MASS CONCENTRATIONS OF RESPIRABLE PARTICULATE AND NICOTINE IN SEVEN SMOKER'S HOMES IN RURAL AREA OF TAIWAN

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*This study examines smoker's impact on his indoor air quality and his relative exposure to respirable particulate and nicotine. The daily indoor/outdoor respirable particulate and nicotine concentrations of seven smoker's homes were concurrently measured over a week in a rural area of Taiwan in the summer and the winter. Personal exposures to respirable particulate and nicotine of sixteen members from these seven families were also measured. Respirable particulate samples were collected on PVC filters by personal pumps with cyclone (flow rate = 1.9 l/min). Nicotine samples were actively collected on the teflon coated glass fiber filters impregnated with sodium bisulfate, extracted by ammoniated heptane, and analyzed by the gas chromatographic method. Indoor respirable particulate concentrations (44 to 107μ/m³) were higher than outdoor (27 to 92μ/m³) in both the summer and winter. In summer, the nicotine concentrations averaged at 0.7 ± 0.6μ/m³ indoors and about 0.5 ± 0.5μ/m³ for personal exposure. In winter, the nicotine concentrations averaged 0.7 ± 1.1μ/m³ indoors and about 0.4 ± 0.5μ/m³ for personal exposure. From correlation analysis, the indoor respirable particulates appeared to be generated from outdoor road dust rather from environmental tobacco smoke. (Chin J Public Health (Taipei): 1996; **15**(5): 425-433)*

Key words: environmental tobacco smoke, respirable particulates, nicotine, road dust, exposure assessment.

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INTRODUCTION

Environmental tobacco smoke (ETS) is a complex mixture of chemicals in gaseous as well as particulate phases.[1] Adverse health effects of ETS exposure are thought to be caused by chemicals in the particulate phase.[2] Many field studies have documented a significant influence of ETS on the suspended particulates concentrations indoors.[3-5] A smoker of one pack of cigarettes daily contributes about 20μ/m^3 to 24-hour indoor particle concentrations at his home.[7] Studies also found that individuals were commonly exposed to ETS in indoor settings like homes, workplaces and public buildings.[8] The contribution of ETS to indoor particulate levels and personal exposure to respirable particulate (RP) probably varied from country to country due to specific environmental conditions and activity patterns in each country. In this study, RP was defined as particulates which can pass a cyclone pre-selector with 50% cut-off size of 5μm. In Taiwan, the import of foreign cigarettes was legalized on January, 1987. The tobacco dose consumed among the general population increased from 28% in 1986 to 32% in 1990.[9] Due to the rising trend in cigarette consumption, ETS is expected to affect the indoor air quality significantly in Taiwan in the future. Thus, this study was conducted to determine whether mass concentrations of RP and nicotine indoors were significantly influenced by ETS in homes of smokers in the rural areas in Taiwan, where no major industrial sources of air pollutants existed. In addition, the environmental conditions and personal activity patterns which affect personal exposure to RP would be identified.

METHODS

Subjects and Sampling Sites

Seven families, with 16 persons, located in two communities of a farming area in central Taiwan were selected to participate in this study. Four of them were located in a community with 30,000 population (zone A), the other three were in a community with 100,000 population (zone B). There are relatively few industrial emissions in these two areas. These seven families are selected because they are neighboring roads and having routine smokers at homes. The father in each family is the only smoker (Table 1). The sampling was carried out in two seasons: August 11 to 17, 1991 (summer) and December 22 to 28, 1991 (winter). Each of the homes had one indoor RP sampler located in the living room and one outdoor sampler in the yard. In the winter sampling, four impactors which measured particles with diameters less than 10μm (PM10) were added inside and outside two homes and at two centrally located sites. One cascade impactor were also used to characterize the size distribution of indoor and outdoor particles by eight different particle sizes . Personal exposure to RP and nicotine were measured by samplers at participants' breathing zones. The indoor RP and nicotine samples were located at approximately 1.2 m above the floor in the living room.

Sampling Devices

The sampler assembly used to collect RP and nicotine is equipped with a 37-mm PVC filter (SKC Inc., USA, pore size = 5μm) ahead a sodium bisulfate treated glass fiber filter. An aluminum cyclone is connected to the filter assembly to allow the particulates with size less than 5μm to pass the inlet at the flow rate of 1.9 l/min. The SKC personal sampling pumps (Model 224-PCXR-7) were set to operate by batteries for 12 hours and by chargers for another 12 hours daily. The Harvard Impactors (ADE Inc., USA) were used to collect suspended particulates with size less than 10 μm at flow rate of 10 l/min. The 8-stage Anderson Ambient Cascade Impactor (Anderson Inc., USA) was used to differentiate particle sizes from 9 to 0.4μm at the flow rate of 28.3 l/min. The flow rates of all sampling pumps were all calibrated by a bubble meter before and after each sampling. (Gillian Instrument Corp., USA)

Table 1. The characteristics of the participants and homes

Participant	Relationship	Age	Occupation	Somking status	Sampling season
A11	Father	52	Retiree	Yes	Both season
A12	Mother	50	Chickenraiser	No	Both season
A21	Father	62	Farmer	Yes	Summer only
A22	Mother	63	Farmer	No	Summer only
A31	Father	47	Shopkeeper	Yes	Both season
A32	Mother	52	Retiree	Yes	Both season
A33	Son	16	Student	No	Both season
A41	Father	61	Retiree	Yes	Winter only
A42	Mother	47	Housekeeper	No	Winter only
*B11	Father	39	Private employer	Yes	Both season
B12	Mother	37	Public employer	No	Both season
B13	Son	10	Student	No	Both season
B21	Father	37	Plumber	Yes	Both season
B22	Mother	32	Barber	No	Both season
B31	Father	39	Postman	Yes	Both season
B32	Mother	37	Teacher	No	Both season

*the participant did not smoke inside his home during the sampling period

Sample Analysis

A balance with 1μg sensitivity (Sartorius Inc., Germany, Model M3p) was used to measure the weight of RP. The nicotine vapor collected on filters was analyzed by the procedures developed by Hammond and Leaderer.[10] (Hammond and Leaderer, 1987). Briefly, the nicotine was desorbed from the filters with water and ethanol. Sodium hydroxide was used to adjust the pH of the solution. Ammoniated heptane was used to extract nicotine. A small amount of heptane solution (3μl) was injected into gas chromatography with a nitrogen selective detector (HP 5890).

Housing Characteristics and Activity Pattern

All participants were asked to fill time-activity data sheets during the sampling period. The data sheets contained information regarding the participant's activity for 24 hours and the chances of encountering ETS. The housing characteristics of seven homes, including size, building materials, and ventilation type, were surveyed and measured by the interviewers. The tobacco butts in participant's living rooms were collected and counted daily.

Quality Control

Results of duplicate samples showed very good agreement between the duplicate pairs for RP and nicotine concentrations. The relative mean deviation was 23 ± 22% for 23 RP duplicate pairs in two seasons, and 23 ± 12% for 10 nicotine duplicate pairs in the summer. Since flow rates of all samples were found to be very stable before and after sampling, the variation in mass and nicotine concentrations is believed to be caused by weighing and analysis. The humidity variations of our weighing rooms may be one possible source of variation in mass concentrations for duplicate samples. For nicotine measurements, the variation may be caused by relatively unstable NPD in quantifying nicotine. Field blanks contained insignificant amount of nicotine. The recovery efficiency of nicotine by ammoniated heptane extraction was about 85%.

RESULTS

Winter indoor and outdoor RP concentrations were found to be significantly higher than summer concentrations. The seasonal concentration difference was about 2.5 times for indoor measurements (107.2μg/m^3 vs. 43.9μg/m^3) and about 3 times for outdoor measurements (91.5μg/m^3 vs. 26.4μg/m^3). In both seasons, the indoor and outdoor RP concentrations were about the same between zone A and zone B. The day-averaged butt counts in the living room in the summer were about 2 times higher than in the winter (11.1 vs. 6.1). However, the nicotine concentrations in the living room were about the same between two sampling seasons (Table 2). On the average, a smoker of one-third to one-half of pack of cigarettes daily contributed to about 16μg/m^3 to 24-hour indoor particulate concentrations in these seven smoker's homes.

Personal exposure to RP had similar seasonal and area variations as the fixed-site RP measurements. The non-smokers were exposed to a higher RP (mean = 103.5μg/m^3) in the winter than in the summer (mean = 49.6μg/m^3). In contrast, there was no significant seasonal difference in personal exposure to nicotine. In the summer sampling, the participants in zone A (mean = 66.5μg/m^3) were exposed to higher RP than those in zone B (mean = 31.9μg/m^3). However, such an area difference in RP exposure was not found in the winter sampling. By comparing personal exposure to RP with the fxed-site RP measurements house by house, we found that the personal exposure levels were more close to the RP concentrations indoors than outdoors (Table 2 & 3).

By comparing the average of the person-

Table 2. Indoor and outdoor concentrations of respirable particulate in two seasons (ug m-3)

	Summer					Winter				
#	No. of sample	Indoor mean(sd)	No. of sample	Outdoor mean(sd)	Butt count*	No. of sample	Indoor mean(sd)	No. of sample	Outdoor mean(sd)	Butt count*
A1	5	55.7(52.9)	5	16.7(9.1)	17.8	7	95.9(40.1)	7	86.4(41.2)	9.6
A2	4	32.0(11.0)			10.2					
A3	5	70.0(37.3)	5	32.2(11.1)	25.2	7	116.6(43.8)	7	87.6(40.8)	9.9
A4						7	1387.1(61.3)			8
B1	5	38.3(16.6)			0	7	96.9(29.3)	7	93.3(44.0)	0
B2	5	18.3(10.7)	5	19.5(10.8)	7.2	7	100.3(41.6)			1.6
B3	5	46.4(21.7)	5	38.3(18.9)	6	7	103.4(40.0)	7	98.7(41.4)	7.9
Mean	29	43.9(32.0)	20	26.7(15.0)	11.1	42	107.2(43.9)	28	91.5(39.6)	6.1

*Daily average butt counts over the sampling period

Table 3. Respirable particulate and nicotine concentrations (ug m-3) for 9 non-smokers in two seasons

	Summer				Winter			
#	No. of sample	RP mean(sd)	No. of sample	Nicotine mean(sd)	No. of sample	RP mean(sd)	No. of sample	Nicotine mean(sd)
A12	5	93.2(86.6)	5	0.2(0.1)	5	113.1(99.8)	4	0.3(0.3)
A22	5	67.5(25.0)	5	0.8(0.6)				
A32	5	62.6(28.1)	5	0.7(0.5)	7	111.7(41.5)	7	0.9(0.9)
A33	5	42.5(9.5)	4	0.4(0.3)	7	113.8(49.1)	7	0.3(0.5)
A42					6	81.4(49.0)	5	0.3(0.3)
B12	4	38.1(12.8)	5	0.2(0.3)	7	103.4(33.7)	7	0.1(0.1)
B13	5	30.8(16.9)	4	0.1(0.1)	7	110.6(51.8)	7	0.1(0.1)
B22	5	26.5(21.6)	5	0.4(0.2)	5	106.9(50.1)	6	0.4(0.2)
B32	5	33.3(25.0)	5	0.8(0.7)	7	87.6(43.5)	7	0.1(0.1)
Mean	39	49.6(25.5)	38	0.5(0.7)	51	103.5(44.5)	50	0.4(0.5)

al exposure to RP to the average of the fixed-site RP measurements day by day, we found a significant daily variation over the sampling period in both seasons. We also found that outdoor RP concentrations in the summer were all lower than 40μg/m^3. However, there was only one measurement with the concentration lower than 40μg/m^3 in the winter sampling season (Figure 1).

The activity patterns indicated that nine non-smokers spent an average of about 87% of their time indoors. Their time fraction of staying in the livingrooms, the place where ETS was generated in homes, was about 17-18% (Table 4). These results of activity survey also indicated that nonsmokers were most likely exposed to ETS at homes between 7 to 11 p.m. in a day.

Table 4. Summery of 9 non-smokers' activity pattern during the sampling periods(%)

Loaction	Summer	Winter
Living room	18%	17%
Kitchen	8%	9%
Bedroom	37%	37%
Workplace	15%	17%
Roadside	5%	8%
other	14%	12%
% of indoor time	86%	88%

The meteorological data for two sampling periods were obtained from a near-by observational station operated by the Taiwan National Meteorological Bureau. The temperature in the summer was about 10-20°C higher than in the winter. In the winter season, however, the atmospheric pressure was higher and the wind was stronger . There were four rainy days in summer sampling period but only one rainy day in the winter sampling period.

The particulate concentrations indoors and outdoors were apparently influenced by the particle size. Indoor RP concentrations were higher than outdoor, but outdoor PM10 concentrations were higher than indoors from the concurrent measurements in two homes in the winter season (Table 5). The results of measurements from the cascade impactor also indicated that indoor particulates had smaller particle sizes than the outdoor particulates. The mass median diameters (MMD) were about 3.3μm for indoor particulates and 4.7μm for outdoor particulates. More specifically, the indoor particulates relatively contained more small size particles than the outdoor particulates. For example, the mass fraction of particles with sizes between 0.4 to 0.7μm were 12.7% for indoor particulates and 8.8% for outdoor particulates (Table 6).

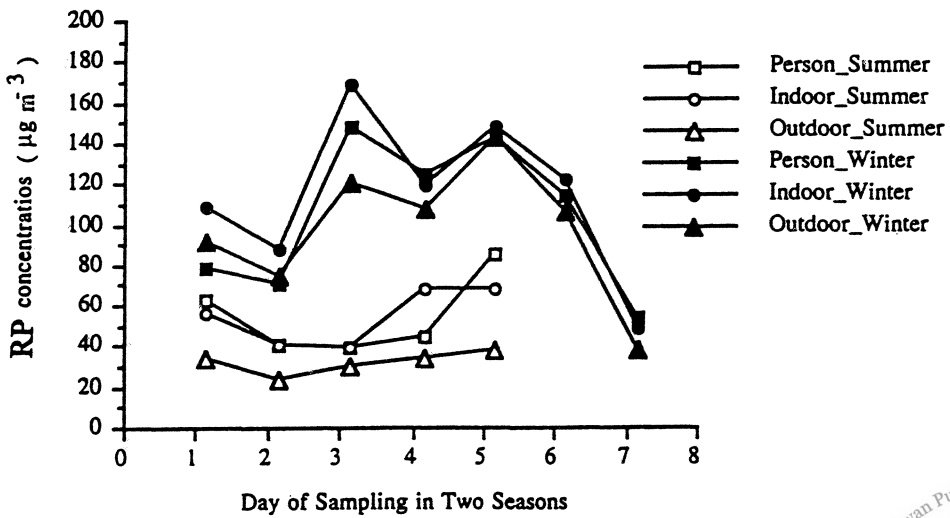

Fig. 1. Daily fiuctuaations of the averaging personal, outdoor, and indoor RP concentrations.

Table 5. Concurrently measured concentrations of PM10 and respirable particulate (ug m-3) in the winter

	HomeA1				HomeB2			
	Indoor		Outdoor		Indoor		Outdoor	
Date	RP	Pm10	RP	Pm10	RP	Pm10	RP	Pm10
12/22	73.1	77.4	83.6	86.2	87.5	152	87.5	*
12/23	62.2	91.7	94.8	113.7	41.7	79.7	57.5	111.6
12/24	147	160.9	159.8	166.6	139.5	163.5	140	203.4
12/25	109.4	137.3	74.5	139.8	138.5	154.7	*	186.7
12/26	130.1	167.1	142.2	183	142.6	189.9	141	195.5
12/27	130.8	143.5	99	196.4	96.7	128.5	106	145.4
12/28	40.4	83.8	37	*	55.6	64.3	32.2	35.6
Mean	99	123	86.6	147.6	100.3	133.2	93.3	146.2

*The sample is lost

Table 6. Size distribution of indoor and outdoor aerosol measured in central Taiwan in the winter

Particle diameter (um)	Indoor		Outdoor	
	Fraction(%)	Cumulative fraction(%)	Fraction(%)	Cumulative fraction(%)
>9.0	21.7	100	21.5	100
5.8-9.0	11.8	78.4	17.1	78.6
4.7-5.8	9.7	66.5	11.5	61.4
3.3-4.7	8.5	56.9	1.4	50
2.1-3.3	10.4	48.4	9.9	48.6
1.1-2.1	13.1	38	13.5	38.7
0.7-1.1	12.1	24.8	16.4	25.2
0.4-0.7	12.7	12.7	8.8	8.8
Mass median diameter	3.3um		4.7um	

DISCUSSIONS

Re-suspended road dust appeared to be an important source of outdoor RP in this studied area for the following reasons. Firstly, there were no significant industrial sources in this area. Secondly, the surface of both paved and unpaved roads was commonly covered by dust from farm fields or construction sites. During the daytime, road dust was re-suspended by heavy traffic on the road. The outdoor measurements were taken very close to the traffic routes in most case. Thirdly, the RP concentrations were particularly low in the rainy days. The outdoor RP concentrations were all lower than 40μg/m^3 in these rainy days. The road dust must have been dampened by the afternoon thunder storms in the summer sampling period and the only raining day in the winter. Unfortunately, the road dust and other emission sources, which affected the indoor RP concentrations directly, were not determined in this study due to the lack of information regarding the elements in the particulates.

A concurrent variation of RP concentrations between outdoor and indoor measurements was found upon looking at daily averaging RP concentrations in both seasons. (Figure 1) Such a concurrent concentration variation seemed not to be influenced by particle sizes since there was a moderate correlation between indoor and outdoor size-specific particle mass-

es measured by the 8-stage Anderson Impactors (r=0.55)(Table 6). These evidences indicated that the indoor RP concentrations were strongly influenced by the outdoor sources. However, the indoor RP concentrations and personal exposure to RP can also be partly attributable to ETS indoors for the following reasons. Firstly, the differences between concurrently measured indoor and RP concentrations were positively correlated with the ratios of the cigarette butts in the livingrooms divided by the volumes of livingrooms (r = 0.55). Secondly, the butt counts were correlated with indoor nicotine measurements (r = 0.49). Thirdly, there was a good correlation between RP and nicotine measurements in the study. In the summer, personal exposures to RP and nicotine were correlated with indoor RP and nicotine measurements, respectively (r = 0.55 and 0.59). In the winter, personal exposure to RP and the indoor RP measurements had an even higher correlation coefficient (r = 0.71). Fourthly, the indoor particulates with smaller particle sizes found in our study may come from combustion sources such as ETS. It has been reported that the diameter of ETS particulates ranged from 0.38 to 0.52μm.[11] As indicated in our study, the particulates with particle size between 0.4 to 0.7μm contributed relatively more weight to the indoor particulates than to the outdoor particulates. Lastly, there were no other major combustion sources, such as coal or wood burning in these homes.

The appropriate use of nicotine as an indicator of ETS has recently been questioned due to the supposedly quick decay of nicotine in the indoor environment.[12] However, the result indicated that nicotine was reasonably an acceptable indicator of ETS indoors considering the correlation between the indoor RP and nicotine concentrations. This might be due to smaller room space in the housing settings in Taiwan than that in western countries.

In this study, RP is defined as particles with size less than 5.0μm, which is different from the definition used by other researchers in the U.S. [13,14] However, the averaging indoor/outdoor RP concentrations and personal exposures measured in this study seemed to be slightly higher than the levels found in the U.S. cities. The amount of RP indoors contributed by ETS in these homes was about 2 to 3 times greater than that reported by Spengler et al.[15] The high outdoor RP levels, the small living space with heavy smokers, and the proximity to main traffic routes of the housing in Taiwan were three possible reasons for such differences.

Besides several research limitations discussed in the above, a relatively small number of observation is another major constraint of this study. It is likely that the data collected in this period may not represent the whole periods in both sampling seasons very well. However, the PM10 concentrations in this areas in the summer are significantly lower than other seasons according to recent air monitoring data reported by Taiwan Environmental Protection Agency. [16] The seasonal difference in outdoor RP concentrations may simply reflect variation in atmospheric dilution among seasons. Furthermore, the site may be representative of general urban communities in Taiwan. Therefore, we should be cautious about making generalization of this result to other urban areas.

CONCLUSION

The road dust can have a major impact on the indoor RP concentrations and personal RP exposures for seven families resided in an area without major industrial sources in central Taiwan. The ETS was found to have a minor effect on indoor RP concentrations in these seven smoker's homes. Pollution prevention programs to cut down the dust on the roads as well as campaigns to reduce smoking at homes are highly recommended in order to protect the ambient and indoor air quality. Moreover, a comprehensive study on the indoor air quality associated with ETS and road dust are still needed in order to fully estimate personal exposure to RP from these two sources in Taiwan.

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REFERENCES

1. National Research Council, Environmental tobacco smoke: measuring exposure and assessing health effect. Washington DC: National Academy Press, 1986.
2. Kuller L.H., Garfinkel L., and Correa P. et al., Contribution of passive smoking to respiratory cancer. Envion Health Perspect. 1986; **70**:57-69.
3. Spengler J.D., Dockery D.W., Turner W.A. , Wolfson J.M. and Ferris B.G., Long-term measurements of respirable sulfates and particles Inside and outside homes. Atmos Environ. 1991; **15**:23-30.
4. Repace J.L. and Lowrey A.H., Tobacco smoke, ventilation, and indoor air quality. Science 1980; **208**:464-472.
5. Burge H.A. and Hoyer M.E. , Indoor Air Quality. Appl Occup & Environ Hyg. 1990; **5**:84-93.
6. Leaderer B.P. and Hammond S.K., Evaluation of vapor-phase nicotine and respirable suspended particle mass as markers for environmental tobacco smoke. Environ Sci Technol.1991; **25**:770-777.
7. ibid. ref. 3.
8. Sexton K. and Hayward S.B., Source apportionment of indoor air pollution. Atmos Environ. 1987; **21**:407-418.
9. Taiwan Tobacco & Wine Monoply Bureau, Report on tobacco and wine consumption in Taiwan. Taipei, Taiwan: Taiwan Tobacco & Wine Monoply Bureau, 1991.
10. Hammond S.K., Leaderer B.P., Boche A.C. and Schenker M., Collection and analysis of nicotine as a marker for environmental tobacco smoke. Atmos Environ. 1987; **21**:457-62.
11. Hinds W.C., Size characteristics of cigarettes smoke. Am Ind Hyg Assoc J. 1978; **39**:48-54.
12. Heavner D.L., Ogden M.W. and Nelson P.R., Multisorbent thermal desorption/gas chromatography/mass selective method for the determination of target volatile organic compounds in indoor air. Environ Sci Technol. 1992; **26**:1737-1746.
13. ibid. ref. 3.
14. ibid. ref. 6.
15. ibid. ref 3.
16. Chan CC, Hwang JS. Selling the Blue Skies: Some Reflections on Air Pollution Fee Policy in Taiwan. J Chin Inst Environ Eng. 1996; **6(3)**.

臺灣鄉村地區七個抽煙家庭呼吸性懸浮微粒及尼古丁濃度評估

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本研究是抽煙者對家庭內空氣品質及其家人暴露於呼吸性微粒與尼古丁的影響，1991年夏季及冬季在臺灣鄉村地區，選取七個抽煙家庭每天測量呼吸性微粒及尼古丁濃度，各為期一個星期。從這七個家庭中又找出14個人做抽煙家庭呼吸性微粒及尼古丁濃度暴露量評估。呼吸性微粒是利用以旋風式集塵器為採樣頭的個人呼吸採樣幫浦 (流量為1.9 l/min) 收集在聚氯乙烯濾紙，而尼古丁是利用有玻璃纖維的鐵氟龍濾紙裱敷硫酸氫鈉加以收集，經氨化庚烷萃取後，以氣相層析儀-氮磷偵測器分析。研究結果顯示兩季的室內呼吸性微粒濃度 (44-107 μg/m³) 都比室外 (27-92 μg/m³) 高，夏季室內尼古丁濃度平均為0.7±0.6 μg/m³，個人尼古丁暴露量則為0.5±0.5 μg/m³，冬季室內尼古丁濃度平均為0.7 ± 1.1 μg/m³，個人尼古丁暴露量則為0.4 ± 0.5 μg/m³。相關性分析顯示，室內呼吸性微粒是趨向由室外道路粉塵產生而較少來自二手煙。(中華衛誌 1996；15(5)：425-433)

關鍵字：二手煙，呼吸性微粒，尼古丁，道路粉塵，暴露評估。

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