#4005

Experiences with Indoor Measurements of Organic Compounds

Helmut Knöppel and Maurizio De Bortoli

Commission of the European Communities – Joint Research Centre
Institute for the Environment
I–21020 Ispra (Varese), Italy

Paper presented at the
Indoor Air Quality International Symposium
AMERICAN INDUSTRIAL HYGIENE CONFERENCE
May 21–26, 1989, St. Louis, Missouri

Experiences with Indoor Measurements of Organic Compounds

Helmut Knöppel and Maurizio De Bortoli

Introduction

Complaints and concern about bad indoor air quality are increasing worldwide. Symptoms such as irritation of the mucous membranes, headaches, nausea, fatigue, and general malaise often are attributed to unsatisfactory air quality in buildings. The term sick building syndrome (SBS, World Health Organization 1983) now is accepted generally to describe the situation when occupants of a building, most often an office building, complain about such symptoms and when the complaints persist for more than two weeks at frequencies significantly greater than 20 % (WOODS 1988). SBS most often is found in air conditioned buildings, however, it is not limited to them (Finnegan and Pickering. 1987). Complaints on bad indoor air quality usually refer, singly or in combination, to the following symptom complexes (Molina et al. 1989):

- Nasal manifestations: Most frequently nasal irritation with rhinorrhea and nasal obstruction, usually described as "nasal stuffiness".
- Ocular manifestations: Dryness and irritation of the mucous membrane of the eye.
- Oropharyngeal manifestations: Dryness and irritation of the throat.
- Cutaneous manifestations: Dryness and irritation of the skin, occasionally associated with a rash on exposed skin surfaces.
- General manifestations: Headaches and generalized lethargy and tiredness leading to poor concentration.

When related to the workplace these symptoms, with the exception of some cutaneous manifestations, improve over weekends and all symptoms usually resolve themselves on holiday.

Four major groups of risk factors have been considered:

- Physical: Temperature, relative humidity, ventilation, artificial light, noise and vibrations, ions, electrostatic charges, inorganic dust, including asbestos and man made mineral fibers (MMMF)
- Chemical: environmental tobacco smoke (ETS), formaldehyde, volatile organic compounds (VOC), semivolatile organic compounds (SVOC e.g., biocides), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), odors
- Biological: molds and their metabolic products
- Psychological

Organic pollution is only one of these risk factors but is often suspected as the cause of complaints about SBS symptoms. This tendency probably is influenced by the important role that indoor pollution by formaldehyde and by some pesticides has played in focusing initially public and scientific attention on the indoor air quality issue and by the finding that many VOC occur indoors at higher concentrations than outdoors. On the other hand, many complex measurements have not succeeded in establishing a cause–effect relationship between organic indoor pollution and complaints. Thus Woods (1988) reports on investigations in 30 office buildings presenting a typical SBS situation where in 80% of the cases physical problems could be identified, in 70% disturbing odors were detected but only in 5% chemical substances (apart from odor) have been measured at levels of concern.

This paper outlines some basic considerations regarding the potential role of organic pollution as a cause or cofactor of SBS symptoms and discusses experiences with the measurement of organic pollution in the light of these considerations. In addition the authors' recent experience with a strategy to minimize the measurement effort for the assessment of VOC in office buildings of the European Parliament (EP), where a not well-substantiated suspect of air quality problems had arisen, will be reported.

Types of Organic Pollution and Their Potential Role for Producing SBS-Type Symptoms

In order to study the impact of organic pollutants on air quality and on indoor air quality in particular, it is appropriate to classify them into four broad groups as shown in **Table I** (World Health Organization 1989). The groups or categories are defined by boiling point ranges, although no sharp limit exists between them. The reason is that in practice the groups are determined by the different methods used to collect organic pollutants from air. The most frequently applied methods are given in column 4 of Table I.

Some low molecular weight aldehydes, in particular formaldehyde, usually are not analyzed together with the broad range of volatile organic compounds but need sampling and analytical methods which are specific for an individual compound or compound class. For the analysis of low molecular weight aldehydes, which is of particular importance for indoor air quality, derivatization with dinitrophenylhydrazine (DNPH) and analysis with high performance liquid chromatography (HPLC) are the most often applied methods. In the following discussions aldehydes are treated together with VOC.

Various known or suspected effects of organic indoor pollutants have been associated with SBS - type symptoms and are summarized in **Table II**. The effects in the table are known or supposed to have thresholds. It is, therefore, useful for the following discussion to have an approximate idea of the ranges of concentration which have been reported for the different categories of organic indoor pollutants. For this purpose in **Table III** some data for total very volatile organic compounds (VVOC), for total VOC and for SVOC concentrations have been collated. For most of the effects in Table II, available knowledge on thresholds or related limit values refers to single compounds. Indoor air, however, usually contains more or less complex mixtures of organic compounds. Therefore, for the sake of simplicity, and because the upper values of the ranges of total concentrations are also indicative for the more abundant single constituents, total concentrations have been preferred in this table.

Unfortunately published data on concentration distributions of organic indoor pollutants are limited to VOC measured in the residential environment and recently have been consolidated for the more frequently detected compounds by a World Health Organization (WHO) working group (World Helath Organization 1989). In Table III the distribution of the sum of all quantified compounds of a German study (Krause et al. 1987), the largest of the data sets considered by the

WHO group, is given. These data correspond to 60%–80 % of the total VOC concentrations. For comparison the total VOC concentrations measured in 80 offices of 10 buildings of the European Parliament (EP) in Brussels, Luxembourg and Strasbourg are published here (Table III and Fig. 1). Sampling (on Tenax®), GC and GC/MS analysis for these measurements have been performed as described earlier (De Bortoli et al. 1986). The measurements of Krause et al. (1987) refer to residences, are 2-week averages, and represent about 70% of the total VOC concentrations. The data reported here for offices are only 10-minute averages. The agreement between the two is excellent, and the data can be considered fairly representative at least for European indoor environments. Higher concentrations may arise in new buildings. For new buildings in Denmark, Mølhave (1986) reports total VOC concentrations of up to 25 mg/m^3.

No data on the distribution of total VVOC are available. Comparative measurements of VVOC and VOC in 16 EP offices (this work) resulted in total VVOC concentrations which ranged from 11% to 90% of the total VOC concentration. Little quantitative data on SVOC in indoor air have been published. Oehme and Knöppel (1987), simulating a "worst case" situation, found in a one-family house a total concentration of 80 µg/m^3. Pesticides which probably are of greatest health concern among SVOC constituents have been found at concentrations ranging from 0.01 to 28 µg/m^3 (Sterling 1985).

Exposure to particulate organic matter as yet has not been associated with effects yielding SBS symptoms. Such effects usually are attributed to the physical or biological properties of particulate matter.

The following briefly discusses whether and in which conditions available knowledge allows one to relate indoor concentrations of organic compounds to the various effects in Table II and, hence, whether and when measurements of organic indoor pollutants may be useful in SBS investigations. Recommendations made in a practical guide for SBS investigations (prepared in the framework of a European collaboration in the field of indoor air qualtiy and its impact on man, Molina et al. 1989) are included.

Odor Annoyance

Odor annoyance is frequently associated with SBS symptoms and, in most cases, is supposed to be caused by organic indoor pollutants. The usefulness of organic measurements for identifying the causes of odor annoyance, however, is limited for the following reasons.

- Odour thesholds of organic compounds vary over more than 10 powers of 10. Those of most intense and frequent indoor pollutants are relatively high (0.1 – >100 mg/m^3).

- There is no generally accepted model for the determination of the odor intensity of complex mixtures like organic compounds in indoor air.

- As a rule of thumb, the perceived strength of an odorous mixture may be estimated with a ±50% accuracy from the strength of the strongest smelling compound (World Health Organization 1989). Therefore, a minor but strongly smelling constituent in indoor air may determine its odor perception.

It follows that chemical measurements in general are not useful to detect the cause of complaints arising from odour annoyance. Other approaches (e.g., Fanger 1988) are necessary and preferable.

An exception is formaldehyde, which among the more frequently detected indoor pollutants has the lowest odor threshold and the highest potential for mucous membrane irritation (Table IV) and is the organic indoor pollutant which most frequently has been identified as a chemical cause of indoor air quality complaints. In addition to formaldehyde, odor annoyance by higher aliphatic aldehydes has been identified as a cause of indoor air quality complaints (van der Wal 1987). Therefore, the measurement of formaldehyde, and possibly of a wider range of aldehydes, is indicated where odor or suspected sources suggest their presence.

Sensory effects

There are sensory effects of organic compounds other than odor which result from their interaction with different parts of the sensory system, in particular with the trigeminal nerve. The work of Mølhave, Bach, and Pedersen (1986) and Mølhave, Jensen, and Larsen (1988) has evidenced these effects in humans and has shown that the effects depend on the total concentration of VOC. The more important results of this research in relation to indoor measurements are the following.

- The lowest human response levels to a mixture of 22 volatile organic compounds typically found in indoor air for several symptoms of a sensory effect (sensation of insufficient air quality; need for ventilation; irritation in eye, nose and throat; headache and general malaise) occur at 8–25 mg/m^3. No such effects have been observed at levels $\leq 3\ mg/m^3$.

- Apart from odor annoyance, these effects are the most sensitive acute effects known until now for a mixture of VOC detected indoors.

- The connection of these effects with SBS-type symptoms suggests that the measurement of VOC respectively of total VOC concentrations may be helpful in identifying causes of complaints in some circumstances, e.g. in new buildings where VOC concentrations above 3 mg/m^3 may occur, in particular within about the first couple of months after completion.

Sensory effects, however, in general do not justify organic measurements in older buildings because of the total VOC concentrations usually found (Table III), unless there are indications of strong sources of organic compounds.

Recently put forward has been the hypothesis that concentration gradients rather than the mean level of concentrations may trigger SBS symptoms as a consequence of lack of sensory adaptation (Noma et al. 1988). This interesting hypothesis needs further investigation.

Mucosal Irritation and Other Acute Effects

Available knowledge on mucosal irritation and acute effects on the central nervous system (CNS) which both may produce SBS type symptoms refers to single substances and is mostly reflected in occupational threshold limit values (TLVs®). Such thresholds, however, are inadequate for an assessment of potential effects of indoor pollution (Sterling 1985) for the following reasons.

- People working in the industrial environment are in general healthier than the general population which also is composed of children, the elderly, and those with preexisting conditions who are potentially more susceptible to the possible adverse effects from exposure to pollutants.
- TLVs do not account for the simultaneous exposure to a mixture of pollutants which is the typical indoor situation.

Therefore, in the absence of more adequate health information, sometimes TLVs or no observable effect levels (NOELs) divided by a protection factor are used in order to assess whether a given indoor exposure may or may not be expected to affect people. Depending on the kind and reliability of the dose-response data and on the importance of the effect on which a TLV or NOEL is based, protection factors between 10 and 100 usually are applied.

Table IV compares (for some of the more frequently detected indoor pollutants for which a TLV exists) 90 percentiles estimated by a WHO working group from published survey data (World Health Organization 1989) and 90 percentiles and maximum concentrations measured by the authors in EP offices with TLV/10 and with a few air quality guidelines (AQG) for outdoor and indoor air published recently by WHO (1987). The latter values have been derived from NOELs applying protection factors of 50 or 100. Apart from formaldehyde all 90 percentiles and maximum values are below the TLV/10 and AQG values. For n-hexane, tri- and tetrachloroethylene the measured concentrations are nearest to these values.

These data indicate that only in exceptional cases organic indoor pollution by compounds other than formaldehyde will cause acute toxic effects which may lead to SBS symptoms.

Effects Caused by Long-Term Exposure

Organic compounds have been suspected of contributing to the prevalence of SBS-type symptoms also through effects caused by long-term exposure such as **sensitization** and **chronic intoxication** influencing the central nervous system (CNS). There exists, however, little evidence which would support this hypothesis for the types and concentration levels of organic compounds detected indoors. With respect to **sensitization**, the following observations can be made.

- A list of chemicals classified as sensitizers of respiratory organs according to European Economic Community Directive 67/548 (labelling of dangerous substances, **Table V**) contains mostly SVOC and none of the compounds contained in a list of 307 organic pollutants detected in indoor air (Berglund, Berglund and Lindvall 1986).
- There are some indications that formaldehyde may cause respiratory tract sensitization (Bach, Mølhave, and Pedersen 1987). They are based on a comparison of performance tests under controlled exposure conditions of subjects with and without previous occupational exposure.
- There is insufficient knowledge about mechanisms of nonallergic hypersensitivity reactions (Schulz 1983) and whether any organic indoor air pollutant may cause such reactions.

For the time being, therefore, measurements of organic indoor pollutants do not appear useful for identifying situations in which sensitization may occur.

Once people are sensitized for allergic or nonallergic hypersensitivity reactions to some chemical(s), they may show SBS symptoms at usually unsuspected concentrations. It is evident that measurements of organic pollutants in buildings where such problems arise only can reveal the cause if the hypersensitivity state and the stimulating chemical(s) are known. Comparison of the most frequently encountered types of reaction of haptens and proteins (yielding potential allergens) shown in **Table VI** (Zaikov 1982) with known indoor air pollutants suggests that aldehydes and chlorinated hydrocarbons are the pollutants which should be considered first in case of allergic hypersensitivity.

In several cases in the Federal Republic of Germany (FRG) prolonged indoor exposure to vapors emanating from wood treated with impregnants containing pentachlorophenol (PCP) has led to suspected **chronic intoxication**. In such cases, among others, typical SBS symptoms like generalized lethargy and tiredness, mental fatigue, headaches, dizziness, and irritability have been observed (Gebefügi and Parlar 1978). In the meantime, PCP no longer is used for indoor applications in the FRG, and its complete ban is under preparation.

Neurological symptoms similar to those for PCP were most prominent in dairy farmers in Michigan after prolonged accidental exposure to polybrominated biphenyls (PBB, a chemical used as flame retardant) where exposure mostly occurred through diet (Andersen et al. 1978). Incidentally, in the FRG recently, indoor air pollution by PBB vaporizing from electronic components in TV receivers and other electronic equipment has emerged as a public issue. Only a very minor concentration (2.7 pg/m^3), however, has been detected in indoor air under rather unrealistic conditions and only when the German chemical industry already had made the decision to substitute PBB as a flame retardant.

These and other experiences (e.g., Sterling 1985) indicate that prolonged indoor exposure to elevated levels of biocides and related compounds may lead to SBS-type complaints. The lack of dose-response information for the observed symptoms, however, does not allow firm associations of complaints with measured indoor air concentrations. It also should be pointed out that concentrations in indoor air of these semivolatile compounds are not necessarily representative of the exposure of inhabitants. Gebefügi and Parlar (1978) have found important amounts of PCP from wood impregnants adsorbed on textiles like bed sheets. Maroni et al. (1987) have found a good correlation of PCP in dust and in the urine of inhabitants in homes where a PCP-containing wood impregnant had been applied. They conclude that skin contact also is an important route of exposure.

The accumulated knowledge of indoor exposure levels and its comparison with effect levels that may lead to SBS symptoms and experience gained with the prevalence of other potential causes or cofactors of SBS symptoms have lead to strategies for SBS investigations that recommend chemical measurements only at a relatively late stage of such investigations. Recently, a working group of the European Concerted Action "Indoor Air Quality and Its Impact on Man" has prepared a guide for SBS investigations (Molina et al. 1989) the recommendations of which are summarized in **Table VII**. It considers orientative chemical measurements only at the third of four steps and more detailed chemical analysis only as the last step. Orientative measurements of total or individual VOC and of formaldehyde are envisaged in newly built or refurbished buildings if significant odors are present. At Step 4, after medical examinations, the assessment of some specific exposures to organic compounds together with a toxicological evaluation may be required.

Strategy for Measurements of VOC in Office Buildings and First Results

Although strategies for complaint building investigations widely accepted by the scientific community recommend organic measurements only at a late stage of a building investigation, situations may arise where measurements of organic pollutants are requested before other more frequent causes of complaints have been investigated. Such a case arose when several people in buildings of the European Parliament (EP) started to complain about bad indoor air quality and indicated indoor pollution by organic chemicals as the probable cause. In this situation the EP administration asked for a survey of the concentrations of volatile organic compounds and of aldehydes.

During three measurement campaigns in Brussels, Luxembourg and Strasbourg, in 50 offices selected as "representative", no unusually high concentrations of VOC could be detected in 10 buildings. In a few offices the formaldehyde concentration was, however, slightly above the WHO guideline value of 100 µg/m^3. In these cases an increase of ventilation with outdoor air was recommended.

In view of the beneficial effect of the measurements on the personnel's attitudes the administration asked for further survey measurements on a regular bases. In this situation a strategy was required which could help to minimize the number of organic measurements, relate these measurements to complaints, and argue against such measurements where no relation to complaints results. Therefore, in collaboration with the medical service of the EP, the decision was made to conduct a questionnaire inquiry on the presence of SBS-type symptoms and on perception/complaints of climatic and other environmental parameters. A 2-page, self-administered questionnaire was distributed among the EP staff. The answers from the symptoms part of the questionnaire (**Figure 1**) were used to calculate a "complaint index" attributing scores to the different symptoms and weights to the different answers and calculating a sum of products of weights and scores.

The answers on the returned questionnaires were used to select six buildings for a further survey of VOC concentrations. In each of these buildings, 2 or 4 (total 20) offices were selected, half of which had a complaint index value near to the maximum and half near to the minimum. This way a more rational choice of measurement locations appears possible than the selection of "representative" offices, which is always ambiguous, in particular if only few measurements are to be made. Some additional measurements were performed in a newly occupied building which had not yet been included in the questionnaire inquiry.

Figure 2 shows the distribution of the total VOC concentrations of all measurements performed in EP buildings (using Tenax® sampling and gas chromatographic analysis). Apart from one high value, all total concentrations are well below 3 mg/m^3. It could be expected, therefore, that the results of the measurements in offices with high and with low complaint indexes show no significant difference (**Figure 3**). The same holds for the formaldehyde concentrations (all below 100 µg/m^3) measured in the six buildings (**Figure 4**).

In order to ease orientative surveys of VOC concentrations in buildings, measurements of total VOC concentrations **without gas chromatographic (GC) separation** have been proposed (Gammage et al.). A direct reading, light weight, portable photoionization detector promises practical advantages for this scope. To test an instrument of this type in 55 offices parallel to Tenax® sampling (with subsequent GC analysis), measurements with a TIP I instrument (Photovac Inc., Thornhill, Ontario, Canada) have been performed. The results are shown in **Figure 5**. The TIP reading (arbitrary units) is plotted versus the total VOC concentration. Though an overall good correlation is found, values scatter considerably, in particular at low VOC concentrations. Moreover, the correlation line differs considerably from a calibration curve measured with a mixture of 6 compounds: benzene (37%), toluene (27%), m-xylene (12%), n-butanol (0.35%), n-heptane (20%) and hexanal (3.8%). A further evaluation of these differences is under way and includes the contribution of VVOC to the TIP reading.

Summary

As outlined in this paper current experience suggests the following recommendations with respect to measurements of organic indoor pollutants aimed at identifying causes or cofactors of complaints in office buildings.

- When buildings with indoor air quality problems are investigated **chemical measurements** should be made **only after** completion of a **technical survey** of the air supply systems, a **questionnaire** inquiry into type and prevalence of complaints, measurements of **ventilation** and **climate** indicators, and assessment of **odors**.

- **Deviations** from this rule may be justified for a **new building** (in particular within the first couple of months after completion) or when there are indications of **strong sources**.

- **Comparative measurements** in locations with **high** and with **low complaint levels** are recommended, in particular if no indications of high exposure locations exist.

- If information on sources does not supply other indications, the measurement of **total VOC** and of **aldehydes** should be the first step of chemical measurements.

References

Andersen, H.A.R., R.Lilis, I.J.Selikoff, K.D.Rosenman, J.A.Valciukas, and S.Freedman, 1978. Unanticipated Prevalence of Symptoms among Dairy Farmers in Michigan and Wisconsin. Environ. Health Perspect. 23: 217–226.

Andersen, I. 1989. Private communication. The list is available at the National Institute of Occupational Health, Lersø Parkallé 105, DK-2100 Copenhagen Ø, Denmark.

Bach, B., L.Mølhave, and O.F.Pedersen, 1987. Human Reactions during Controlled Exposure to Low Concentrations of Formaldehyde: Performance Tests. In Indoor Air '87 edited by B.Seifert, H.Esdorn, M.Fischer, H.Rüden, and J.Wegner, Vol.2. Berlin: Institute for Water Soil and Air Hygiene, pp. 620–624.

Berglund, B., U.Berglund, and T.Lindvall, 1986. Assessment of Discomfort and Irritation from the Indoor Air. In Proc. AIQ '86. Managing Indoor Air for Health and Energy Conservation. Atlanta, GA: American Society of Heating, Refregerating and Air-Conditioning Engineers, Inc. (ASHRAE). pp. 138–149.

De Bortoli, M., H.Knöppel, E.Pecchio, A.Peil, L.Rogora, H.Schauenburg, H.Schlitt, and H.Vissers, 1986. Concentrations of Selected Organic Pollutants in Indoor and Outdoor Air of Homes in Northern Italy. Environ. Int. 12: 343–350.

Fanger, P.O. 1988 Introduction of the Olf- and the Decipol-Unit to Quantify Air Pollution Perceived by Humans Indoors and Outdoors. Energy and Buildings 12: 7–19.

Finnegan, M.J. and C.A.C.Pickering, 1987. Prevalence of Symptoms of the Sick Building Syndrome in Buildings without Expressed Dissatisfaction. In Indoor Air '87 edited by B.Seifert, H.Esdorn, M.Fischer, H.Rüden, and J.Wegner, Vol.2. Berlin: Institute for Water Soil and Air Hygiene, pp. 542–546.

Gammage, R.B., D.L.Hansen, and L.W. Johnsen. Indoor Air Quality Investigations: A Practitioner's Approach. Environ. Int.: in press.

Gebefügi, I.and H.Parlar, 1978. Zur Riskoabschätzung von Pentachlorphenol in der Umwelt (Risk Estimate of Pentachlorophenol in the Environment). GSF-Report 0414. München: Gesellschaft für Strahlen- und Umweltforschung m.b.H., p. 33.

Krause, C., W.Mailahn, R.Nagel, B.Schulz, B.Seifert, and D.Ullrich, 1987. Occurrence of Volatile Organic Compounds in the Air of 500 Homes in the Federal Republic of Germany. In Indoor Air '87 edited by B. Seifert, H.Esdorn, M.Fischer, H.Rüden, and J.Wegner, Vol.1. Berlin: Institute for Water Soil and Air Hygiene, pp. 102–106.

Lafontaine, A. 1983. Public and Occupational Health Significance of Allergic Responses and Hypersensitivities Induced by Man-made Chemicals. In Health Aspects of Chemical Safety, Interim Document 12: Allergy and Hypersensitivity to Chemicals. Copenhagen: World Health Organization, Regional Office for Europe, and Luxemburg: Commission of the European Communities, Health and Safety Directorate, pp. 13–29.

Maroni, M., H.Knöppel, H.Schlitt, S.Righetti, 1987. Occupational and Environmental Exposure to Pentachlorophenol (Report nr. EUR 10795 EN). Luxembourg: Commission of the European Communities, Office for Official Publications of the EC

Mølhave, L. 1986. Indoor Air Quality in Relation to Sensory Irritation due to Volatile Organic Compounds. ASHRAE Trans. 92(1): 2954.

Mølhave, L., B.Bach, and O.F.Pedersen, 1986. Human Reaction to Low Concentrations of Volatile Organic Compounds. Environ. Int. 12: 167–175.

Mølhave, L., J.G.Jensen, and L.Larsen, 1988. Acute and Subacute Subjective Reactions to Volatile Organic Air Pollutants (Communication of the Institute of Environmental and Occupational Medicine). Aarhus (Denmark): Institute of Environmental and Occupational Medicine, University of Aarhus

Molina, C., C.A.C.Pickering, O.Valbjørn, and M.De Bortoli, 1989. "Sick Building Syndrome", a Practical Guide (Report nr. 4 of the COST-Concerted Action "Indoor Air Quality & Its Impact on Man" (COST project 613), Report nr. EUR 12294 EN). Luxembourg: Commission of the European Communities, Office for Official Publications of the EC.

Noma, E., B.Berglund, U.Berglund, I.Johansson, and J.C.Baird, 1988. Joint Representation of Physical Locations and Volatile Organic Compounds in Indoor Air from a Healthy and Sick Building. Atmos. Environ. 22: 451–460.

Oehme, M. and H.Knöppel, 1987. Analysis of Low Volatile ($>C_{15}$) and Particle Bound Indoor Pollutants: Assessment of a Sensitive Method and First Results. In Indoor Air '87 edited by B.Seifert, H.Esdorn, M.Fischer, H.Rüden, and J.Wegner, Vol.1. Berlin: Institute for Water Soil and Air Hygiene, pp. 210-214.

Sterling, D.A. 1985. Volatile Organic Compounds in Indoor Air: An Overview of Sources, Concentrations, and Health Effects. In Indoor Air and Human Health edited by R.B.Gammage and S.V.Kaye. Chelsea, Michigan: Lewis Publishers, Inc., pp. 387–402.

Schulz, K.H. 1983. Allergy to Chemicals: Problems and Perspectives. In Health Aspects of Chemical Safety, Interim Document 12: Allergy and Hypersensitivity to Chemicals. Copenhagen: World Health Organization, Regional Office for Europe, and Luxemburg: Commission of the European Communities, Health and Safety Directorate, pp. 1–12.

van der Wal, J.F. 1987. Thermal Insulation as a Source of Air Pollution. In Indoor Air '87 edited by B.Seifert, H.Esdorn, M.Fischer, H.Rüden, and J.Wegner, Vol.1. Berlin: Institute for Water Soil and Air Hygiene, pp. 79–83.

Woods, J.E. 1988. Recent Developments for Heating, Cooling and Ventilating Buildings. In Healthy Buildings '88, edited by B. Berglund and T. Lindvall, Vol. 1, Stockholm, Sweden: Swedish Council for Building Research, pp. 99–107.

World Health Organization 1983. Indoor Air Pollutants: Exposure and Health Effects (EURO Reports and Studies No. 78). Copenhagen: WHO, Regional Office for Europe.

World Health Organization 1987. Air Quality Guidelines for Europe (WHO Regional Publications, European Series No.23). Copenhagen: WHO, Regional Office for Europe.

World Health Organization 1989. Indoor Air Quality: Organic Pollutants (EURO Reports and Studies No. 111). Copenhagen: WHO, Regional Office for Europe.

Zaikov, K. Immunetoxicology of Pesticides. In Health Aspects of Chemical Safety – Interim Document 9: Toxicology of Pesticides. Copenhagen: World Health Organization, Regional Office for Europe, pp. 78–87.

TABLE I.
Classification of Organic Indoor Pollutants [A]

Description	Abbre-viation	Boiling point range [B] from °C	to °C	Sampling methods typically used in field studies
Very volatile (gaseous) organic compounds	VVOC	<0	50–100	batch sampling, adsorption on charcoal
Volatile organic compounds	VOC	50–100	240–260	adsorption on Tenax®, graphitized carbon black or charcoal
Semivolatile organic compounds	SVOC	240–260	380–400	adsorption on PUF [C] or XAD-2
Organic compounds associated with particulate matter (particulate organic matter)	POM	>380		collection on filters

[A] Adapted from World Health Organization (1989)
[B] Polar compounds are at the higher side of the range
[C] Polyurethane foam

TABLE II
Effects of Organic Chemicals Associated with SBS–type Symptoms

Effect	Compounds
<u>Acute effects</u>	
Odor annoyance	Wide range of compounds, mostly VOC
Sensory effects	(Total) volatile organic compounds
Mucous membrane irritation and other acute effects	Wide range of compounds (VVOC, VOC, SVOC)
<u>Chronic effects</u>	
Sensitization	Little knowledge, mostly on SVOC
Chronic intoxication	Little knowledge (some indications for PCP and PBB)

TABLE III
Concentrations of Various Groups of Organic Compounds in the Indoor Environment

Compound Group	Concentration ($\mu g/m^3$)			
total VVOC [A] (16 offices)	mean:	34% ± 2% of total VOC		
	range:	11%–90%		
total VOC	Min.	50%ile	90%ile	Max.
500 homes, 2 week average [B]	72	330	710	2670
10 office buildings 84 offices, 10 min average [A]	13	220	870	3930
new buildings [C]				25000
SVOC				
total in "dirty" sample [D]		80		
various pesticides [E]		0.01–28		

[A] data measured by the authors
[B] total of quantified compounds (60%–80% of total VOC): Krause et al. (1987)
[C] highest value detected in new danish buildings: Mølhave, Bach, and Pederson (1986)
[D] Oehme and Knöppel (1987)
[E] Sterling (1985)

TABLE IV

Comparison of Concentrations of Frequently Detected Indoor Pollutants with Estimated Lower Concentration Limits for Irritation

	Concentrations (µg/m3)				
	WHO (1989)	80 offices (10 buildings)		TLV/10 (TWA)	AQG (WHO 1987)
Compound	90%ile	90%ile	max	(mg/m^3)	(mg/m^3)
n-hexane	20	10	1730	18	–
n-heptane	15	24	210	160	–
cyclohexane	100	n.d.[A]	n.d.[A]	105	–
methylcyclohexane	100	<15	27	16	–
toluene	150	45	280	37.5	8 [B]
m,p-xylene	40	10	20	43.5	–
trichloroethylene	20	–	640	27	1 [C]
1,1,1-trichloroethane	20	40	3670	190	–
tetrachloroethylene	20	160	1250	33.5	5 [C]
i-butanol	5	<14	59	15	–
formaldehyde	60	122	139	0.15[D]	0.1
acetaldehyde	30	25	57	18	–
n-hexanal	5	<14	19	(13.8 [E])	–

[A] n.d. = not detected.
[B] Protection factor of 50 applied to NOEL for CNS and mucosal irritant effect.
[C] Protection factor of 100 applied to estimated NOEL for CNS effect.
[D] Suspected human carcinogen.
[E] Value corresponding to 0.003·RD50 (concentration expected to cause a 50% decrease in respiratory rate of mice resulting from sensory irritation) reported in the Danish list of sensory irritants (Andersen 1989).

TABLE V[A]
Classification of Chemicals Sensitizing *Respiratory Organs* according to EEC Directive 67/548

Sensitizing Compound	Classification
dicyclohexylmethane-4,4'-diisocyanate	toxic
isophorone diisocyanate	toxic
hexamethylene diisocyanate	toxic
2,2,4-trimethylhexamethylene-1,6-diisocyanate	toxic
2,4,4-trimethylhexamethylene-1,6-diisocyanate	toxic
2,3-epoxy-1-propanol	toxic
diphenylmethane-4,4'-diisocyanate	harmful
diphenylmethane-2,4'-diisocyanate	harmful
diphenylmethane-2,2'-diisocyanate	harmful
1,5-naphthylene diisocyanate	harmful
maleic anhydride	irritant
trimellitic anhydride	irritant
tosyl isocyanate	irritant

[A] Adapted from Lafontaine (1983)

TABLE VI.
Most Frequently Encountered Types of Reaction of Haptens with Proteins

Hapten	Reaction	
Halogen	$R\text{-}Cl + NH_2$ of protein $\Rightarrow R\text{-}NH\text{-}$	(protein)
Isocyanate	$R\text{-}N=\underset{\underset{O}{\parallel}}{C} + NH_2$ of protein $\Rightarrow R\text{-}NH\text{-}\underset{\underset{O}{\parallel}}{C}\text{-}NH\text{-}$	(protein)
Thioisocyanate	$R\text{-}N=\underset{\underset{S}{\parallel}}{C} + NH_2$ of protein $\Rightarrow R\text{-}NH\text{-}\underset{\underset{S}{\parallel}}{C}\text{-}NH\text{-}$	(protein)
Aldehyde	$R\text{-}\underset{\underset{O}{\parallel}}{C}H + NH_2$ of protein $\Rightarrow R\text{-}CH=N\text{-}$	(protein)
Organomercury	$R\text{-}Hg + HS$ of protein $\Rightarrow R\text{-}Hg\text{-}S\text{-}$	(protein)
Mercaptide	$R\text{-}SH + SH$ of protein $\Rightarrow R\text{-}S\text{-}S\text{-}$	(protein)

TABLE VII
Summary of Stepwise Investigations of Buildings with Problems

Step	Type of investigation	Performed by (Proposals)	Actions (Examples)
1	Technical survey and use of questionnaire	Industrial physician Safety representative Maintenance engineer	Contact experts for evaluation; organize new actions; inform
2	Inspection and guiding measurements of climate indicators	Safety engineer Ventilation engineer	Clean and adjust ventilation; stop humidifiers; (re)move smokers and pollution sources
3	Measurements of ventilation, climate indicatiors, and other implicated factors	Safety engineer Industrial hygienist Ventilation engineer	Increase ventilation; arrange sun-shielding
4	Medical investigation, specific measurements of suspected components	Medical doctor Industrial hygienist	Renew furniture; change on-going activities or building materials; move staff; mount local exhaust

STATE OF HEALTH

Have you suffered from any of the following symptoms in the last fortnight:

	No	Occasionally	Frequently, i.e. at least once a week	If frequently - do the symptoms persist at home	
				Yes	No
Itchiness, prickling sensations or other forms of irritation affecting: . the eyes . the nose . the throat including the symptoms of colds and chills					
Dry skin or rash					
Headaches or headachiness					
Unaccustomed lethargy or fatigue					
Malaise or dizziness					
Other					

Have you consulted a doctor on these symptoms ....

Figure 1. Symptoms' part of the questionnaire used for the investigation of complaints in EP buildings.

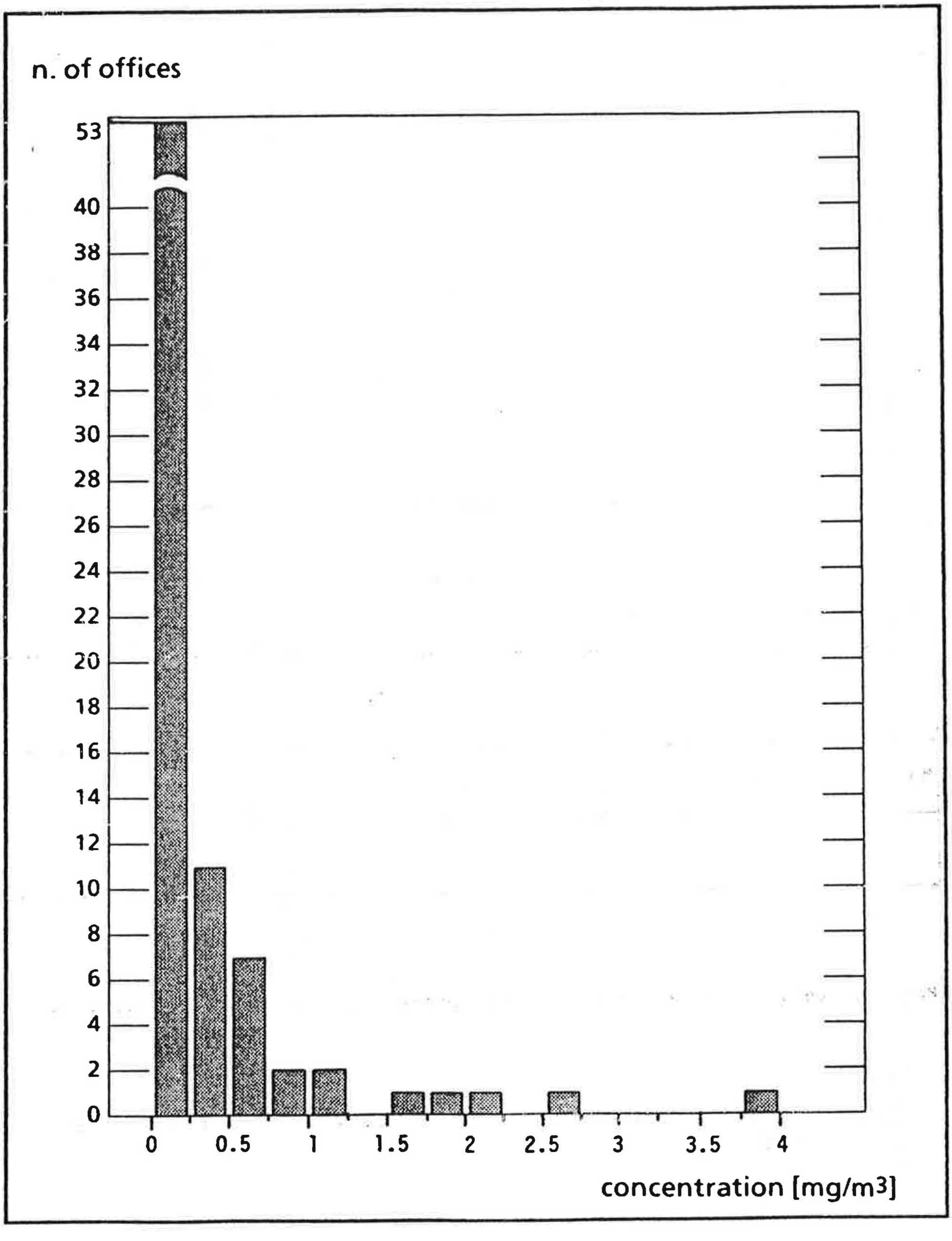

Figure 2. Distribution of total VOC ($\geq C_6$) concentrations measured in EP buildings.

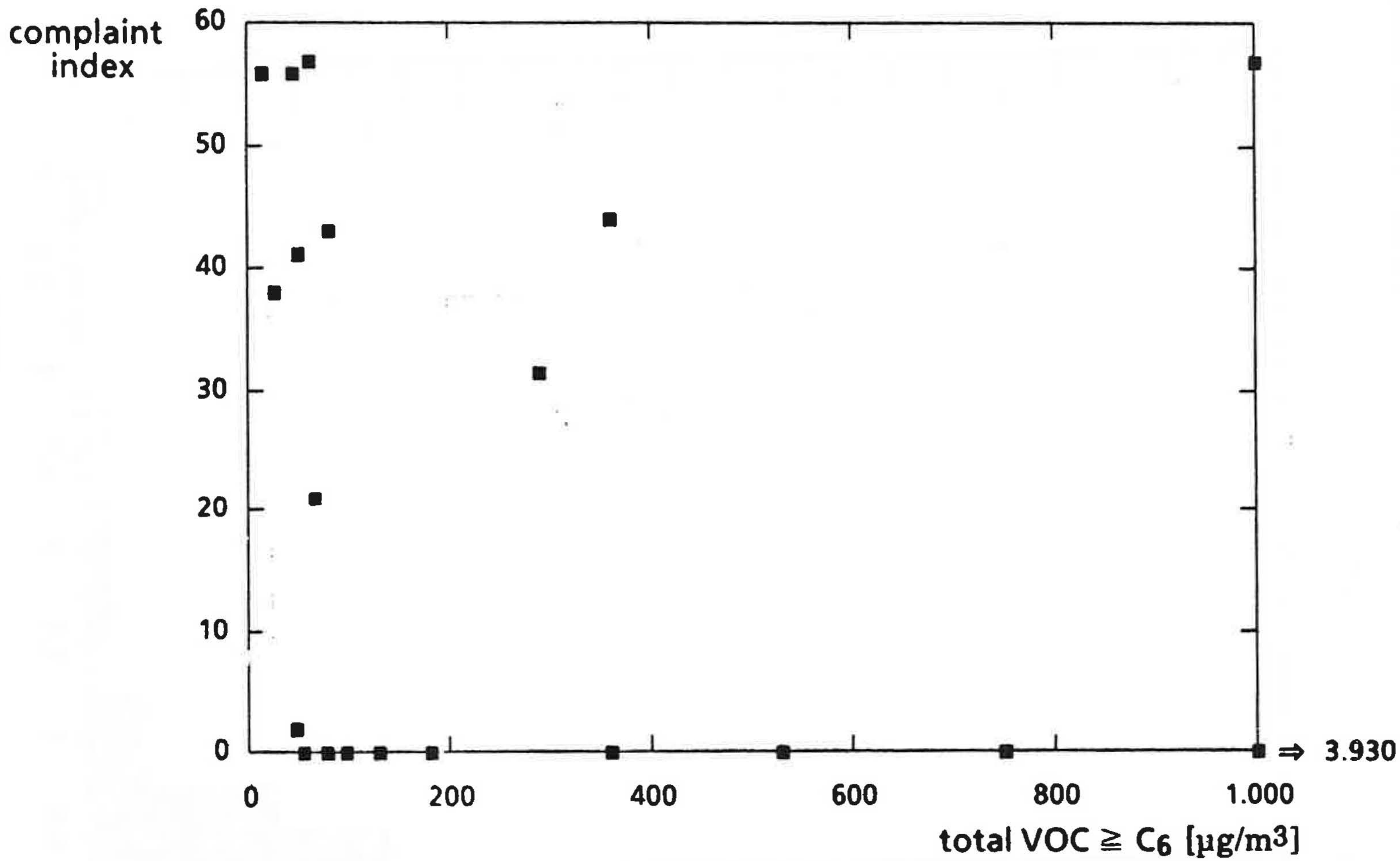

Figure 3. Plot of the complaint index in EP offices versus measured total VOC concentrations.

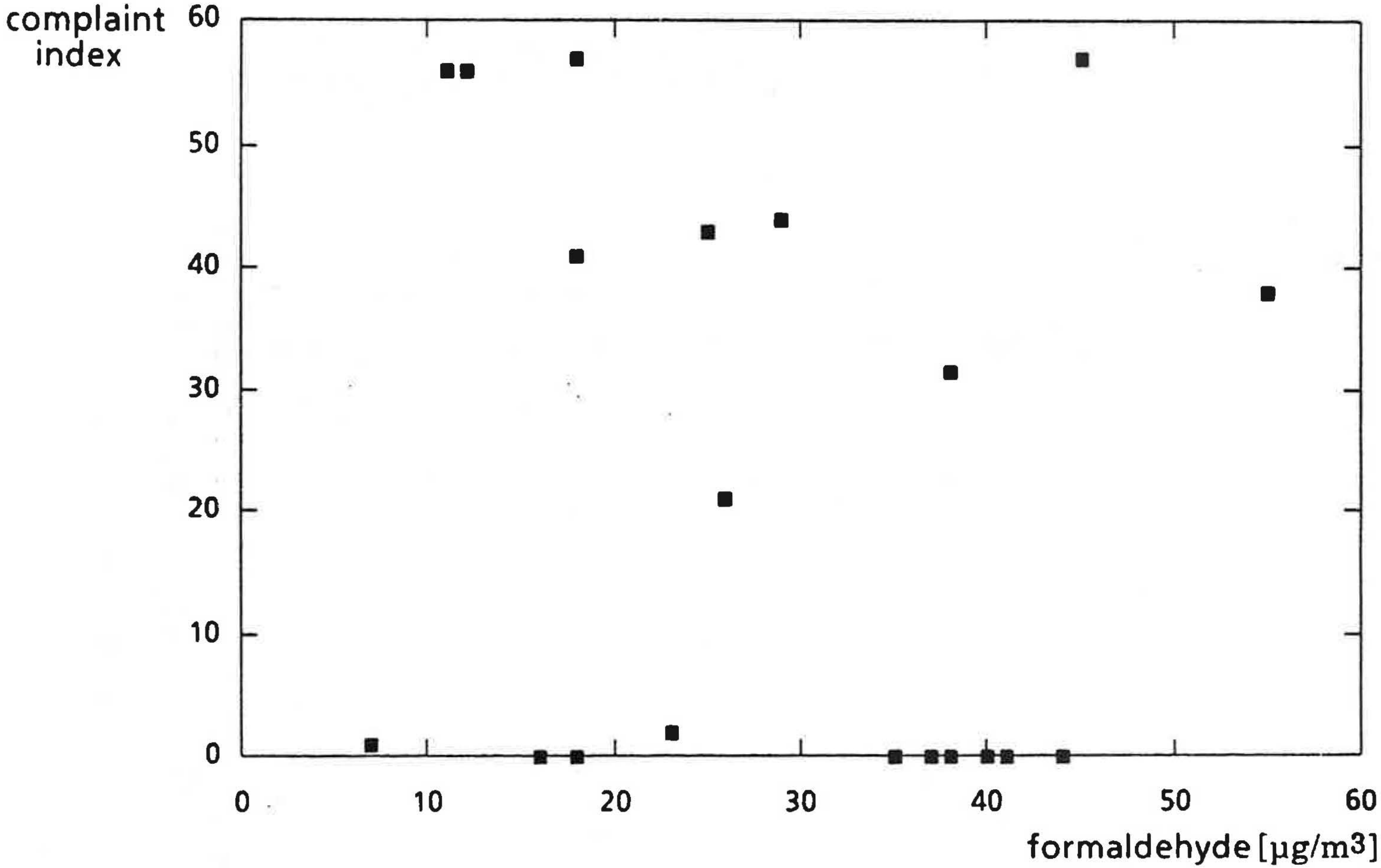

Figure 4. Plot of the complaint index in EP offices versus measured formaldehyde concentrations.

21

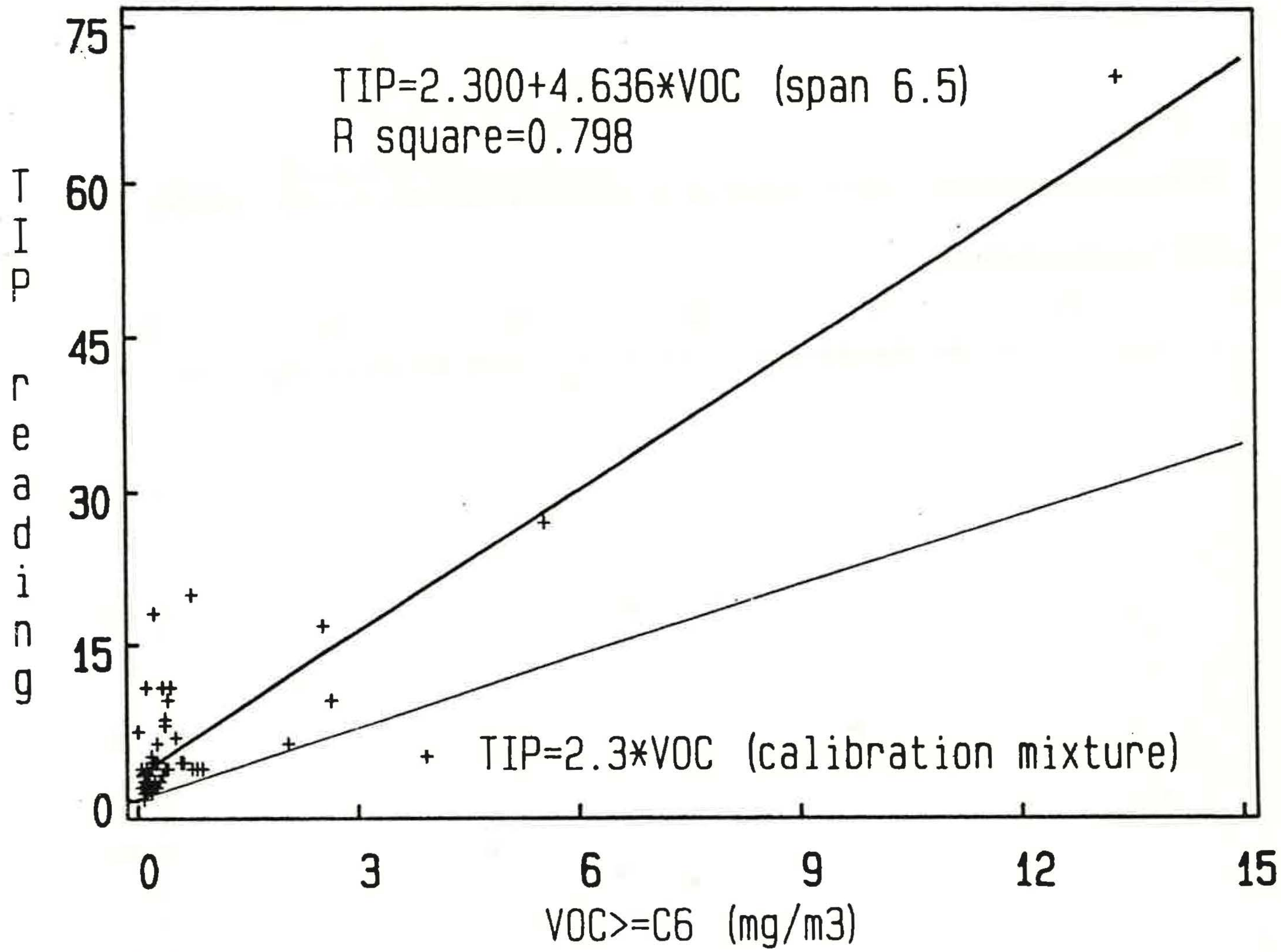

Figure 5. Correlation of the TIP I photo-ionization detector response with total VOC measurement using Tenax® sampling and gas chromatographic detection-