

Urban benzene pollution and population exposure

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Benzene is among the gasoline components and is airborne by vehicular traffic. It is a myelotoxic and leukaemia-inducing compound [1-3]. The risk level, expressed as myeloid leukaemia cases increment estimate among the population not professionally exposed to benzene, has been stated to range 3.8 to 7.5 cases every million people exposed during the lifetime to $1 \mu\text{g}/\text{m}^3$ [4-6]. All the estimates deal with exposure, not with environmental concentration. Since the two parameters can be not coincident, the citizens' risk level, which depends on actual exposure, can not be simply estimated by means of urban pollution. Therefore, once a socially acceptable exposure risk level is stated by a political decision, one can set a limiting value for benzene concentration in urban air only if the relationship between personal exposure and urban pollution is known. We find the citizens' exposure level, whatever their occupation or the fraction of time spent outdoors, is higher than urban average level and is equal, on average in Europe, to twice its value.

To establish this relationship, six towns and a sample of their citizens and their homes have undergone environmental monitoring for an entire year. The towns were distributed among the Northern, Central and Southern European countries, comprising a wide range of different lifestyles, climates and development features.

In each of the towns of Antwerp (Belgium), Athens (Greece), Copenhagen (Denmark), Murcia (Spain), Padua (Italy) and Rouen (France), one hundred sampling sites on average have been chosen. The sampling sites were distributed along the knots of a multi-scale grid drawn over the town map. A multi-scale grid is characterised by a variable mesh size: closer where pollution sources density is higher, progressively looser elsewhere. While maintaining tolerably little the number of sampling sites, this approach provided very similar results to those one would have obtained by covering the whole town with the closer mesh size grid [7]. Within each town, the sampling sites have been divided among an 85% of background sites, a 10% of hot spots and a 5% of periurban sites. The background sites were open spaces as squares or parks or streets apart from the intense traffic. The hot spots coincided with road crossings or roads with intense or slowed down traffic. The periurban sites were chosen in peripheral areas with scarce or very flowing traffic. The percentage distribution was based on the idea that people spend their time, on average, in the different kinds of places more or less with the same distribution.

Once each two months, from September 1997 to September 1998, the sampling sites have been uninterruptedly monitored, from Monday morning to Friday afternoon, by means of radial symmetry passive samplers [8], developed by ourselves and named *radiello*. This device relies on spontaneous diffusion of gaseous molecules driven by a concentration gradient across a diffusive barrier. Diffusing molecules are captured by an adsorbing material with a constant uptake rate which, in the case of benzene, is $80 \cdot 10^{-6} \mu\text{g}/\text{min}$ each $\mu\text{g}/\text{m}^3$ in air. To obtain concentration values one just needs to know the collected amount and the exposure time. The authors tested the sampler reliability both in standard atmosphere chamber and in the actual sampling sites. We found a maximum bias value of 4.45% and a coefficient of variation of 2.5 – 22.0% for 120 samplers

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exposed for 4.5 days to benzene concentrations in the range from 1.5 to 47 $\mu\text{g}/\text{m}^3$.

At the same time fifty volunteers have undergone personal sampling for the same duration. The volunteers were non-smoking and equally divided into exposed and non-exposed people. Actually, any citizen is exposed to benzene: the distinction is between people who, due to the duties of their job, spend a lot of time outdoors, and people who spend more time indoors, in schools or offices. In the first group policemen, postmen, street sweepers, stall-holders, bus and taxi drivers were comprised. The second group was composed of students, teachers and clerks. The volunteers' movements within the town area have been checked by an individual diary. The monitoring activity has been extended to the volunteers' homes also, furnishing surprising outcomes about the domestic pollution contribution to the overall personal exposure level. Personal and home monitorings have been carried out by the same technique and for the same duration of the environmental ones.

Both environmental and personal data relative to volunteers and their homes have been subjected to strict validation procedures. Environmental samples

coming from spoilt samplers or giving uncertain analytical results have been rejected: 3147 data have passed the validation tests. The validation procedure regarding the volunteers' and homes' data has been more selective, since also the volunteer behaviour had to be considered. This has been accomplished both by the detailed examination of the personal diary and, in case of controversy, by conversation with the volunteer. At the end of the validation process, 1559 data of personal exposure and 1499 of indoor home sampling have been accepted. Therefore, the experimental data base is made of 6205 measurements, quite equally distributed over the six towns.

All the results are summarised in figure 1. The proposed data represent the average of the mean values measured during all of the six campaigns in each town. The urban pollution means were obtained averaging all the data collected over each whole city territory.

A first interesting observation is that the urban pollution level, as an annual average, increases in Europe from North to South as shown in figure 2, ci-contre.

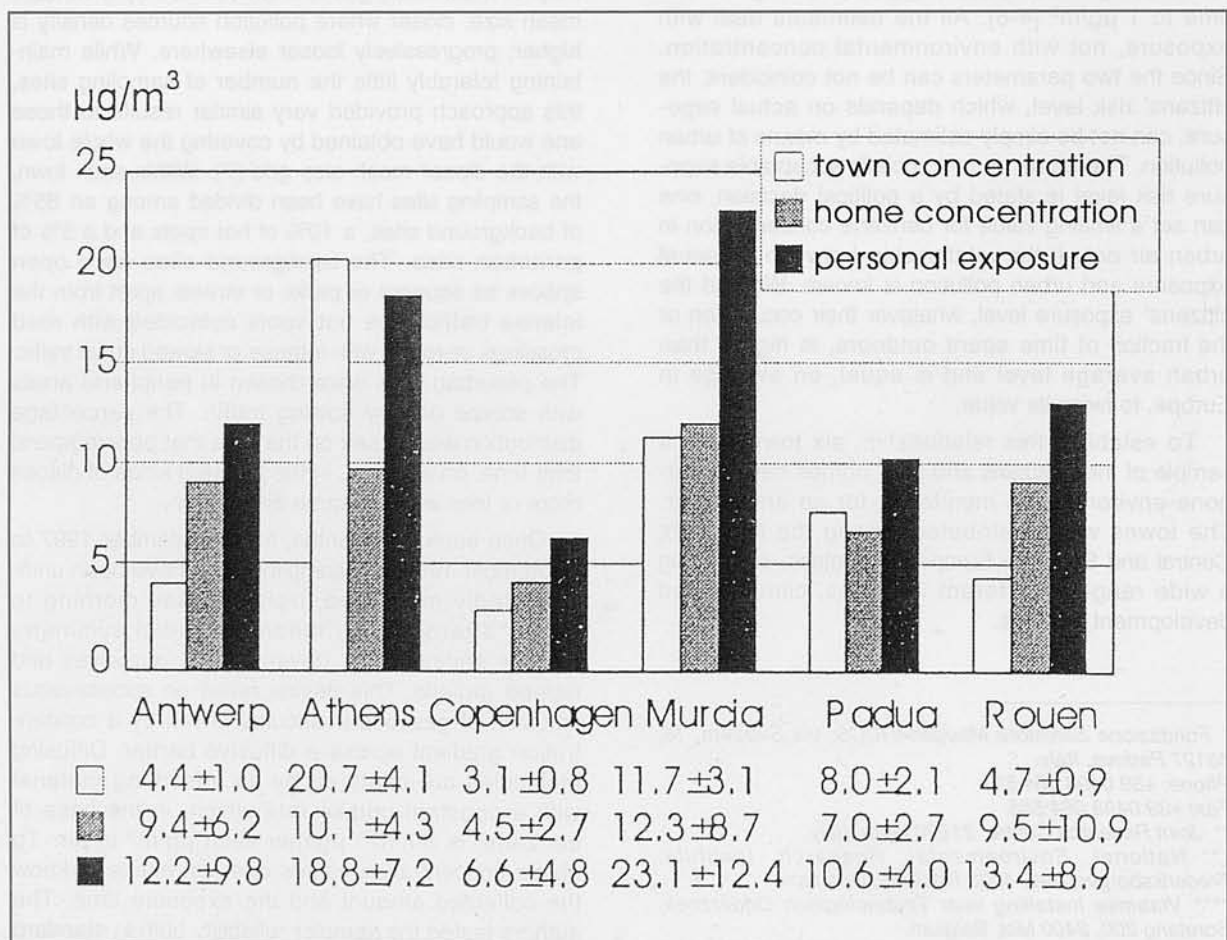


Figure 1.

Annual values for benzene concentration as averages of the six monitoring campaigns, concerning urban pollution, home concentration and personal exposure levels. Figures express concentrations in $\mu\text{g}/\text{m}^3$.

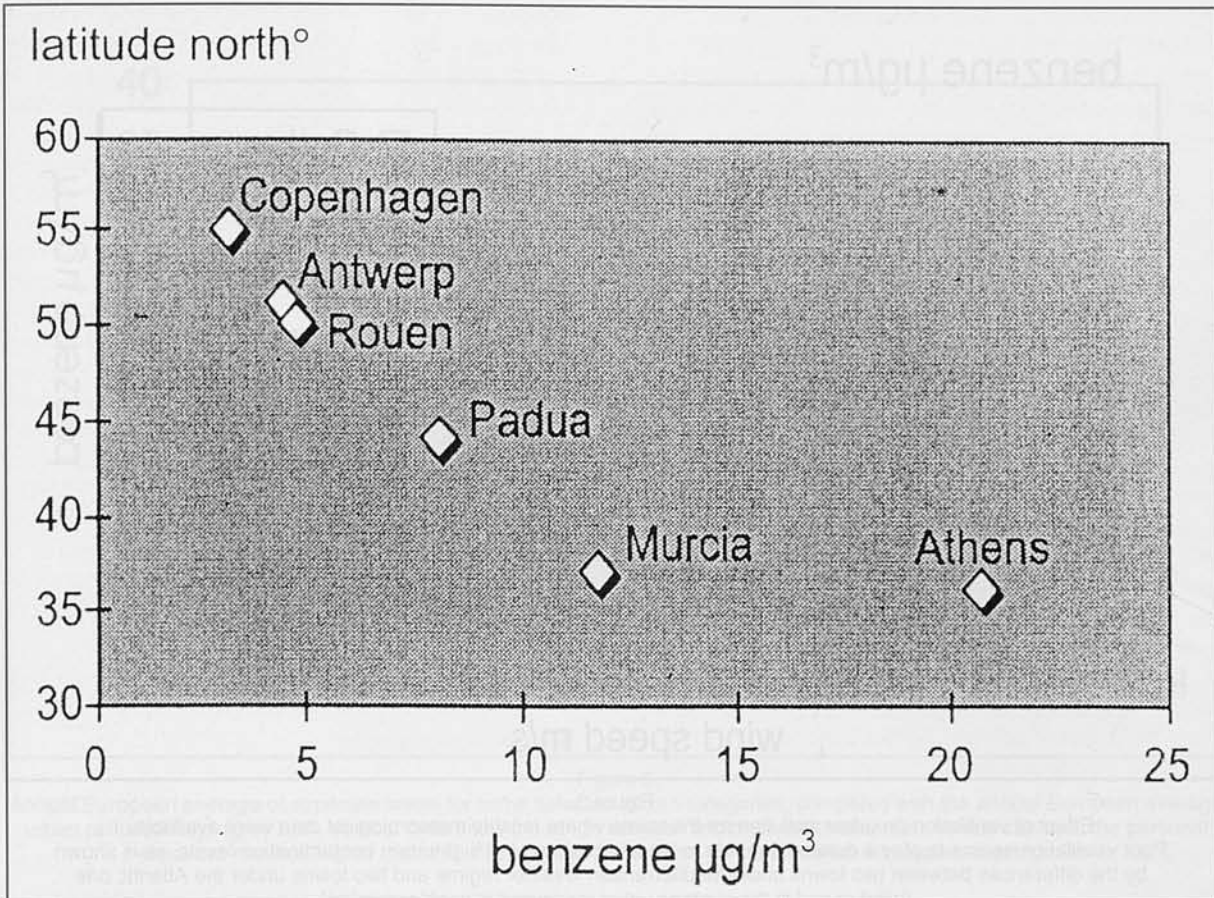


Figure 2.
Annual average urban pollution levels as a function of city latitude.

Several reasons might be brought forward to explain this experimental finding, one of which is the difference in meteorological conditions. A decrease of the average pollution level has been measured experimentally in correspondence with the increase of average wind speed during each sampling campaign (Figure 3, p. 510).

Towns in Northern Europe are constantly windy, being subject to the passage of Atlantic atmospheric disturbances, whereas the Mediterranean towns (Padua, Murcia and Athens) have weather conditions influenced by the persistent anticyclone regime.

Nevertheless, personal exposure and home monitoring data do not reflect the differences observed between Northern and Southern European towns in urban pollution levels. The ratio between the most polluted town, as an annual average, and the least polluted one is equal to 6.7, but the same ratio between personal exposure average values drops to 3.6 and even to 2.7 when indoor home measurements are concerned.

The results appear to be even more interesting if one compares citizens' exposure and indoor pollution levels with urban pollution values. As is clear from figure 4, p. 510, benzene exposure level of European citizens is higher than the average urban pollution

level, except for Athens due to the reasons that will be clearer later. This is true for all the citizens' categories, non-exposed included (Figure 5, p. 511).

The experimental data suggest an explanation of the phenomenon. As far as the daily concentration profile is concerned (Figure 6, p. 511), benzene concentration oscillates between very low values during night time and very high in the middle of the day and in the evening. Since most people get about in the streets when benzene concentration is 1.5 – 2.5 times higher than daily average, one can estimate that the actual outdoor exposure is about twice than that calculated basing on the daily urban average concentration and the time spent outdoors.

Nevertheless, this contribution is only a fraction of the total. By reconstructing the exposure history of the volunteers by means of their diaries, one realises that people spend, on a European average, about 22% of their time outdoors (for work, shopping, transportation, spare time activities, etc.), about 60% of the time at home and the remaining about 18% in indoor places different from home (schools, offices, pubs, restaurants, etc.). Therefore, the contribution due to staying at home becomes very important. On a European basis, excluding Athens, the average pollution level at home has come out to be 1.51 times

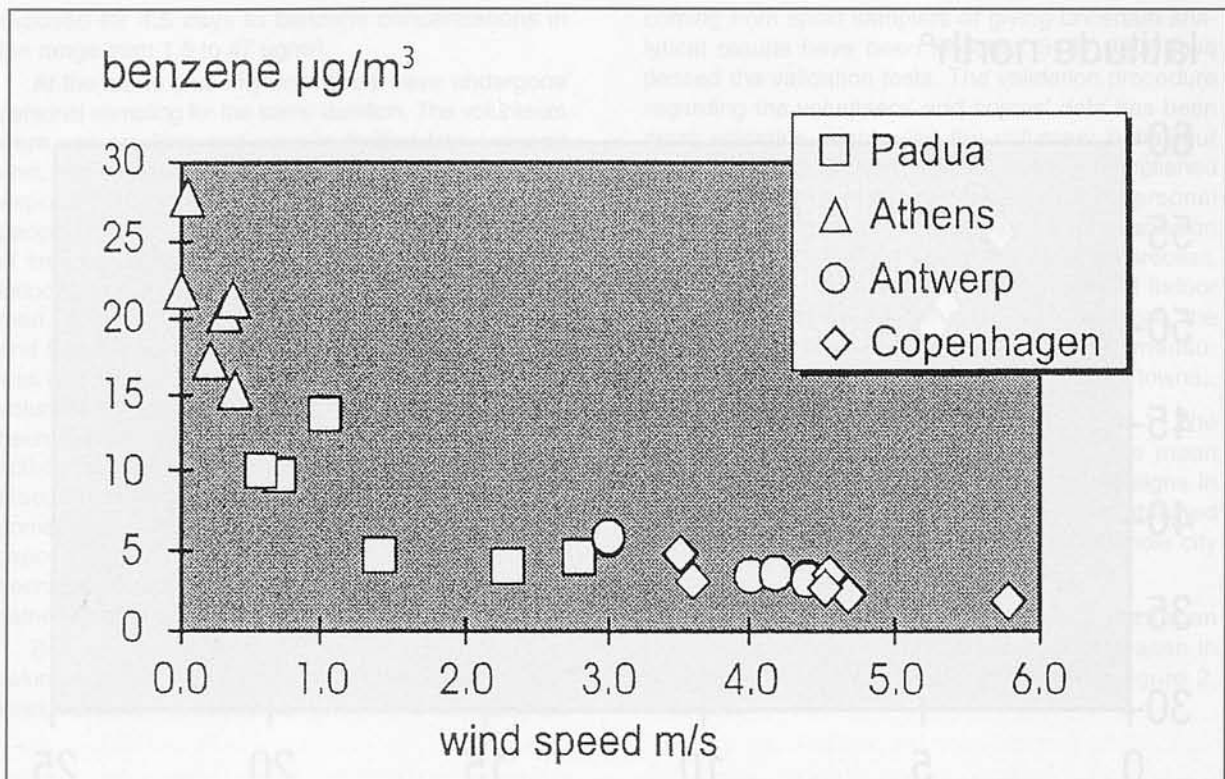


Figure 3.

Effect of ventilation on urban pollution for the towns where reliable meteorological data were available. Poor ventilation seems to play a determining role in the establishment of high urban contamination levels, as is shown by the differences between two towns under Mediterranean weather regime and two towns under the Atlantic one (wind speed is the average value measured in each campaign).

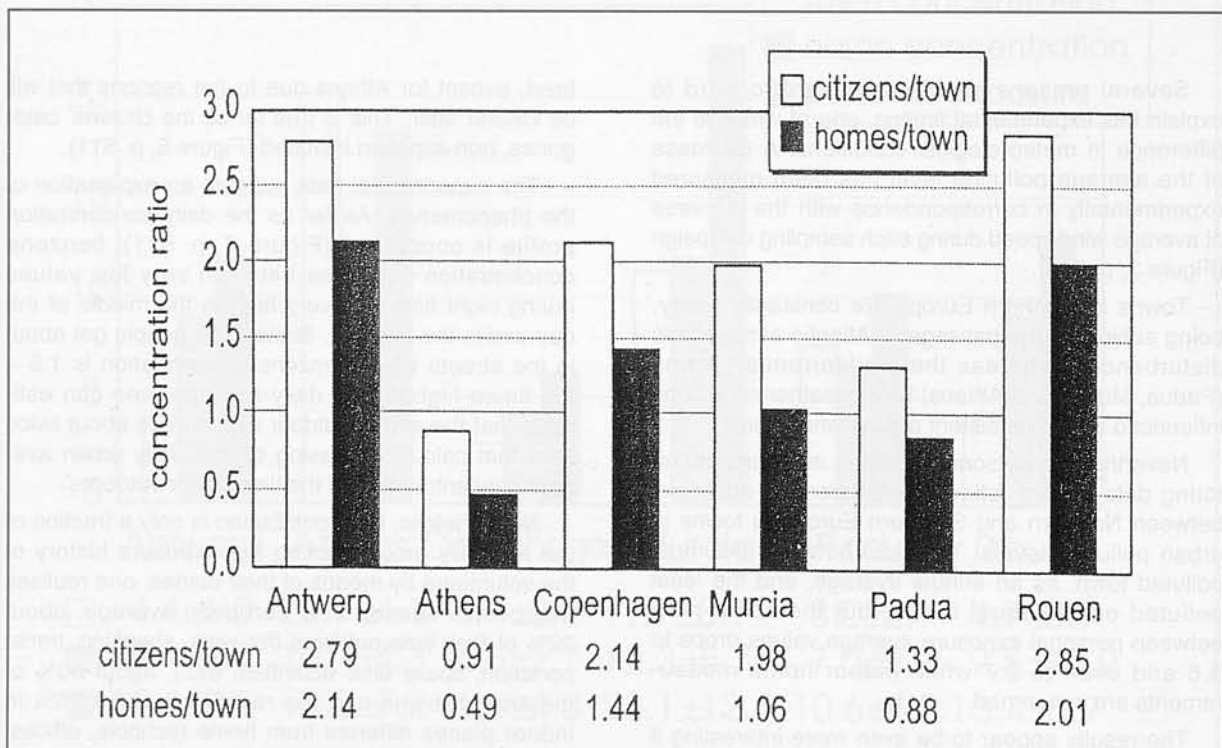


Figure 4.

Personal exposure and home pollution level ratios with urban pollution as annual averages for each town.

On European basis, average citizens' exposure/town pollution ratio value was 2.00.

On the same basis and omitting Athens (see text), average homes/town pollution ratio value was 1.51.

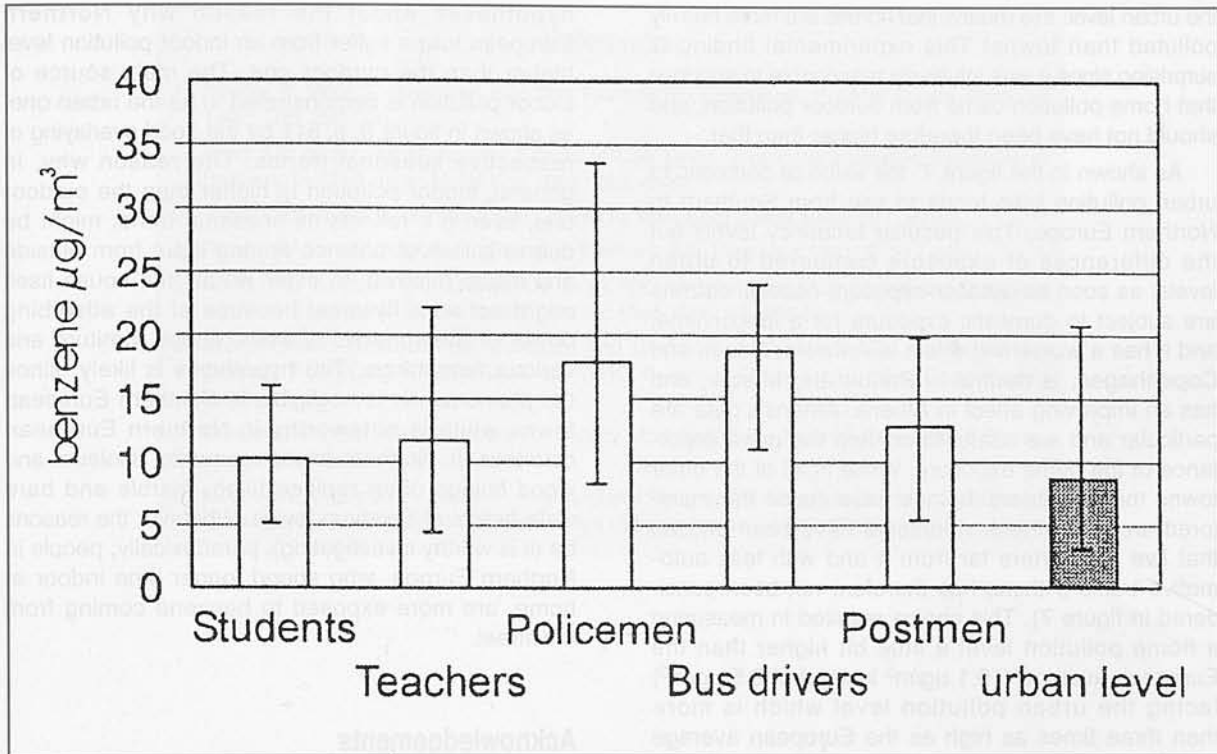


Figure 5.

Annual European average of exposure levels for some selected citizen categories, compared with the annual European average urban pollution level (grey bar). Vertical lines show the range between minimum and maximum. As one can see, the personal exposure resulted higher than the urban pollution level also for the so-called non-exposed categories.

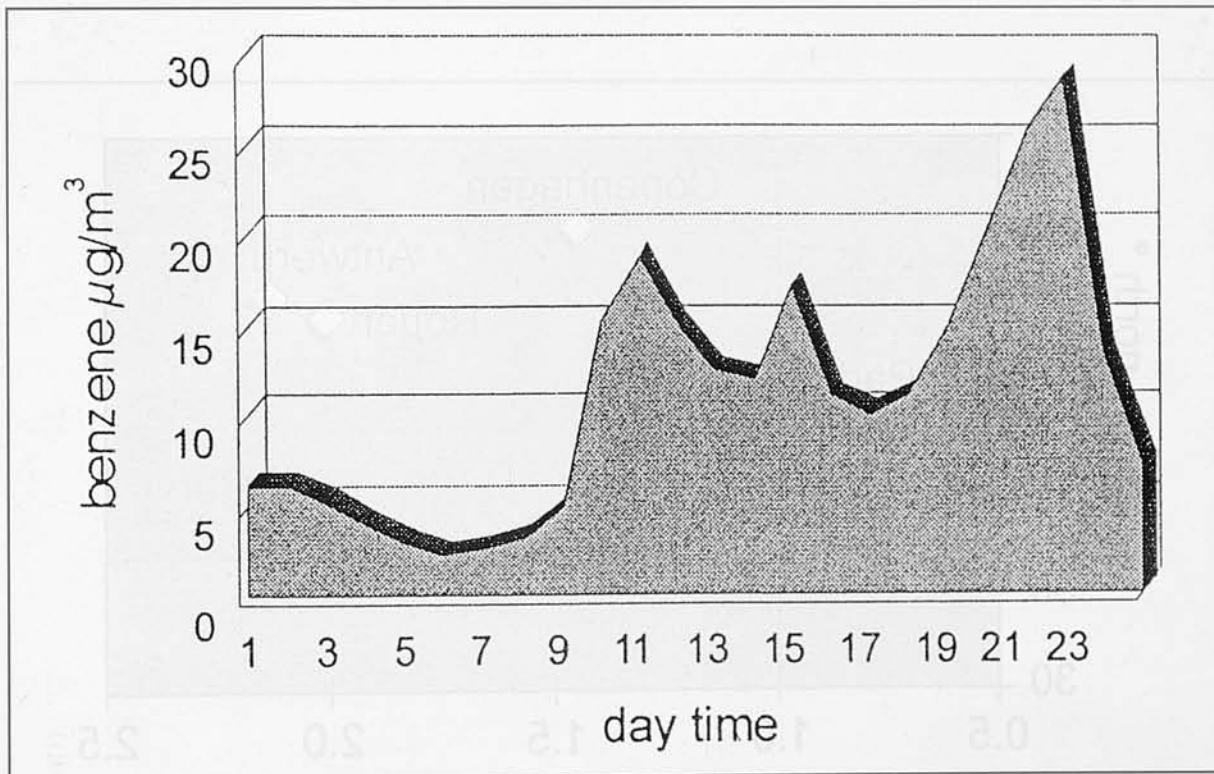


Figure 6.

Typical daily profile of benzene hourly average concentrations, obtained by a BTX automated analyser. Data refer to the last campaign in Padua; each hourly value is the average over the whole monitoring campaign. Similar profiles have been obtained in other towns equipped with the same instrumentation, with minor variations in the peak time, depending on local lifestyles.

the urban level: this means that homes are more heavily polluted than towns! This experimental finding is surprising since it was intuitively reasonable to suppose that home pollution came from outdoor pollution, and should not have been therefore higher than that.

As shown in the figure 7, the value of domestic to urban pollution ratio tends to rise from Southern to Northern Europe. This peculiar tendency levels out the differences of exposure compared to urban levels: as soon as outdoor exposure ceases, citizens are subject to domestic exposure for a longer time, and it has a worsening effect in Antwerp, Rouen and Copenhagen, is neutral in Padua and Murcia, and has an improving effect in Athens. Athens's data are particular and are useful to confirm the great importance of the home exposure. While in all of the other towns the volunteers' homes were inside the monitored area, in Athens volunteers have been chosen that live in quarters far from it and with less automotive traffic (Athens has therefore not been considered in figure 7). This choice resulted in measuring a home pollution level a little bit higher than the European average ($10.1 \mu\text{g}/\text{m}^3$ instead of $8.5 \mu\text{g}/\text{m}^3$) facing the urban pollution level which is more than three times as high as the European average ($20.7 \mu\text{g}/\text{m}^3$ instead of $6.4 \mu\text{g}/\text{m}^3$). Well, as can be seen from the figure 1, p. 508, the overall personal exposure level in Athens turned out to be $18.8 \mu\text{g}/\text{m}^3$, that is only a 40% higher than the European average ($13.2 \mu\text{g}/\text{m}^3$).

The gathered data allow us to put forward some

hypotheses about the reason why Northern European towns suffer from an indoor pollution level higher than the outdoor one. The main source of indoor pollution is demonstrated to be the urban one, as shown in figure 6, p. 511 by the good overlaying of respective seasonal trends. The reason why, in general, indoor pollution is higher than the outdoor one, even if it reflects its seasonal trend, might be due to a lack of balance among input from outside and inside removal. In other words, the house itself might act as a flywheel because of the adsorbing power of the surfaces of walls, floors, furniture and various furnishings. The hypothesis is likely, since the phenomenon is negligible in Southern European towns while is noteworthy in Northern European countries. In Northern towns moquette, linoleum and bare walls often replace tiling, marble and bare walls typical of Southern towns. Whatever the reasons be (it is worthy investigating), paradoxically, people in Northern Europe, who spend longer time indoor at home, are more exposed to benzene coming from the street.

Acknowledgements

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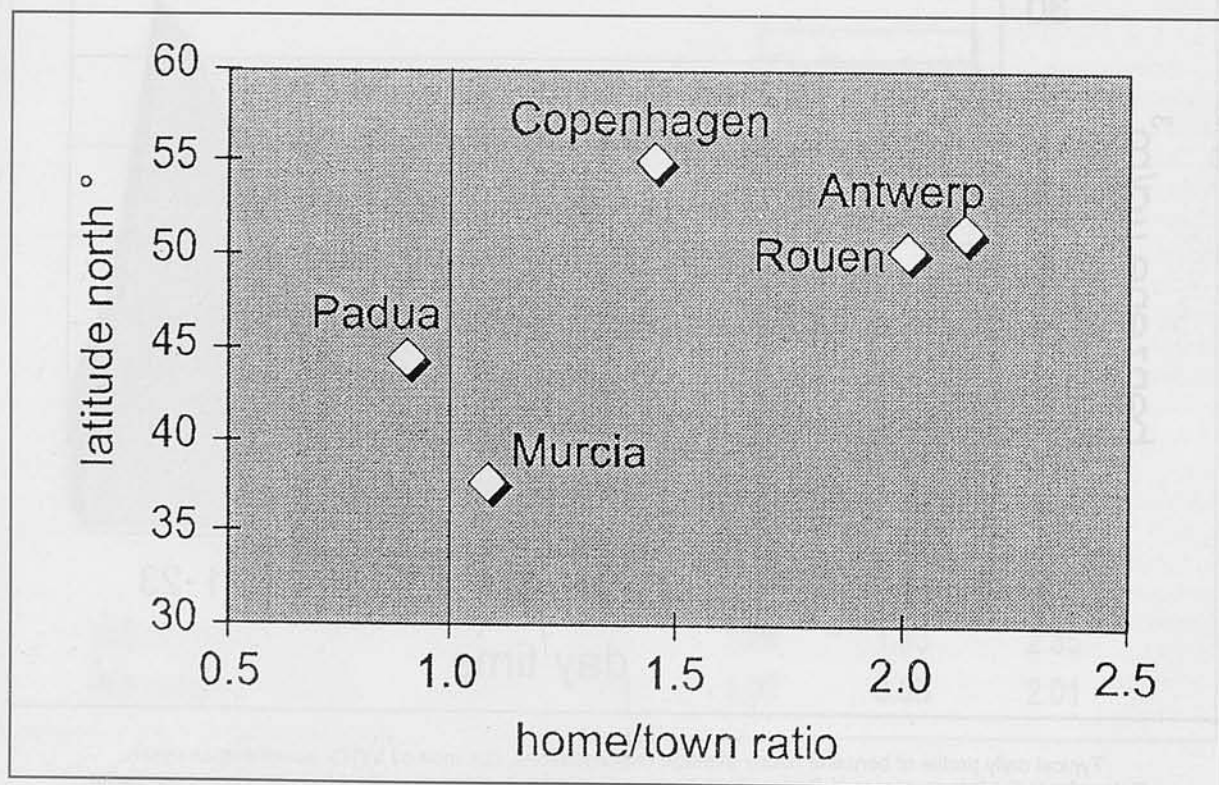


Figure 7.
Home to urban pollution ratios as a function of latitude.

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