas chromatography-mass spectrometer (Shimadzu Co., Japan) with helium as the carrier gas for separate in a Rtx®5-ms fused silica column with 0.25-μm df and 30-m length (Restek Co., USA). The oven temperature was raised from 33°C to 60°C at 3°C/min and held for 4 min, and then raised to 80 °C at 5°C/min and held for 6 min and the mass spectrometer was operated on a scan mode.

For ETS analysis, XAD-4 resin was desorbed with 1 mL of 0.01% triethylamine in ethyl acetate. The vials were then sealed and placed in an ultrasonic bath for 30 min to aid desorption[6]. A 1-μL aliquot was then injected on a GC/MS. The oven temperature was raised from 80°C to 200°C at 20°C/min and held for 10 min and the mass spectrometer was operated on a scan mode. Six target pollutants were selected for this investigation based on the pretest of ETS monitoring using the gas sampling analysis as described previously. The pollutants included nicotine, phenol, 1-hexanol, nonanal, benzoic acid, and hexadecane. The method detection limits (MDL), which followed the US EPA guideline procedure (7), were 0.18, 0.78, 1.79, 1.41, 0.15, and 1.51 μg, respectively.

## Results and Discussions

### Effect of smoking locations

Levels of six organic gases were monitored for three periods: (S1) the room

was vented for two days and no smoking occurred; (S2) the occupant smoked in the bedroom; and (S3) the occupant smoked in the bathroom. Figure 2 shows comparison of the 24 hr average concentrations of the organic gases measured in the bedroom and bathroom when the air conditioner was off. Uncertainty range shown is based on ± one standard deviation from duplicate samples.

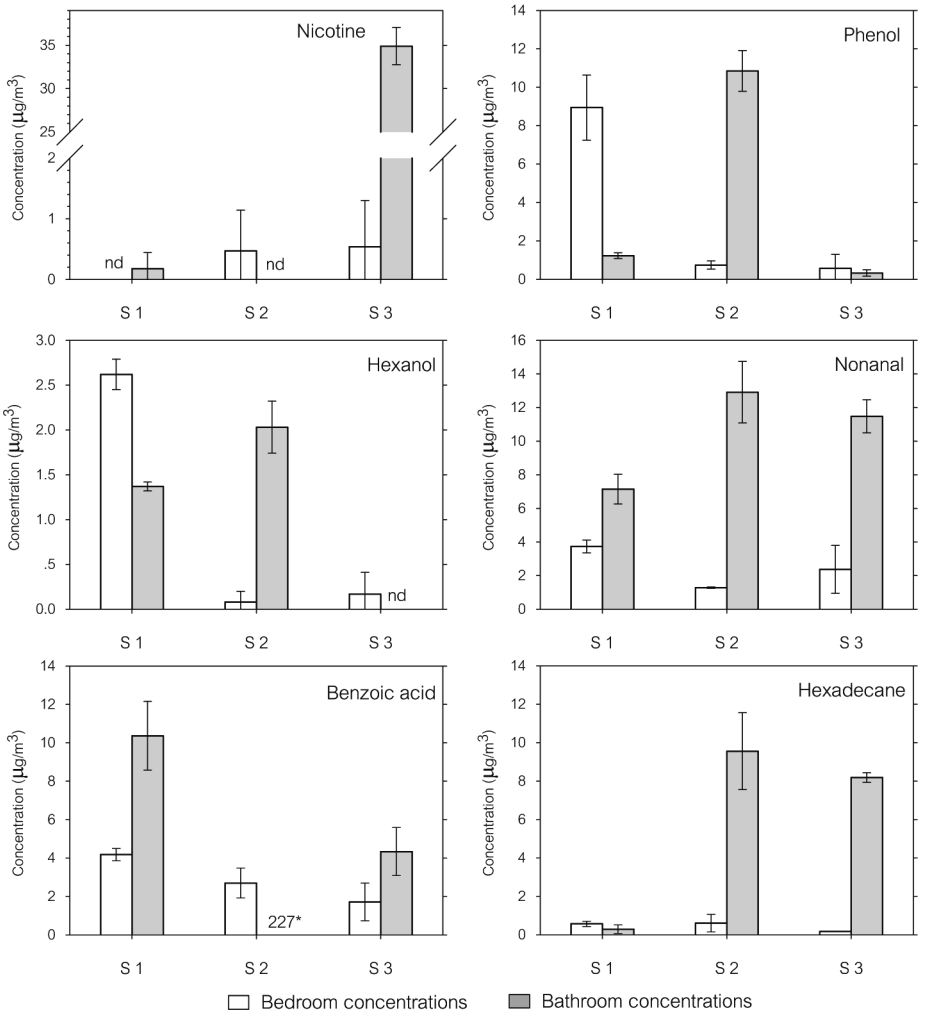


**Figure 2** Levels of organic gases in the bedroom and bathroom for three experimental settings when an air conditioner off. S1 = No smoking and venting room for two days. S2 = Smoking in the bedroom. S3 = Smoking in the bathroom. nd denotes not detected and "227*" represents the benzoic acid concentration of 227±31 μg/m$^3$ in the bathroom for S2

Considering levels of nicotine, a potential marker for ETS, shows that smoking in the bedroom area increased the nicotine concentration in the bedroom to 0.47 μg/m$^3$ as compared to non detectable background concentration (S1) with no air conditioning setting. In the bathroom-smoking trial, nicotine was detected in the bedroom with the concentration of 0.54 μg/m$^3$, while the bathroom concentration was found at the significantly higher concentration of 34.9 μg/m$^3$. Although both bedroom- and bathroom-smoking trials were conducted with the same smoking rate of 10 cigarettes per day, the bathroom size is 7.5 times smaller than the bedroom size. Thus, the smoking-room concentration for the bathroom was observed to be higher than that for the bigger-size bedroom. Note that the detected nicotine levels in this study are typical for homes with smokers[8]. Furthermore, the relatively closed values of 0.47 and 0.54 μg/m$^3$ for the two scenarios suggest that air transfers between the zones could contribute to an increased concentration in the living area next to the smoking area. Estimates of the air flows based on Equations(1) and (2) indicated that approximately 15±9% of the bedroom's ventilation was from the bathroom as shown in Table 1. Similarly, the experiment conducted in the room setting with air conditioning exhibited an increase of the nicotine concentration in the bedroom from non detectable to 1.78 μg/m$^3$ as the occupant smoked in the bathroom.

**Table 1** Measurements of room ventilation and air flow from the bathroom to bedroom.

| Trial | $Q_{bed}$ (m$^3$/h) | $Q_{bath\text{-}bed}$ (m$^3$/h) | Contribution of $Q_{bath\text{-}bed}$ to $Q_{bed}$ (%) |
|---|---|---|---|
| S1 | 64 | 12 | 19 |
| S2 | 61 | 11 | 18 |
| S3 | 62 | 4 | 7 |
| Average | | | 15±9 |

For other organic compounds, their background concentrations in the bedroom and bathroom varied from 0.29 to 10.4 μg/m$^3$ (Figure 2). Phenol, nonanal, and benzoic acid were detected at relatively high concentrations. These compounds are commonly used in personal care products other than in ETS constituents. Phenol is used in mouthwash, sore throat lozenges, sunscreen, skin lightening agents, and hair dyes[9]. Nonanal is found in essential oils, including rose, citrus, pine oils[10]. Benzoic acid is used as a food preservative for acidic food and beverage and used as

topical antiseptics and inhalant decongestants[11]. Note that the benzoic acid concentration in the bathroom for the S2 trial was detected at very high concentration of 22±31 μg/m$^3$. This may be due to the occupant activities using some specific products containing benzoic acid. When smoking was occurred in the bedroom, the concentrations of these organic compounds were not observed to increase as compared with the background concentrations. These organic compounds may not be a good tracer for estimation of ETS levels because they are also commonly found in the air of a typical indoor setting.

### Effect of room ventilation

Figure 3 shows levels of the organic compounds measured in the bedroom when the occupant smoked in the bedroom for two scenarios, i.e., an air conditioner off and an air conditioner on. In other words, the ETS monitoring was conducted with the different room ventilation means. When the air conditioner was off, ventilation occurred naturally through a variety of unintentional and intentional openings in the room envelope. An estimate of the room ventilation rate averaged from three experimental trials was 63±2 m$^3$/hr. When the air conditioner was turned on, the room ventilation was induced mainly by mechanical means. Moreover, pressure differences associated with indoor/outdoor temperature differences or room air circulation may cause infiltration to a certain degree. The estimated room ventilation rate was as high as 1070±532 m$^3$/hr. The relatively high variation may be partially resulted from the unstable outdoor air condition during the experimental periods.

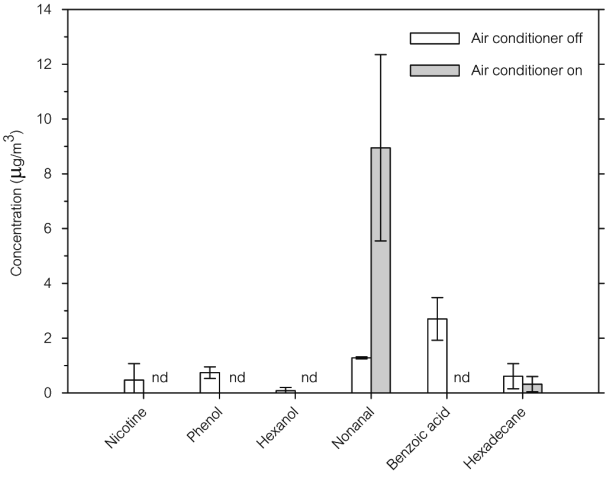


**Figure 3** Levels of organic compounds in the bedroom when smoking in the bedroom for two scenarios: air conditioner off and air conditioner on

As expected, the nicotine and other organic pollutants were detected at negligible or lower concentrations when the room ventilation rate was increased by 10 times, except for nonanal. This suggests that an increase of the room ventilation could remove or reduce the airborne contaminants that are initially released from the sources. However, it is technically desirable to control contaminants, likes ETS, at source before they are emitted to the room air. Ventilation for contaminant control may not be effective for non smoker exposure to the second hand smoke because of the mechanisms of sorption and desorption. Ventilation could initially remove ETS released to the room air. The ETS remainder would sorb onto indoor surfaces and be re-emitted at other times[12]. For nonanal, it was unclear why the concentration was observed relatively high when the air condition was turned on.

## Conclusions

This study demonstrated that air transfers between zones can play an important role in an increase of nicotine concentration in a non smoking area adjacent to a smoking area such as a studio room. Smoking in the bathroom led to the detected nicotine in the main living area at a relatively closed magnitude as the smoking occurred in the main living area. Thus, the occupants living in a non smoking area but adjacent to a smoking area are still pone to health risks associated with exposure to ETS. Although an increase of room ventilation rate exhibited the reduction of nicotine concentration in the living area, source control is still desirable for complete prevention of ETS exposure to non smokers.

## Acknowledgement

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