대한위생학회지. 제15권 제2호(2000)
Korean J. Sanitation. Vol. 15, No. 2, pp10~17(2000)

시간활동도를 이용한 이산화질소 개인노출 예측
- 한국의 서울과 호주의 브리스베인의 비교 연구 -

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Estimation of Personal Exposure on Nitrogen Dioxide Using Time Activity
- Comparative Study between Seoul, Korea and Brisbane, Australia -

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Abstract

현대 생활에서 대부분의 사람들은 90%이상을 실내(가정, 일반사무실, 실내작업장, 공공건물, 지하시설물, 상가, 음식점, 자동차, 지하철 등)에서 생활하기 때문에 실내공기질(indoor air quality)은 개인이 오염물질에 노출되는 주요한 요인이다. 이산화질소(NO_2)는 고온의 연소과정에서 발생되는 부산물로써 차량, 발전소와 산업장 등에서 발생되고 있다. 실내에서 이산화질소의 농도는 가스레인지, 케로센(kerosene) 난방기, 흡연에 주로 영향을 받는다. NO_2는 호흡기 증상과 관련된 각종 질환을 유발시키는 것으로 보고되고 있다. 본 연구는 한국의 서울에서 직장인 95명의 시간활동도가 조사되었으며, 호주 브리스베인에서 직장인 57명의 시간활동도와 동시에 각 가정의 실내·외 및 직장의 NO_2 농도를 측정하였다. 또한 개인 NO_2 노출이 측정되었다. 대부분의 사람들은 실내에서 많은 시간을 보내기 때문에 시간가중 평균 모델을 이용하여 개인 NO_2 노출을 예상하였으며, 예상된 노출과 측정된 노출정도를 비교하였다. 그리고 Monte-Carlo 시뮬레이션을 이용하여 각 도시의 빈도분포를 예상하였다. 본 연구의 결과를 보면 다음과 같다.

1. 서울의 95명의 직장인들은 실내에서 약 83.8%의 시간을 보냈으며, 브리스베인의 57명의 직장인들은 실내에서 약 88.3%의 시간을 보냈다.
2. 브리스베인에서 측정된 실내의 NO_2 평균농도는 10.5ppb(±5.6), 실외의 NO_2 평균농도는 14.5ppb(±5.8), 직장에서의 NO_2 평균농도는 18.2ppb(±5.0)였다. 개인의 NO_2 노출은 평균 15.0ppb(±5.2)였다. 개인의 NO_2 노출은 실외의 NO_2 농도(r=0.42)보다 실내의 NO_2 농도(r=0.49)에 상관성이 더 높았다.
3. 시간 가중치 모델을 이용한 개인 NO_2 노출은 측정된 개인 NO_2 노출과 통계학적으로 상관성을 가지고 있었다 (r=0.58). 예측된 개인 NO_2 노출은 측정된 NO_2 노출보다 낮게 나타났으며, 이것은 출퇴근 등에 의한 교통의 이동에 따른 노출 때문인 것으로 생각되었다.
4. NO_2 농도 분포를 log-normal 분포, 시간활동도를 Normal 분포로 가정하고 Monte-Carlo 시뮬레이션을 했을 때 서울의 직장인의 개인 노출은 평균 36.7ppb(±10.9)였으며, 브리스베인의 직장인의 개인 노출은 평균 13.7ppb(±4.1)였다.

I. Introduction

Nitrogen dioxide(NO_2) is a by-product of high temperature fossil fuel combustion. Various anthropogenic indoor and outdoor combustion sources make the gas one of the most ubiquitous pollutants in urban environment.[1] Despite of wide distribution of sources, indoor NO_2 concentration is the dominant risk factor to personal exposure. Individuals were found to spend about 90% of their days indoors and about two-thirds of the day inside their homes.[2]

Nitrogen dioxide is a corrosive and highly oxidizing gas with a characteristic pungent odor which has been described as stinging, suffocating and irritating. A variety of human experimental studies under controlled conditions that may increase airway responsiveness.[3] Some chamber studies with volunteers have shown a small effect on airway responsiveness in asthmatics exposed at NO_2 concentrations similar to near home combustion appliances.[4,5]

The presence of a gas range has been identified as one of the major factors contributing to indoor and personal NO_2 exposures. Significantly higher NO_2 exposures were 34.8ppb and 20.5ppb in homes with and without gas ranges, respectively.[6] The use of a gas range provided a mean indoor/outdoor(I/O) NO_2 ratio of 1.19, compared with 0.69 for those homes without gas ranges.

Personal exposure is defined as the contact between a pollutant and the personal receptor. Exposure assessments are used to define the magnitude and duration of exposure to individuals and populations. Personal exposure to NO_2 has not been characterized in Korea, thought the usage of gas range is prevalent. Since most people spend over 80% of their time indoors, personal exposure can be approximated as the time-weighted average of micro-environmental concentrations.

Since certain human activities stand out as higher exposure, studies of human activity patterns have recently taken on increased emphasis.[7,8] In this study, time activities of 95 and 57 office workers in Seoul, Korea and in Brisbane, Australia were investigated with personal NO_2 exposures using passive sampler, respectively.

The purpose of this study was to estimate the personal NO_2 exposure using time weighted average model. Estimated personal NO_2 exposures were compared with measured personal NO_2 exposures. From frequency distribution of measured NO_2 concentration, the estimation of NO_2 exposure of office workers was simulated using time weighted average model.

Table 1. Table of time activity

	Indoor			Outdoor			Trans-portation
	Home	Office	Other	Near home	Near Office	Other	
6:00-6:29 AM							
6:30-6:59							
· ·							
11:30-11:59							
12:00-1:00 PM							

Ⅱ. Methods

The time activity of 95 office workers and 57 office workers was measured during 1-day period in October 1999 in Seoul, Korea and in June 1999 in Brisbane, Australia. Participants filled out an activity diary about their homes and their surroundings during the course of the study (Table 1). The activity diary consisted of half-hour time bands during the daytime and of one-hour time bands form midnight to 6 a.m. During 1-day study period, participants were asked to report in this diary whether they were indoors at home, work or elsewhere; outdoors at home work or elsewhere; or in transit in any form of motor vehicle or public transportation.

NO_2 concentrations and personal NO_2 exposures of residential indoor, residential outdoor and workplace indoor were measured from six offices located in Brisbane, Australia. In Seoul, Korea, the residential indoor, outdoor and workplace NO_2 concentrations, and personal NO_2 exposures measured by Levy et.al. were used.

Passive filter badges were utilized for all NO_2 measurements. The filter badges are small (5x4x1 cm) and light weight (15 g), and they do not involve pumps and other equipment.[9] The filter badges absorb NO_2 on a triethanolamine solution on a cellulose fiber filter12. The use of a mass transfer coefficient of 0.10 cm/sec results in a measurement error of under 20%.[10] Duplicates for filter badge were deployed once a week to ensure the integrity the data. The exposed NO_2 badges were analyzed with a spectrophotometer (Beckman DU 640).

Personal exposure can be approximately estimated as the time-weighted average of micro-environmental concentration. Although not all environments were measured in this study, personal NO_2 exposure was estimated using indoor home exposure, workplace exposure and outdoor home exposure according to equation (1):

$$P_i = (IH_I \cdot I_i + OH_I \cdot O_i + WI_I \cdot W_i) / (IH_I + OH_I + WI_I) \quad (1)$$

Where, P_i= estimated time-weighted average personal NO_2 exposure for participant i, IH_I= number of hours spent inside the home for participant i during sampling period, OH_I= number of hours spent outside the home for participant i during sampling period, WI_I= number of hours spent inside the office for participant i during sampling period, I_i= measured average indoor NO_2 concentration for participant i, O_i= measured average outdoor NO_2 concentration for participant i, W_i= measured average office NO_2 concentration for participant I.

The personal exposure from the equation (1) might be significantly lower than the measured personal exposure, because not all microenvironmentals were measured. Using @Risk software program(Palisade Co.), personal NO_2 exposure were simulated by equation (1) from frequent distribution of measured NO_2 concentrations.[11]

Ⅲ. Results and Discussion

1. Analysis of time activity

A total of 95 office workers was recruited one organization in Seoul. Mean age of participants was 42.1(±7.6). The number of male and female were 72 and 23 respectively. In Brisbane, 57 office workers were recruited in six organizations. Mean age of participants was 39(±9.1). The number of male and female were 50 and 7 respectively.

Time activities of 95 workers in Seoul and 57 workers in Brisbane were compared in Table 2. Fraction of seven environments by the time of the day in Seoul was shown in Figure 1. Fraction of indoor, outdoor and transportation by

Table 2. Fraction of time in Brisbane, Australia and Seoul, Korea

		Indoor			Outdoor			Transportation
		Home	Office	Other	Near home	Near Office	Other	
Brisbane, Australia (57 workers)	Total hours	757.2	403.4	65.6	15.3	27.8	15.0	105.0
	Mean hours	13.1 (±4.9)	6.9 (±3.0)	1.2 (±1.5)	0.3 (±0.3)	0.5 (±0.6)	0.3 (±0.5)	1.7 (±0.9)
	%	54.5	29.1	4.7	1.1	2.0	1.0	7.6
	Total %	88.3			4.1			7.6
Seoul, Korea (95 workers)	Total hours	1130.5	702.3	71.3	50.0	114.5	58.5	146.0
	Mean hours	11.9 (±2.9)	7.4 (±3.5)	0.8 (±1.4)	0.5 (±0.8)	1.2 (±1.8)	0.6 (±1.4)	1.5 (±1.3)
	%	49.7	30.9	3.1	2.2	5.0	2.6	6.4
	Total %	83.8			9.8			6.4

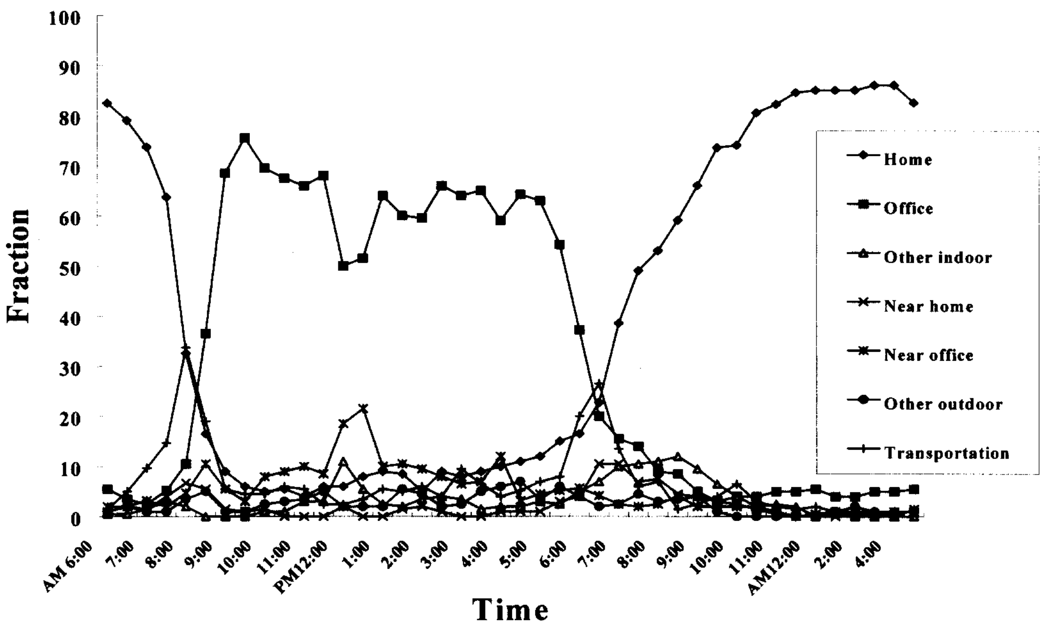

Figure 1. Fraction of seven environments by time of the day in Seoul, Korea.

the time of the day in Seoul was shown in Figure 2.

Office workers in Seoul spent their more time in office, comparing with workers in Brisbane. In transportation, workers in Brisbane spent their time rather than those in Seoul. It was considered as developed public traffic system in Seoul. Most office workers in Seoul and Brisbane were found to spend their times indoors above 90% and about one-half of the day inside their homes. Therefore, personal exposure of NO_2 could be affected by indoor NO_2 concentration.[12,13)]

Ninety-five participants in Seoul completed an

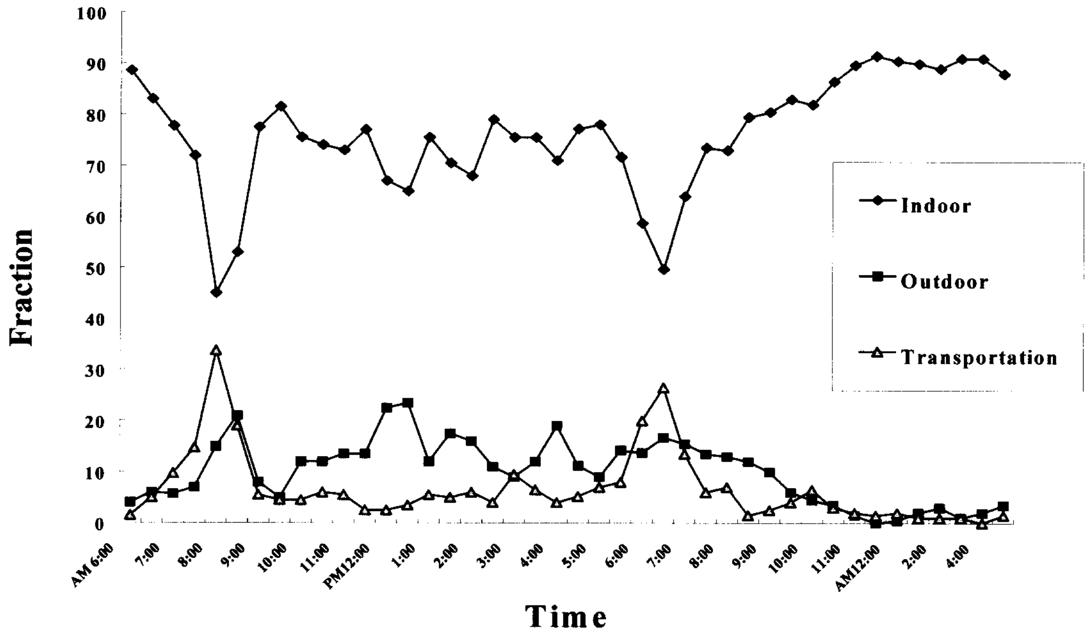

Figure 2. Fraction of indoor, outdoor, and transportation by time of the day in Seoul, Korea.

activity diary during the sampling period. The participants spent majority of their time indoors. Fraction of total indoor time was 83.8%. Participants spent 49.7% of their time in homes. Participants stayed inside of the workplace 30.9%. Fraction of total outdoor time was 9.8%. Transportation time accounted for 6.4%. Fifty-five participants in Brisbane completed an activity diary during the sampling period. The participants spent majority of their time indoors. Total indoor time was 88%. Mean time that participants spent in their homes was 54%. Participants stayed inside of the workplace for 29%. Total outdoor time was 4%. About half of the outdoor time was spent near the workplace. Transportation time accounted for 7.7%.

2. Measurement of NO_2 concentrations and personal NO_2 exposure

The NO_2 concentrations and the mean I/O ratio in Seoul and Brisbane in winter are shown in Table 3. As for those in Seoul, data measured by Levy et al[6] were used. The NO_2 concentrations both indoor and outdoor in Seoul were higher than those in Brisbane, though NO_2 concentrations were not measured for same

Table 3. Mean and standard deviation of NO_2 measurements(ppb)

City and Country	Indoor	Outdoor	Office	Personal	I/O ratio
Seoul, Korea*	43.2±14.8 (n=31)	52.2±20.0 (n=33)	25.0±16.1 (n=7)	47.9±15.5 (n=30)	1.0±0.5
Brisbane, Australia	10.5±5.6 (n=57)	14.5±5.8 (n=57)	18.2±5.0 (n=57)	15.0±5.2 (n=57)	0.8±0.6

* Levy et al. 1998[6].

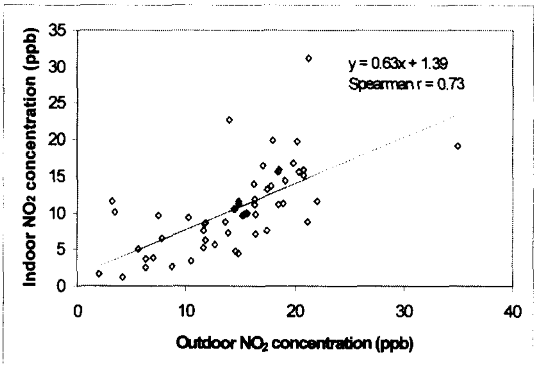

Figure 3. Relationship between indoor and outdoor NO_2 measurements in Brisbane, Australia.

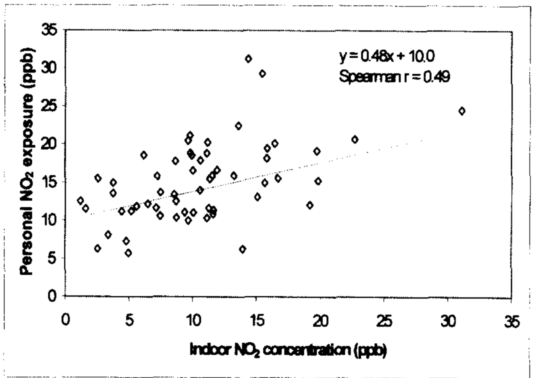

Figure 4. Relationship between personal and indoor NO_2 measurements in Brisbane, Australia.

period in both Seoul and Brisbane.

Indoor NO_2 concentrations were correlated with outdoor NO_2 concentrations, as shown in Figure 3. The Spearman correlation coefficient was 0.73. Personal exposures were correlated more strongly with indoor NO_2 concentrations than with outdoor NO_2 concentrations, as shown in Figures 4. The Spearman correlation coefficient was 0.49 for indoor concentrations, compared with 0.42 for outdoor concentrations.

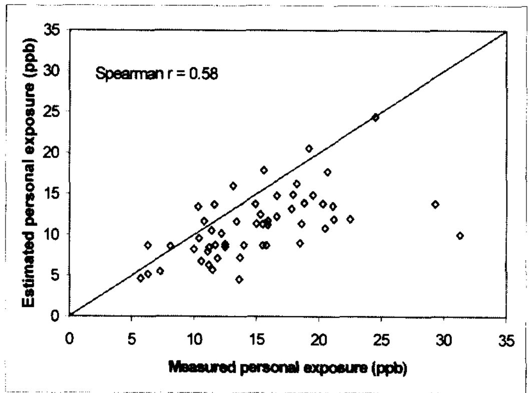

Figure 5. Association between measured personal NO_2 exposure and estimated personal exposure by microenvironmental model in Brisbane, Australia.

3. Estimation of NO_2 exposure

Since most people spent their time indoors, personal NO_2 exposure could be estimated with combination time activity and NO_2 concentrations measured in indoor, outdoor, and workplace using equation (1). This time-weighted average would omit transportation or time spent in other indoor and outdoor environments, and would contain some errors in workplace exposures where participants were from multiple workplaces or extremely large workplaces. The estimated personal NO_2 exposure was significantly associated with the measured personal exposure with a Spearman correlation coefficient of 0.58, as shown in Figure 5. The estimated personal NO_2 exposure of 11.2±4.0ppb was significantly lower than the measured personal exposure of 15.2±5.3ppb (paired t-test, $p<0.001$). Therefore differences between estimated personal NO_2 concentration and measured personal NO_2 concentration were considered as mainly transportation part, as shown in Figure 2. Our findings suggest a need of exposure assessment during transportation for the construction of an accurate personal NO_2 exposure model.

4. Frequency distribution using Monte-Carlo simulation

Using the time weighted average model, Monte-Carlo simulation was operated. Generally pollutants concentrations are log-normal distribution.[11] Assuming the NO_2 concentrations of indoor, outdoor and workplace were distributed as log-normal and time activity patterns were normal distribution, personal NO_2 exposures were estimated in Seoul and Brisbane, respectively, as shown in Table 4 and Figure 6.

Table 4. Personal NO_2 exposure (ppb) by Monte-Carlo simulation

	Mean	Min	Max
Seoul	36.7(±10.9)	9.6	87.8
Brisbane	13.7(±4.1)	2.4	54.8

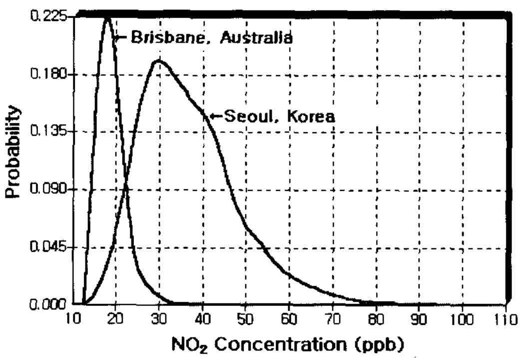

Figure 6. Monte-Carlo simulation of personal NO_2 exposure by the time weighted average model.

Ⅳ. Conclusions

This study was carried out to estimate the personal NO_2 exposure using simple time weighted average model, comparing the time activity pattern and measured NO_2 concentrations in Seoul, Korea and in Brisbane, Australia. The results of this study were as follows ;

1. Spent times in indoor were 88.3% and 83.8% in Seoul, Korea and in Brisbane, Australia respectively.
2. Mean indoor and outdoor NO_2 concentrations, and mean personal NO_2 exposure were 10.5ppb(±5.6), 14.5ppb(±5.8) and 18.2ppb(±5.0) respectively. Personal exposures were correlated more strongly with indoor NO_2 concentrations (r=0.49) than with outdoor NO_2 concentrations (r=0.42).
3. Time weighted average model could be used to estimate the personal NO_2 exposure. Estimated personal NO_2 exposure was significantly associated with the measured personal exposure with a Spearman correlation coefficient of 0.58.
4. Estimated personal NO_2 exposure of 11.2ppb (±4.0) was significantly lower than the measured personal exposure of 15.2ppb(±5.3). Difference between estimated and measured personal NO_2 exposures could be considered as another factor like transportation.
5. Since most people spend their times in indoor, microenvironmental model could be used to estimate the personal NO_2 exposure. Assuming the NO_2 concentration is log-normal distribution, personal NO_2 exposures were simulated. Simulated personal mean NO_2 exposures were 36.7ppb(±10.9) and 13.7ppb(±4.1) in Seoul and in Brisbane, respectively.

Acknowledgements

This study was partially supported by a QUT researcher development grant and a Commonwealth Government of Australia-Korea Fellowship.

References

1. Lee, K., Levy, J.I., Yanagisawa, Y. and Spengler, J.D.: The Boston residential nitrogen dioxide characterization study : classification and prediction of indoor NO_2 exposure, Journal of the Air & Waste Management Association, 48, 736-742, 1998.
2. USEPA : Exposure Factors Handbook I, General Factors, EPA/600/P-95/002Fa, 1997.
3. World Health Organization (WHO). Air Quality Guidelines for Europe. European Series No. 23. WHO : Copenhagen, Denmark. 297-310, 1987.
4. Bauer, M.A., Utell, M.J., Morrow, P.E., Speers, D.M. and Gibb, H.P.: Inhalation of 0.3 ppm nitrogen dioxide potentiates exercise-induced bronchospasm in asthmatics, Am.Rev.Respir. Dis. 134, 1203-1208, 1986.
5. Mohensin, V .: Airway responses to nitrogen dioxide in asthmatic subjects J. Toxicol. & Environ. Health, 22, 371-380, 1987.
6. Levy, J.I., et al.: Impact of residential nitrogen dioxide exposure on personal exposure: An international study, Journal of the Air & Waste Management Association, 48, 553-560, 1998.
7. USEPA : Exposure Factors Handbook Ⅲ, Activity Factors, EPA/600/P-95/002Fc, 1997.
8. Israeli, M. and Nelson, C.B. : Distribution and expected time of residence for US households, Risk Analysis, 12(1), 65-72, 1992.
9. Yanagisawa, Y. and Nishmura, H.: A badge-type personal sampler for measurement of personal exposures to NO_2 and NO in ambient air Environment International, 8, 235-242, 1982.
10. Lee, K., Yanagisawa, Y., Spengler, J.D. and Billick, I.H.: Wind velocity effects of sampling rate of NO_2 badge. J. Expos. Anal. Environ. Epi. 2, 207-219, 1992.
11. Smith, R.L.: Use of Monte Carlo simulation for human exposure assessment at a Super-fund site, Risk Analysis, 14(4), 433-439, 1994.
12. Dockey, D.W., Spengler, J.D., Speizer, F.E., Ferris, B.G., Ware, J.H. and Brunekreef, B.: Associations of health status with indicators of indoo air pollution from an epidemiological study in six U.S. cities. In proceedings of the 4th International Conference on Indoor Air Quality and Climate, 2, 203-207, 1987.
13. Esmen, N. A. : The status of indoor air pollution, Environmental Health Perspectives, 62, 259-265, 1985.