# EXPOLIS-INDEX

## Human Exposure Patterns for Health Risk Assessment: Indoor Determinants of Personal Exposures in the European EXPOLIS Population in Athens, Basel, Grenoble, Milan, Helsinki, Oxford, and Prague

*Final Report – Introduction, Summary, and Conclusions*

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**1. INTRODUCTION** .......... **2**

**2. OBJECTIVES AND METHODS** .......... **2**

THE EXPOLIS STUDY .......... 3
WORK PACKAGE 1: TIME-MICROENVIRONMENT-ACTIVITY PATTERNS IN EUROPE .......... 3
WORK PACKAGE 2: PERSONAL EXPOSURES TO VOC IN EUROPEAN CITIES .......... 4
WORK PACKAGE 3: SOURCE APPORTIONMENT FOR PERSONAL EXPOSURE .......... 4

**3. RESULTS AND CONCLUSIONS** .......... **4**

**4. RECOMMENDATIONS** .......... **6**

**5. ACKNOWLEDGMENTS** .......... **7**

**6. MAJOR PROJECT MILESTONES** .......... **7**

MAJOR PROJECT MEETINGS AND TELEPHONE CONFERENCES .......... 7
ABSTRACTS .......... 8
PREPARED AND SUBMITTED PUBLICATIONS .......... 9
TALKS .......... 9

**7. REFERENCES** .......... **10**

# 1. INTRODUCTION

Health risk assessment aims at quantifying the potential adverse health effects of human exposure to environmental pollutants. Exposure assessment plays a key role in the risk assessment procedure. A description of the exposure distribution of the noxious agent in a population is required before the associated risk and health impact may be quantified. For risk quantification on a population level, the full range of the exposure distribution should be described, including the upper end of high exposure groups.

The challenge of human exposure assessment lays in the combination of spatio-temporal variability of the pollutants and time-microenvironment-activity patterns of populations. Total personal exposure to air pollutants can be conceptualized as the sum of exposures from various sources encountered indoors, outdoors and through individual activities. While exposures to e.g. fine particulates ($PM_{2.5}$) originating from outdoor air have been shown to be quite similar for a population living in the same neighborhood or community (Oglesby, Kunzli et al. 2000) indoor exposures can differ substantially between persons, depending on indoor sources (e.g. material of furniture or walls) and individual activities (e.g. smoking or use of consumer products such as paintings, sprays etc.).

Given the complexity of these challenges, there are substantial gaps in the knowledge of human population exposure patterns, which build the basis for health risk assessment. Whereas these issues have been investigated in rather large settings in the United States, such as the PTEAM study on personal exposure (Clayton, Perrit et al. 1993), or the NHEXAS survey (Pellizzari, Perritt et al. 1999), no European data were available until the initiation of EXPOLIS (Air pollution exposure distribution within adult urban populations in Europe) by Jantunen (Jantunen, Hanninen et al. 1998). Our research agenda aimed at filling gaps of knowledge particularly for Europe. The research agenda on human exposure patterns, with particular focus on indoor environments, made use of not yet analyzed data of the extensive EXPOLIS Combined International Database (EXPOLIS-CIDB). To our knowledge, EXPOLIS is the only available European research data set so far which includes personal, indoor, outdoor and work place exposure data as well as extensive information on personal time-microenvironment-activity patterns among a multi-national sample of European adults.

In the following sections we briefly summarize the objectives, methods, results, and conclusions of the work conducted within the CEFIC grant of EXPOLIS-INDEX. All details are contained in the three separate reports.

# 2. OBJECTIVES AND METHODS

The research goals were broken down into three major packages. The third Work Package integrated the results of Work Package 1 (time microenvironment activity patterns) and Work Package 2 (VOC exposures) into a comprehensive description of human indoor exposure patterns, thus, providing pertinent information for health risk assessment and mitigation strategies.

After the initial insertion of the Oxford dataset into the EXPOLIS CIDB and preparation of the complete dataset for subsequent analysis, the 3 Work Packages were executed as described below. All packages relied on the EXPOLIS study; thus, we first describe the main methodological aspects of this project.

## *The EXPOLIS Study*

EXPOLIS was undertaken from 1996 to 2000 within the EU 4th Framework program (EU Contract ENV4-CT96-0202). The EXPOLIS protocol included 48-hour measurements of personal exposures, home indoor and outdoor as well as workplace levels of major air pollutants (Jantunen, Hanninen et al. 1998). These included fine particle mass ($PM_{2.5}$) and elemental concentrations (37 elements), volatile organic compounds (30 VOCs), carbon monoxide (CO), and, in four centers, nitrogen dioxide ($NO_2$). In addition, black smoke (BS; light absorption of PM) has been measured to estimate elemental carbon on the $PM_{2.5}$-filters. Time-microenvironment-activity data, short-term recall data on frequency and duration of equipment use and activities (e.g. use of consumer products) as well as questionnaire data on the home and work environment of the participants complete the collected exposure information. The time-microenvironment-activity diary had a time resolution of 15 minutes, with multiple activity entries allowed for each 15 min slot. Thus, participants provided activity for rather short periods of time. A total of 432 subjects, randomly selected from the adult working-age population of the urban areas Athens (Greece), Basel (Switzerland), Grenoble (France), Helsinki (Finland), Prague (Czech Republic), and Milan (Italy), participated in the full exposure protocol. A further 827 subjects completed the time-microenvironment-activity diary and questionnaires only. Since the initial EXPOLIS data collection, the UK Department of Environment, Food and Rural Affairs (DEFRA), formerly Department of Environment, Transport and the Regions (DETR) funded a further exposure assessment study in Oxford. The study applied the same standard operating procedures as those used in the EXPOLIS core protocol. The study population in Oxford consisted in 50 adult participants for the full protocol, including personal monitoring, and 120 subjects completing the TMADs.

## *Work Package 1: Time-Microenvironment-Activity Patterns in Europe*

In the search for determinants of time-microenvironment-activity patterns in Europe the purpose of the first Work Package was to characterize the variability of time spent by the adult urban European population in eleven different microenvironments on average workdays among various sociodemographic subgroups and the seven study cities.

> The following specific steps were carried out:
>
> - Statistical description of the variability of time spent in microenvironments and activities between and within the EXPOLIS cities and, between and within subgroups, as well as within individuals (day to day variability).
> - Comparison of the average time spent in microenvironments and activities between subgroups and assessment of impact of personal and external characteristics on time spent in microenvironments and activities using logistic and linear regression techniques.
> - Assessment of the relative variability of time spent in microenvironments and activities within cities, persons and days using nested analysis of variance.

This first step also provided the basis for integrating time-microenvironment-activity data into source apportionment analysis with elemental and VOC data collected in EXPOLIS.

### *Work Package 2: Personal Exposures to VOC in European Cities*

The purpose of the second Work Package was to describe the personal exposure to VOC in the EXPOLIS cities and to examine if different implications about the patterns of personal exposure and areas for control strategies may be derived from looking at relationships between microenvironmental concentrations and personal exposures in the upper end of the distribution rather than median levels across populations.

> The following specific steps were carried out:
>
> - Comparison of VOC exposure patterns on person and in residential and workplace environments across Europe using descriptive statistics.
> - Assessment of the relationship between microenvironmental and personal exposure levels in the upper end of the distribution compared to the population median.

### *Work Package 3: Source Apportionment for Personal Exposure*

This last and integrative step aimed at quantifying the relative importance of indoor sources on total personal exposures. The observed personal exposure patterns were translated into recommendations for exposure mitigation strategies in regard to indoor sources.

> The following specific steps were carried out:
>
> - Assessment of microenvironmental contributions of outdoor, home, workplace, and other sources to personal exposure using environmental apportionment techniques.
> - Assessment of Intake Fractions: the masses of pollutants that reach a person compared to the masses emitted by the various sources.

The detailed results of each of the three work packages are available as separate reports.

## 3. RESULTS AND CONCLUSIONS

By far the largest fraction of an average workday of the European urban population is spent indoors (overall average: 87.4%). This is true in all seven cities and for all subgroups by gender, age, education level, living with children, smoking status, working status, employment status, living with alone, season, home location, and housing characteristics. The city averages do not differ much for broad microenvironment categories (total time indoors, total time outdoors, and total time in transit). However, looking more into details, we did find noticeable differences in average work schedules and work durations as well as in durations of time spent at home indoors and in the usage of various means of transportation. In comparison, the within city variability, caused by various socio-demographic factors, was much larger. The most common factors found to be associated with differences in time-microenvironment-activity patterns are gender, education level, work status, employment status, living alone, children at home, and season. Out of these, work status, employment status, and living alone often exhibited the same qualitative effect in all seven cities. However, effects of other factors were often bidirectional. In particular, the relevance of gender was rather heterogeneous across the study cities. The role of women in the workforce differs across Europe and can primarily be divided in two groups with opposing effects: (1) Helsinki and Prague, where women work on average longer than men, and (2) Athens, Basel, Grenoble, Milan, and Oxford.

In addition to already mentioned variability between cities and individuals, we also found substantial day-to-day variability for all microenvironments. Time spent at work indoors and time spent indoors exposed to ETS are the most stable time-activities between two consecutive days of an individual.

In the search for environmental tobacco smoke exposure mitigation strategies among non-smokers, we focused on indoor locations away from home, as these may be better suited to regulations than private homes. Our results highlight the need to strengthen workplace smoking regulation as it reflects the key determinant for ETS exposure.

A further aspect of time-microenvironment-activity patterns is the time of day of certain activities. We showed that the seven cities exhibited very different population-wide activity patterns over a whole day. Major differences were observed in regard to the number and start time of traffic rush hours as well as where time during lunch and in the evening (time off work in general) is spent.

Using the personal exposure levels to various pollutants, we further illustrated that often the relationship between median indoor, median outdoor and median personal exposure may not reflect the patterns observed in the upper end of the personal exposure distribution. Thus, prioritization of the microenvironments for control measures based on median exposures may exclude important areas where effectively focused control measures would be possible, and may therefore have little impact on the most harmful exposures and highest risks. Control strategies targeting activities that lead to exposures in the upper end of the distribution would reduce the variability associated with population median values by bringing the upper end of the exposure distribution closer to median values. Thus, compliance with health-based regulations would be more protective for the higher exposed fraction of the population, within whom adverse health effects would be more expected, while also reducing mean and median values.

We have shown, that some approximations can be made to separate the contributions of different microenvironments to personal exposure. In the cities in the EXPOLIS study, sources in the home, outdoors and in other microenvironments all appeared to be important in determining VOC exposure, while workplace microenvironments played a less important role for most individuals.

The intake fractions, i.e., the masses of pollutants that reach a person compared to the masses emitted by the various sources, for indoor sources are distributed log normally in all the cities, with mean values in the 10-3 to 10-2 range. The lowest values were observed in Athens and the highest in Helsinki, reflecting the different ventilation patterns due to climate differences. In general, the intake fractions within a population display a limited variability. Since the means and 95th percentiles differ by a factor of 2-3 (rather than by orders of magnitude), the potential for reducing exposure based on realistic ventilation and activity rates is limited. Although the information collected during the EXPOLIS study does not have the power to representatively capture the most extreme conditions, it still represents the population of the cities sampled. It appears that the range of exposures to VOCs from residential indoor sources is rather limited, insomuch as it depends on individual activities and indoor ventilation. What is most likely to determine a wider range of actual exposures is the strength of the different sources. The fact that intake fractions for indoor sources are 2-3 orders of magnitude greater than those for neighborhood and urban outdoor sources highlights the significance of closed environments, long exposure times and proximity to the sources to exposures indoors. Body burdens from the indoor sources, however, depend also on the total amounts released in these environments.

It has been shown that sources located both indoors and outdoors produce major contributions to personal exposure to VOCs in European cities. The relative proportion of these contributions varies for different compounds, but those associated with traffic emissions show higher outdoor contributions as it is to be expected. Indeed, exposure to those compounds owes a large contribution to other locations/activities, such as time spent in traffic. It is apparent, then, that strategies of air pollution management that address only outdoor sources would ignore much of the potential population exposure. While this conclusion is not new, the difficulties of intervention in indoor air quality and traffic management must be acknowledged. In addition, some of the indoor sources of VOCs may actually be secondary, i.e. they release over time adsorbed compounds whose origin lies outdoors.

# 4. RECOMMENDATIONS

Determinants of time-microenvironment-activity patterns need to be taken into account in exposure assessment, epidemiological analyses, exposure simulations, as well as policies and the shaping of preventive strategies in order to focus on those with time-microenvironment-activity patterns that ultimately determine exposures. Our data may give some guidance for the design of future exposure studies by highlighting areas where additional information may be gathered by questionnaires and/or microenvironment sampling. Associations between environmental exposures and health effects may vary across the subgroups given their potentially different exposure patterns. Determinants of time-microenvironment-activity patterns may be useful, therefore, in epidemiological studies in the absence of direct measurements of time-microenvironment-activity patterns or exposures. Furthermore, mitigation strategies may be targeted towards subgroups with time-activity-patterns that lead to the highest personal exposures.

From a public health standpoint, more attention should be given to investigate indoor air quality in residential, rather than focusing on commercial, public and occupational buildings only. The indoor microenvironments appeared to play a sometimes significant role as reservoirs for outdoor-generated VOCs through sorption/desorption processes. Depending on the diurnal concentration and temperature variability, these processes could be exploited to reduce personal exposure, although the extent of this effect must be ascertained through specific research.

Although both workplace and residential indoor environments contribute to personal exposure, the role of the latter is overwhelming, for the working age population studied in EXPOLIS. The need to investigate occupational exposure is essential for specific groups of laborers and even more so for highest exposed working individuals. The importance of air quality in the workplace, with its consequences on productivity, is also undeniable. It would seem, however, that from a public health standpoint, the impact of residential air quality is most significant, and appears to have received insufficient attention in scientific investigations. An increased focus on residential buildings is therefore encouraged.

Exposure reduction strategies aimed at indoor sources should focus more on reducing the content of hazardous compounds in household and building products rather than on ventilation or building strategies. This recommendation derives from two considerations. In the first place, while differences exist between different geographical locations (e.g. intake fractions from Athens and Helsinki), practical constraints of climate and energy costs restrict the potential intervention on ventilation.

Secondly, a recommendation of larger residences (which indeed would reduce exposure) would face similar obvious limitations. It is apparent, then, that given the limited ability to reduce intake fractions, the method of choice to reduce exposures lies in reducing the source strengths of consumer products, furnishings and/or building materials, depending on the compounds of interest.

## 5. ACKNOWLEDGMENTS

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## 6. MAJOR PROJECT MILESTONES

### *Major Project Meetings and Telephone Conferences*

| Date, Location | Attendees | Main Decisions |
|---|---|---|
| Aug 5/6, 2002<br>ISPM, Basel | CS, DC, LO, NK, PM, Taronna | Discussion of main research plan and possible collaboration between ISPM and Uni Milan |
| Aug 13, 2002<br>Vancouver, ISEE 2002 | Alm, KK, Koistinen, MJ, MN, RS | Initial presentation and discussion of the 3 Work Packages, assessment of interest and possible collaboration |
| Aug 27-30, 2002<br>Imperial College, London | CS, HKL, MN | Initiation of collaboration, determination of feasibility of inclusion of EXPOLIS Oxford in EXPOLIS-INDEX |
| Sept 11, 2002<br>telephone conference | CS, LO, NK | Approval of integration of EXPOLIS Oxford, discussion of collaboration proposals, approval of project's administrative structure and communication plan |
| Oct 23, 2002<br>telephone conference | CS, HL, KK, LO, MJ, MN, NK, PC | Basic approval of collaboration with RE in WP2, update of work breakdown structure of WP1 |
| Nov 14, 2002<br>ETH, Zurich | CS, DC, LO, MJ, MN, MT, NK | Definition of collaboration with RE in WP2, update of definition of WP3, definition of publication deadlines, outline |

| | | |
|---|---|---|
| | | of related projects and their interaction with EXPOLIS-INDEX |
| Dec 9, 2002<br>telephone conference | CS, LO, MJ, NK | Specification of relocation of CS from ISPM (Basel) to USC (Los Angeles), specification of main schedule of following 6 months |
| March 14, 2003<br>UC Berkely | CS, RE | Initiation of collaboration for WP2, discussion next of research steps |
| May 13, 2003<br>telephone conference | CS, HKL, LO, MN, NK, RE | Discussion and approval of prepared abstracts for ISEA 2003 |
| Sept 23, 2003<br>Stresa, ISEA 2003 | CM, CS, HKL, LO, MJ, MN, NK, VI | Presentation and discussion of results from WP1 and WP2, discussion of next steps in WP1, WP2 and the initiation of WP3 |
| Jan 27, 2004<br>USC, Los Angeles | CS, JG, NK | Review of used statistical procedures |
| July 1, 2004<br>USC, Los Angeles | CS, NK, RE | Discussion of Results from WP1 and WP2, approval of extended research agenda for WP2 |
| Aug 12, 2004<br>ISPM, Basel | CS, NK | Approval of paper "Time-activity patterns in seven regions of Europe" (Schweizer) |

Explanation of Name Abbreviations:

| | | | |
|---|---|---|---|
| CM | Chris Money | MJ | Matti Jantunen |
| CS | Christian Schweizer | NK | Nino Künzli |
| DC | Domenico Cavallo | PC | Paolo Carrer |
| HKL | Hak Kan Lai | PM | Patrick Mathys |
| JG | Jim Gauderman | RE | Rufus Edwards |
| KK | Klea Katsouyanni | RS | Radim Sram |
| LO | Lucy Bayer-Oglesby | VI | Vito Ilacqua |

## *Abstracts*

Edwards, R., C. Schweizer, et al. (2003). VOC personal exposures in EXPOLIS populations in Athens, Helsinki, Oxford and Prague. 13th Annual Conference of the International Society of Exposure Analysis, Stresa.

Ilacqua, V. and M. Jantunen (2003). Contributions of indoor, outdoor, and other sources to PM2.5 exposure in four European cities. 13th Annual Conference of the International Society of Exposure Analysis, Stresa.

Lai, H. K., M. J. Nieuwenhijsen, et al. (2003). Determinants of residential indoor VOC and PM2.5 levels in six European cities - the EXPOLIS study. 13th Annual Conference of the International Society of Exposure Analysis, Stresa.

Lai, H. K., M. J. Nieuwenhijsen, et al. (2003). Residential indoor VOC levels in six European cities - the EXPOLIS study. 13th Annual Conference of the International Society of Exposure Analysis, Stresa.

Schweizer, C., N. Künzli, et al. (2003). Time-Microenvironment-Activity-Patterns (TMAP) across Europe: How homogenous is the European adult urban population? 13th Annual Conference of the International Society of Exposure Analysis, Stresa.

## *Prepared and submitted publications*

Edwards, R. D., C. Schweizer, et al. VOC personal exposures in EXPOLIS - relationships to indoor, outdoor and workplace concentrations. Atmospheric Environment 2004; submitted.

Edwards, R. D., C. Schweizer, et al. VOC personal exposures in EXPOLIS - questionnaire predictors. 2004; prepared.

Ilacqua, V., O. Hänninen, et al. Contributions of indoor, outdoor and other sources to personal VOC exposure in five European cities. Indoor Air 2004, prepared.

Ilacqua, V., O. Hänninen, et al. Intake fraction distributions for indoor VOC sources in five European cities. Indoor Air 2004, prepared.

Lai, H. K., H. ApSimon, et al. Determinants of indoor air concentrations of PM2.5, black smoke and NO2 in six European cities (EXPOLIS study). Atmospheric Environment 2004; submitted.

Lai, H. K., H. ApSimon, et al. Determinants of indoor VOCs in six European cities - EXPOLIS study. 2004, planned.

Schweizer, C., R. D. Edwards, et al. Time in Traffic in seven European cities. Environmental Health Perspective 2004; prepared.

Schweizer, C., R. D. Edwards, et al. Indoor Time-Activity Patterns in seven Regions of Europe. Journal of Exposure Analysis and Environmental Epidemiology 2004; submitted.

## *Talks*

| Date | Location | Speaker | Title, Topic |
|---|---|---|---|
| Nov 27, 2002 | ISPM, Basel | Schweizer | General introduction to EXPOLIS-INDEX |
| Sept 24, 2003 | Stresa, ISEA 2003 | Ilacqua | "Contributions of indoor, outdoor, and other sources to $PM_{2.5}$ exposure in four European cities" |
| Sept 24, 2003 | Stresa, ISEA 2003 | Künzli | General introduction to EXPOLIS-INDEX |
| Sept 24, 2003 | Stresa, ISEA 2003 | Lai | "Determinants of residential indoor VOC and $PM_{2.5}$ levels in six European cities – the EXPOLIS study" |
| Sept 24, 2003 | Stresa, ISEA 2003 | Schweizer | "Time-microenvironment-activity-patterns (TMAP) across Europe: How homogeneous is the European adult urban population?" |
| Oct 23, 2003 | USC, Los Angeles | Künzli | "Pollutants versus Surrogates – A conflict of Interest in Air Pollution Research?" |
| Nov 20, 2003 | Brussels, CEFIC-LRI meeting | Lai | "EXPOLIS – Human Exposure Patterns and Models for Health Risk Assessment" |
| July 1, 2004 | USC, Los Angeles | Künzli | General introduction to EXPOLIS-INDEX |
| July 1, 2004 | USC, Los Angeles | Edwards | "VOC Exposures in EXPOLIS" |
| July 1, 2004 | USC, Los Angeles | Schweizer | "Time-microenvironment-activity patterns across Europe" |

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Pellizzari, E. D., R. L. Perritt, et al. National human exposure assessment survey (NHEXAS): exploratory survey of exposure among population subgroups in EPA Region V. *Journal of Exposure Analysis and Environmental Epidemiology* 1999; 9(1): 49-55.