AIR POLLUTANT EXPOSURE OF ADULT POPULATION IN MILAN (EXPOLIS STUDY)

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ABSTRACT
In the framework of the EXPOLIS project a random Milan population sample of 250 subjects was selected for questionnaire applications ("diary sample"). An "exposure sample" (50 office workers) was selected for pollutant exposure evaluation. The results of the Milan study are compared with those of the other European centers participating to the project (Athens, Basel, Grenoble, Helsinki and Prague). The average time spent by the subjects in the different microenvironments varies little between the cities (95-97% of their time indoors, 2-4% in commuting and 1% outdoor). High PM2.5 workplace levels were found in Milan and Athens (58.6 and 60.1 $\mu g/m^3$). In all the cities TVOCs and benzene levels were higher in indoor environments and in personal exposure than outdoor concentrations. In all the cities the highest CO exposure were found during commuting (1.5-6.5 mg/m^3). The degree of perceived air pollution annoyance was higher during commuting than at workplace and home.

INDEX TERMS
Exposure assessment, Particles, VOCs, CO

INTRODUCTION
The overall personal exposure to environmental pollutants depends on the concentrations of pollutants in the various micro-environments, where individuals spend their time, and the amount of time spent in each of these micro-environments. Data on personal exposure levels of the general population to airborne pollutants are still limited in Europe, as information on population exposure so far is mostly available from measurements provided by outdoor fixed monitoring networks (Jantunen, 1998). In the EXPOLIS study (Air Pollution Exposure Distributions of Adult Urban Populations in Europe) personal exposures and microenvironmental concentrations of selected air pollutants were measured in six European cities: Athens, Basel, Grenoble, Helsinki, Milan and Prague. The main objective of this study was to determine the frequency distributions and other basic statistics of the exposures of European adult urban populations to air pollutants: volatile organic compounds (VOC), carbon monoxide (CO) and respirable particulate matter ($PM_{2.5}$). The air pollutants were selected based on their health effects and their environmental concerns as follows: CO to represent exposure to traffic exhausts and indoor combustion sources; VOCs because of health and welfare concerns both indoors and outdoors, because many VOCs are useful source

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markers, and because the presently available data are of very variable quality; $PM_{2.5}$ because inhalable particles are presently the air pollutants of greatest health concern and interest, and because no $PM_{2.5}$ exposure studies on representative population samples have been reported so far. The EXPOLIS design and methodology have been described in Jantunen et al. (1998). In this paper the overall results of the Milan study are compared with those observed in the other Expolis cities participating to the project.

METHODS

The target populations of the EXPOLIS study are the adult urban populations of Europe. In each city, a large base population sample was formed and subsamples for questionnaire applications and exposure measurements were drawn from this base sample. These population samples are described and the representativity of them is evaluated in more detail in Rotko et al. (2000) and Oglesby et al. (2000). In the framework of this study a random Milan population sample of 250 subjects (25-55 year old) was selected from the census for questionnaire applications (the "diary sample"). These subjects compiled: a Questionnaire concerning home, workplace and commuting characteristics; a Retrospective recall questionnaire concerning activities of the last 48 hours; a Time Microenvironment and Activity Diary (TMAD). An "exposure sample" (50 subjects) comparable with the office worker group of the "diary sample" was selected from office workers of public and private buildings for the pollutant exposure evaluation. These subjects compiled the questionnaires and the TMAD and were monitored for 48 hours for $PM_{2.5}$, CO and VOCs.

The measurements were performed from fall of 1996 to winter of 1997-98. Each subject carried a personal exposure monitoring case, and her/his home, inside and outside, and workplace were equipped with microenvironmental measuring equipment for 48 hours. The workplace concentrations were measured for the normal working hours. The home inside and outside concentrations were monitored from the time when the subject would normally return from work to the time when she/he would normally leave home for work.

The CO concentrations were continuously determined by the Langan CO Enhanced Measurer T15 based on diffusion air flow to a CO specific electrochemical detector. The VOCs were thermally desorbed from the tubes and subsequently analyzed by GC separation and simultaneous detection by MSD and FID (in Basel the VOC samples were collected on Carbotrap and analyzed by Carbotech, SA using GC/FID technique). The $PM_{2.5}$ sample filters were weighed before and after sampling in each center using a microbalance, and archived in a refrigerator for later elemental/chemical analyses. Detailed methods and quality assurance results are in Georgoulis et al. (2001), Jurvelin et al. (1997 and 2001) and Koistinen et al. (1999). A common relational database (EXPOLIS Access DataBase, EADB) was developed using Microsoft Access 7.0 to contain all data useful for the EXPOLIS study (Hänninen et al. 1998).

RESULTS AND DISCUSSION

Description of Diary and Exposure samples for the six EXPOLIS cities is shown in Table 1. *Time spent in microenvironments* (Table 2 - 3). The average time spent at home varies little among the cities, from the lowest in Milan and Helsinki (13.50 h/d) to the highest in Athens (15.45 h/d). The average time spent at work progresses almost in reverse order, from 4.08 h/d in Athens to 6.34 h/d in Milan. The average total time spent in commuting is about 2 hours per day in all cities (1.88 - 2.20 h/d). The total time spent outdoors varies around 1 hour per day (0.67 - 1.20 h/d). European urban dwellers spend 95 - 97 % of their time indoors. There is a difference in the passive exposure to tobacco smoke; the ETS exposure is highest in Milan,

Athens and Basel (54-65%) and smallest in Helsinki (27%). In Milan subjects are exposed to ETS 19% at home, 44% in office and 36% in other indoor environments

Table 1. General description of the Diary and Exposure samples for the six EXPOLIS cities

	MILAN	ATHENS	BASEL	GRENOBLE	HELSINKI	PRAGUE
DIARY S.	250	50	282	7	234	36
Women (%)	124 (49.6)	32 (64)	154 (54.6)	3 (42.8)	144 (61.5)	27 (75)
Men (%)	126 (50.4)	18 (36)	128 (45.4)	4 (57.2)	90 (38.5)	9 (25)
EXPOSURE S.	50	50	50	80	201	50
Women (%)	27 (54.0)	26 (52.0)	28 (56.0)	46 (57.5)	113 (56.2)	29 (58)
Men (%)	23 (46.0)	24 (48.0)	22 (44.0)	34 (42.5)	88 (43.8)	21 (42)

Table 2. Summary statistics of Time-Microenvironment Data, including all subjects (daily mean time in decimal hours)

	MILAN n. 300	ATHENS n. 100	BASEL n. 322	GRENOBLE n.84	HELSINKI n. 445	PRAGUE n. 84
INDOOR	21.27	20.82	20.77	21.33	20.50	20.82
Home	13.50	15.45	13.52	14.43	13.50	14.11
Work	6.34	4.08	5.56	5.04	5.79	5.55
Elsewhere	1.43	1.29	1.69	1.85	1.21	1.42
COMMUTING	2.05	2.07	2.04	1.88	1.97	2.20
OUTDOOR	0.67	1.20	1.18	0.76	1.03	0.92

Table 3. Summary statistics of Time-Activity-Diary Data, including all subjects (doers in %)

	MILAN n. 300	ATHENS n. 100	BASEL n. 322	GRENOBLE n.84	HELSINKI n. 445	PRAGUE n. 84
COMMUTING						
Bike/walk	80	58	93	51	74	76
Moto	7	15	8	0	3	4
Car/taxi	72	80	53	81	72	62
Bus/tram	40	24	48	20	42	76
Train/metro	29	9	11	1	19	49
ACTIVITIES						
SMOKING	31	16	26	0	22	19
ETS EXPOS.	65	54	53	40	27	39
ETS at home	19	25	13	8	8	11
ETS at work	44	24	21	18	9	18
ETS elsewher	36	27	33	17	16	18

$PM_{2.5}$ (Table 4). Median PM2.5 levels in Milan are higher in office (58.6 µg/m^3) than at home (34.7 µg/m^3) and outdoor (40.2 µg/m^3). The PM levels are lower than those found in other

Table 4. PM 2.5 exposure levels (median and 25th–75th percentiles; µg/m^3)

	MILAN	ATHENS	BASEL	HELSINKI	PRAGUE
HOME					
Indoor	**34.7** (16.4-63.8)	**26.6** (17.3-39.2)	**16.0** (11.8-27.2)	**8.2** (4.9-12.9)	**24.8** (17.8-38.9)
Outdoor	**40.2** (29.4-51.0)	**27.2** (20.5-41.9)	**16.8** (10.7-24.5)	**7.4** (4.9-13.0)	**25.9** (18.8-37.1)
WORK	**58.6** (43.1-80.2)	**60.1** (33.2-113)	**17.5** (10.7-32.6)	**7.3** (3.9-14.5)	**29.3** (21.0-43.7)
PERSONAL					
Daytime	-	**35.2** (25.0-54.0)	**17.7** (13.7-25.8)	**10.5** (6.4-18.8)	**30.2** (23.2-53.3)
Nightime	-	**22.8** (13.8-33.8)	**17.9** (12.5-27.2)	**7.8** (5.1-14.8)	**19.6** (12.6-34.2)
48h	-	**29.1** (19.6-50.2)	**19.9** (14.3-29.8)	**9.9** (6.4-17.7)	**25.1** (19.0-42.3)

building studies carried out in Milan (Carrer, 1999). High workplace levels were also found in Athens (60.1 μg/m^3). The exposures at home and in workplaces in Basel, Helsinki and Prague are rather similar, but in Milan and Athens significantly higher in the workplaces. Presence of smoking significantly increases the PM2.5 levels (Table 5).

Table 5. PM 2.5 exposure levels grouped by smoking exposure (median; μg/m^3)

	MILAN Smoking*		**ATHENS Smoking***		**BASEL Smoking***		**HELSINKI Smoking***	
	NO	**YES**	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
HOME								
Indoor level	38.7(*	24.5	25.3	31.0	14.2	29.5	7.2	30.3
Personal	-	-	24.9	40.0	17.9	28.5	8.9	40.2
WORK								
Indoor level	56.5(*	58.6	54.3	59.8	16.8	27.3	6.6	39.9
Personal	-	-	36.7	27.9	18.1	22.5	9.3	24.3
PERSONAL								
48h	-	-	28.8	67.4	17.5	36.9	8.4	22.6

*** Home and Work: exposure to environmental tobacco smoke – Personal: active smoking**

VOCs (Table 6). In Milan, TVOCs levels are higher at home (382 μg/m^3) and in office (346 μg/m^3) than outdoor (226 μg/m^3). The TVOC home levels are in agreement with those found in other building studies carried out in Milan (Cavallo, 1993; Carrer, 1996; Carrer, 2000). High TVOC indoor levels were also found in Athens and in Prague. The median TVOC exposures in Helsinki are about 1/3 to 2/3 of the other cities. TVOC personal exposure levels are usually higher than home indoor, workplace and outdoor concentrations. The TVOCs are comparable with those found in the European AUDIT project in Greece, France and Finland (range 100-400 μg/m^3) (Bluyssen, 1996).

Table 6. TVOCs exposure levels (median and 25th–75th percentiles; μg/m^3)

	MILAN	**ATHENS**	**BASEL**	**HELSINKI**	**PRAGUE**
HOME					
Indoor	**382** (276-839)	**562** (270-827)	-	**227** (148-338)	**413** (255-686)
Outdoor	**226** (134-381)	**170** (104-312)		**42.3** (29-63)	**125** (82-158)
WORK	**346** (237-584)	**393** (245-679)	-	**133** (86-212)	**293** (160-468)
PERSONAL	-	**643** (404-962)	-	**206** (154-312)	**475** (314-859)

Benzene (Table 7). Median benzene levels in Milan are similar at home and in office (9.8 μg/m^3), rather higher than outdoor levels (9.1 μg/m^3).

Table 7. Benzene exposure levels (median and 25th–75th percentiles; μg/m^3)

	MILAN	**ATHENS**	**BASEL**	**HELSINKI**	**PRAGUE**
HOME					
Indoor	**9.8** (6.3-18.4)	**6.3** (5.0-14.5)	**2.4** (1.6-3.1)	**2.0** (0.6-3.1)	**7.1** (5.1-10.1)
Outdoor	**9.1** (6.0-18.9)	**7.5** (4.8-12.5)	**1.3** (0.5-2.0)	**1.5** (0.9-2.0)	**4.6** (2.8-6.2)
WORK	**9.8** (5.5-19.4)	**13.5** (7.1-17.7)	**2.3** (1.7-3.2)	**2.2** (1.0-3.6)	**7.9** (4.1-10.6)
PERSONAL	-	**12.8** (8.8-19.0)	**2.8** (1.8-5.6)	**2.6** (1.8-3.6)	**9.8** (6.8-12.5)

These levels are lower than those found in 1995 (daily exposure: 21.2 μg/m^3) (Carrer, 2000). Benzene levels are slightly lower than the target level of 10 μg/m^3 established in Italy for the

outdoor air (Ministerial Decree, 1994). High benzene levels have been observed in Athens (workplace: 13.5 μg/m^3; personal exposure: 12.8 μg/m^3). Lower benzene levels are in Basel, Helsinki and Prague. In all the cities indoor levels and personal exposure levels are higher than the outdoor concentration, i.e. most of the benzene exposure does occur indoors and a part of the exposure also comes from indoor or personal sources.
CO (Table 8). Comparisons with CO data measured in the other EXPOLIS cities is described elsewhere (Georgoulis L. et al. 2001). In all the cities the highest CO exposure were found during commuting (1.5-6.7 mg/m^3).

Table 8. Carbon monoxide exposure levels (mean; mg/m^3)

	MILAN	ATHENS	BASEL	HELSINKI	PRAGUE
EXPOLIS DATA					
Indoor	**1.30**	**2.02**	**1.18**	**0.59**	**1.84**
Outdoor	**1.60**	**4.70**	**1.50**	**0.72**	**1.32**
Commuting	**2.60**	**6.69**	**1.60**	**1.46**	**2.03**
48 h	**1.45**	**2.51**	**1.21**	**0.66**	**1.86**
AMBIENT DATA	**1.84**	**4.16**	**1.00**	**0.54**	**1.19**

Perceived air pollution annoyance (Table 9). At home the degree of annoyance was mostly quite low in all cities (0 to 3%), except Prague (19.8%). The annoyance at work is higher than at home, in particular a high degree is in Milan (8.7%), Athens (11.1%) and Prague (10.8%). In all the cities the highest degree of annoyance is referred during commuting (7.1 to 53.5%). The data-analysis of the EXPOLIS project has just started. Using the EXPOLIS database, a probablistic simulation technique will be developed to assess the population exposure distributions of selected subpopulations or selected urban areas for selected future scenarios. The modeling framework is presented in Hänninen et al. (1997) and Kruize et al. (1998).

Table 9. Degree of perceived air pollution annoyance (% responding)

	MILAN n. 300	ATHENS n. 100	BASEL n. 322	GRENOBLE n.84	HELSINKI n. 445	PRAGUE n. 84
At HOME						
Low (0-3)	75.6	80.0	76.5	89.5	83.0	43.0
Medium (4-7)	22.4	17.0	22.6	10.5	14.0	37.2
High (8-10)	2.0	3.0	0.9	0.0	3.0	19.8
At WORK						
Low (0-3)	48.0	45.8	72.0	72.7	67.0	52.7
Medium (4-7)	43.3	43.1	23.2	23.4	27.0	36.5
High (8-10)	8.7	11.1	4.8	3.9	6.0	10.8
COMMUTING						
Low (0-3)	18.7	33.7	29.2	62.4	52.0	10.5
Medium (4-7)	49.5	40.2	47.0	30.6	40.0	36.0
High (8-10)	31.8	26.1	23.8	7.1	8.0	53.5

CONCLUSIONS

The time spent in the different microenvironments varies little among the cities; in general European urban dwellers spend 95-97% of their time indoors, 2-4% in commuting and 1% outdoor. In Milan, Basel and Prague more than 50% of the subjects are exposed to environmental tobacco smoke. The results show high PM2.5 workplace levels in Milan, Athens and Prague. TVOCs and benzene levels are higher in indoor environments and in personal exposure than outdoor concentrations, suggesting that most of the TVOCs and benzene exposure does occur indoors and comes from indoor or personal sources. In all the

cities the highest CO exposure were found during commuting. The degree of perceived air pollution annoyance is higher during commuting than at the workplace and at home.

ACKNOWLEDGEMENTS
This work has been supported by EU Contract No. ENV4-CT96-0202 (DG 12 – DTEE).

REFERENCES

Bluyssen P, De Oliveira Fernandes E, Groes L *et al.* 1996. European Audit study in 56 office buildings. Indoor Air, 6, pp. 221-238.

Carrer P, Cavallo D, Troiano P *et al.* 1996. Assessment of the eye irritation in office workers after combined exposure to volatile organic compounds and other work-related factors. In: Yoshizawa, S. (ed.) *Proceedings of Indoor Air '96,* International Conference on Indoor Air Quality and Climate, Nagoya, Vol. 2**,** pp. 297-302.

Carrer P, Cavallo D, Maroni M, Foà V. 1999. Airborne particles and human health: state of the knowledge and research perspectives. Europ J of Oncology, 4, 5, pp. 545-551.

Carrer P, Maroni M, Alcini D *et al*. 2000. Assessment through environmental and biological measurements of total daily exposure to volatile organic compounds of office workers in Milan, Italy. Indoor Air, 10, pp. 258-268.

Cavallo D, Alcini D, De Bortoli M *et al*. 1993. Chemical contamination of indoor air in schools and office buildings in Milan, Italy. In: Seppanen O (ed.) *Proceedings of Indoor Air '93,* International Conference Indoor Air Quality and Climate, Helsinki, 2**,** pp. 45-49.

Georgoulis LB, Hänninen O, Samoli E *et al.* 2001. Personal CO Exposures in Five European Cities and Its Determinants. Submitted to Atmos. Environ.

Hänninen O, Kruize H, *et al*. 1997. Simulation framework for assessing air pollution exposure distributions of urban populations in the Expolis project. Society of Exposure Analysis (ISEA) annual meeting, Research Triangle Park, NC, November 2-5, 1997.

Hänninen O, Samoli E, Breugelmans O *et al*. 1998. EXPOLIS Database for Exposure Assessment and Simulation with Data from Six European Cities. Society of Exposure Analysis (ISEA) and International Society for Environmental Epidemiology (ISEE) annual meeting, Boston, MA, August 16-19, 1998 (Abstract No: 263 P), Epidemiology 9(4): July 1998 Suppl. p S88.

Jantunen MJ, Hänninen O, Katsouyanni K *et al*. 1998. Air pollution exposure in European cities: Expolis study. J Exposure Analysis Environmental Epidemiology, 8, pp. 495-518.

Jurvelin J, De Bortoli M, Cavallo D *et al*. 1997. Methodology and quality assurance of VOCs measurements in the EXPOLIS study. In: Manzo L, Descotes J and Hoskin J (eds): VOCs in the environment. Risk assessment and neurotoxicity. PIME Press, Pavia, pp. 27-32.

Koistinen K, Kousa A, Tenhola V *at al*. 1999. Fine Particle ($PM_{2.5}$) Measurement Methodology, Quality Assurance Procedures and Pilot Results of the EXPOLIS Study. Journal of Air and Waste Management Association, 49, pp. 1212-1220.

Kruize H, Breugelmans O, de Hollander A *et al*. (1998). Microenvironmental exposure simulation in EXPOLIS. Epidemiology, 9: S87.

Oglesby L, Rotko T, Krutl P *at al*. 2000. Personal exposure assessment studies may suffer from exposure-relevant selection bias. J Exp Anal Envir Epid, 10, pp. 251-266.

Rotko T, Oglesby L, Künzli N, Jantunen MJ. 2000. Population sampling in European air pollution exposure study, EXPOLIS: Comparisons between the cities and representativity of the samples. J. Exp Anal Envir Epid, 10(4), pp. 355-364.