EUROPEAN AUDIT PROJECT TO OPTIMIZE INDOOR AIR QUALITY AND ENERGY CONSUMPTION IN OFFICE BUILDINGS

Contract JOU2-CT92-0022

FINAL REPORT

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Title: European Audit Project to optimize Indoor Air Quality and Energy consumption in office buildings

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Key words: Indoor Air Quality, ventilation, guidelines, sensory evaluations

ABSTRACT

A European project started at the end of 1992, in which current methods as well as a trained panel were used to investigate office buildings all over Europe. The main aim of this EC-Audit was to develop assessment procedures and guidance on ventilation and source control, which help to optimize energy use in office buildings while assuring indoor air quality. Participants from 16 institutes in 11 countries (The Netherlands, Denmark, France, Belgium, United Kingdom, Greece, Switzerland, Finland, Norway, Portugal, Germany) joined.

A common agreed Europe-wide method to investigate indoor air quality in office buildings, including a common agreed European questionnaire and walk-through survey checklist were developed.

In nine countries, six or more office buildings were selected. Measurements were performed at five selected locations in each building. The buildings were studied while normally occupied and ventilated to identify the pollution sources in the spaces and to quantify the total pollution load caused by the occupants and their activities and the ventilation systems. The investigation included physical and chemical measurements, assessment of the perceived air quality in the spaces by a trained sensory panel, and measurement of the outdoor air supply to the spaces. The physical and chemical measurements in the spaces included measurements of noise, concentrations of carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOC), and the thermal parameters: operative temperature, air temperature, relative humidity and air velocity. Airflows between the selected spaces and adjacent spaces were measured when necessary. Additional measurements in the adjacent spaces included measurements of CO, CO_2 and TVOC and assessments of the perceived air quality. In the mechanically ventilated buildings the perceived air quality of the supply air in the five selected spaces were assessed by the sensory panel. At one of the five selected locations of each building the measurement further comprised measurement of individual volatile organic compounds (VOC), and of airborne particulate matter. All chemical measurements were also performed outdoors. A questionnaire for evaluating retrospective and immediate symptoms and perceptions was given to the occupants of the buildings.
The building characteristics were described by use of a check-list. The annual energy consumption of the buildings and the weather conditions were registered.

This report presents the results, conclusions and recommendations of the audit performed in 56 buildings in Europe. Furthermore, assessment procedures of indoor air quality and energy performance of office buildings are discussed and challenges for the future are given.

The originally set objectives were fulfilled.

TABLE OF CONTENTS

AIMS OF RESEARCH

- Contribution to the European IAQ database of existing European office buildings with respect to symptoms/complaints of occupants, perceived indoor air quality evaluations of a trained panel, pollution sources, ventilation and energy consumption.

- Development of assessment procedures and guidance on ventilation and source control to optimize indoor air quality and energy use in office buildings.

- Development of a common agreed Europe-wide method to investigate indoor air quality in office buildings.

- Comparison of IAQ-related parameters across several European countries.

DATA BASE REPORT

Contract number: JOU2-CT92-0022

Title: European Audit Project to optimize Indoor Air Quality and Energy consumption in office buildings

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Main objectives:

- Development of assessment procedures and guidance on ventilation and source control to optimize indoor air quality and energy use in office buildings.
- Development of a common agreed Europe-wide method to investigate indoor air quality in office buildings.

Description

The European IAQ audit project consists of five phases.

Phase 1: Preparational seminar

A seminar is held for the participants to develop an European IAQ Audit procedure for office buildings in the form of a manual to execute phase 2, 3 and 4. The seminar is held in Morges (Switzerland). The seminar is concluded with a manual some months after.

Phase 2: Pilot Study

The participating organisers and/or assistants are invited to the selected country (Denmark) and learn how to execute the manual, produced in phase 1, in a pilot-study of one selected office building. The manual is revised.

Phase 3: Preparation IAQ Audit project

Each participating country (except Belgium and Portugal) selects 6 buildings according to the selection criteria presented in the revised manual of phase 2. In each country the team which will perform the auditing is taught with the use of the manual how this should be done.

Phase 4: IAQ Audit Project

The 6 selected buildings are investigated as described in the determined manual.
Detailed studies, for example on source identification, ventilation and energy consumption, are specifically done by BBRI (Belgium) and SBI (Denmark).

Phase 5: Final Reporting

In this last phase of the project, all results and findings are summarized, and correlations, comparisons, recommendations and conclusions are given.

Key words: indoor air quality, ventilation, guidelines, sensory evaluations

1. INTRODUCTION

1.1 State-of-the Art

The state-of-the-Art on IAQ (Indoor Air Quality) and Energy consumption was determined in a workshop (1,2). A summary of the outcome is presented here, as well as other projects that are currently being executed or have been in the last two years.

The achievement of health and comfort in the indoor environment combined with energy efficiency requires both minimisation of human exposure to indoor air pollution i.e. source control and a well-functioning and energy efficient heating, ventilating or air-conditioning system.

Technology available in the sixties along with the economic expansion and an increase in income stimulated the development of new forms of building construction, new heating systems and also new ventilation systems. Due to low energy prices, high ventilation rates were no real problem. The strong increase in energy prices due to the energy crisis in the seventies significantly changed the situation. Research activities in the second half of the seventies and the beginning of the eighties were primarily focused on strategies to reduce energy consumption. Environmental issues became more and more important towards the end of the eighties. Health issues and increased concern related to the quality of the indoor environment received great interest from the public and the media. The challenge of the near future is simultaneously to aim at low energy consumption and a comfortable and healthy environment;

During the past twenty years IAQ has received growing attention. Many complaints with respect to IAQ occur and the causes of these complaints are often not found in spite of thorough measurements of indoor air. This phenomenon as well as the outcome is often called Sick Building Syndrome (SBS).

In Europe, the Indoor Air Quality issue had already emerged in the late sixties, first in the Northern countries, in particular in Denmark and Sweden, whereas in most mediterranean countries it has been perceived only relatively recently.

Ventilation

In many buildings with known problems, unsatisfactory ventilation is suspected or shown to be a contributor. The measurement of air change is, however, not a common feature of air quality investigations. Without having routine knowledge of the air change rates in buildings, ventilation rate recommendations to improve building air quality are hard to make.

Until now, only a few buildings or dwellings have been examined for the performance of their ventilation systems, and most of these buildings were located in the Nordic countries. Insufficient information is available on a European level.

Ventilation performance can be measured with the use of tracer gases.

The actual ventilation performance should be compared with ventilation needs for thermal comfort and IAQ, as identified by analysing all the possible indoor air pollutant contributions.

Sources

To be able properly to characterise the indoor environment, it is important to understand the sources of indoor air pollutants. These sources can be placed in the following categories: outdoor environment (air, soil and water), people and their activities (man himself, energy production, smoking, office equipment and chemicals), materials (building materials, furnishings) and HVAC (Heating, Ventilating and Air Conditioning) systems.

Source control reflects the general philosophy of environmental protection: preventing rather than curing. The obvious way of reducing the ventilation requirement for IAQ is to reduce indoor pollution sources. The ventilation requirement is proportional to the pollution load. The question is how high is the pollution load in buildings?

IAQ measurement

Measurement of the contents of the air by chemical/physical methods is not adequate to indicate or define the comfort aspect of the indoor air. Quantification and identification of each of the hundreds of compounds present in the indoor air is impossible with the instruments developed so far. A threshold limit (odour and/or irritation) is not available for each of the identified compounds and even less is known about the effects of mixtures of pollutants.

A recent advance in the measurement of IAQ is based on the use of independent visitors, with the human nose as the instrument to quantify IAQ. This method requires a panel of subjects which is trained to evaluate the air quality immediately after the panel enters the building or space. When the ventilation rate of the evaluated building of space is determined together with the evaluation of the perceived air quality (in decipol), an indication of the pollution-load (in olf) of that building or space can be established.

Questionnaires given to the occupants of an investigated building is a way to determine patterns of symptoms and complaints. Many different questionnaires have been developed although there is some common ground in most of them.

SBS/Patterns of symptoms/complaints

Sick Building Syndrome (SBS) comprises a group of symptoms that are common in the general population, but which are more prevalent in some buildings than in others. The principal symptoms are lethargy, headache, blocked nose, runny nose, dry eyes, sore eyes, dry throat and sometimes dry skin and rashes. SBS is a multi-factorial cause-effect problem. It is seldom possible to explain the symptoms occurring through the influence of a single factor like formaldehyde or dust.

The symptoms related to buildings are supposed primarily to depend on the quality of the air and the hygro-thermal climate and to a lesser degree on sound and lighting conditions plus a range of individual and job related factors. Draughts and high and low temperatures appear frequently in connection with unspecified complaints.

To some extent these symptoms have been blamed (in many cases unfairly) on energy efficiency measures. This has created certain opposition to the implementation of further energy efficiency technology.
To show that energy efficiency can be achieved without detriment to the indoor environment, would overcome some of the resistance to making energy savings in buildings.

Other projects

EPA Base programme
The U.S. EPA's office of Radiation and Indoor Air (ORIA) has initiated a major study of indoor air quality (IAQ) to fill a significant data gap that exists regarding baseline IAQ in public and commercial office buildings. The goal of the study is to define the status of the existing building stock with respect to determinants of IAQ and occupant perceptions. The crosssectional study, entitled Building Assessment Survey and Evaluation (BASE) programme, is collecting baseline data characterizing public and commercial office buildings (3). The buildings are randomly selected without regard to IAQ complaints, using an agreed-upon core set of building parameters and methodologies. Core parameters have been selected which are measured in a representative space in each building. These core parameters include environmental measurements, and administration of an occupant questionnaire, and characterization of the HVAC system and the building itself.
Over the next 3 to 5 years approximately 200 buildings will be studied. So far, a nine-building pilot study to test and refine the protocol has been completed (4).

The indoor climate in the Swedish housing stock
A nation-wide survey (The ELIB study) of the indoor climate in Swedish residential buildings, was carried out in Sweden from 1991 to 1993 (5). With the help of a postal questionnaire survey, almost 20,000 residents in about 3,300 single-family houses have given an account of their experiences of and feelings about their indoor climates. Inspections and measurements in just over 1,100 of these residential buildings have yielded a technical description of the indoor climates. The survey provides a base for evaluating what indoor-climate defects and deficiencies exist in the national housing stock, their size and location in the housing stock and who in the population are exposed to them.

1.2 Objectives

The following objectives were originally set:

- Contribution to the European IAQ database with respect to:
  - assessment of symptoms/complaints in existing European office buildings, according to a standard questionnaire survey, in relation to perceived indoor air quality evaluations from a trained panel of assessors who visit each building;
  - identification and quantification (chemical and sensory) of pollution sources in existing European office buildings;
  - assessment of pollution load caused by the building itself in different parts of Europe;
  - assessment of ventilation rates and evaluation of ventilation performance in existing European office buildings;
  - assessment of energy consumption in existing European office buildings.

- Development of assessment procedures and guidance on ventilation and source control to optimize indoor air quality and energy use in office buildings. The challenge of the near future is simultaneously to aim at a low energy consumption and a comfortable and healthy environment. The guidance will be available to committees responsible for CEN-standards and other European guidelines.

- Development of a common agreed Europe-wide method to investigate indoor air quality in office buildings.

- Comparison of IAQ-related parameters across several European countries.

1.3 Method

The European IAQ audit project consisted of five phases.

.Phase 1: preparational seminar, in which a meeting was held for the participants to develop a European IAQ Audit procedure for office buildings in the form of a manual. The summary of this meeting was reported by TNO (6). At this meeting the participants of the project contributed in the form of a written and oral presentation on a pre-decided topic related to the project. The first draft manual was presented and discussed (7).
The contents of the seminar included the following topics:

a. The selection procedure of the office buildings to be audited. Selection criteria were discussed.
b. The assessment of a common agreed European checklist for a walk-through survey of the selected buildings, to select representative rooms to be investigated, to identify possible pollution sources, to describe the building construction, furnishings, activities, energy consumption and occupant distribution. Existing checklists were used as a starting point.
c. The assessment of a common agreed European questionnaire. The questions to be included were discussed with reference to existing questionnaires.
d. The assessment of common agreed measurements to be executed and procedures to be

followed in phases 2 and 4. The investigation in phase 2 and 4 consisted of five parts.

1. A walk-through survey of the selected building(s), which should be executed with the use of the agreed European checklist.
2. A questionnaire survey with the agreed European questionnaire.
3. An indoor climate and indoor air quality investigation, comprising the following.
   - General light, noise and thermal comfort measurements in the selected rooms of each selected building.
   - General indoor air quality measurements in the selected rooms of each selected building.
   - Perceived air quality determination in decipol with a trained panel in the selected rooms of the selected buildings.
4. A ventilation study comprising ventilation rate measurements and ventilation performance determination in the selected rooms of the selected buildings,
5. Detailed studies in a few buildings including source identification and ventilation performance.

e. Planning and optimisation of the experiments.

f. The outline of the report that each participating country contributed in phase 4, and the analysis techniques applied.

g. Assessment of the season, the time interval, and duration and repetition of measurements and procedures.

The seminar was held in Morges (Switzerland) at December 17 and 18, 1992. The Swiss Federal Institute of Technology was the host.

.<u>Phase 2: pilot study</u>, in which the determined manual in phase 1 was executed for one building in one country. The participating organisers and/or assistants were invited to the selected country (Denmark) at April 26-28 1993 and learned how to execute the manual in a pilot-study of one selected office building. Preparations were made by the host (University of Denmark).
The first draft manual was revised according to the discussions in Morges and resulted in a second draft manual (8). In the pilot study, one building was investigated according to the second draft manual. A summary of this meeting was reported by TNO (9).
From the discussion on the third day of this meeting several working groups were established to elaborate on specific topics of the manual.

.<u>Phase 3: preparation IAQ Audit project</u>, in which each participating country (except for Belgium and Portugal) selected 6 buildings according to the selection criteria presented in the manual, and in which the auditing teams were trained. In each country the team which performed the auditing was taught with the use of the manual how this should be done.
The contributions of the working groups, established in Denmark, were partly added to the third draft manual (10) and were presented/discussed on a third meeting in Paris at September 6 and 7, 1993. CSTB was the host. The summary of this meeting was reported by TNO (11).
Two extra participants (the Technical University of Budapest in Hungary and the Technical University of Berlin in Germany) were accepted by all participants. Unfortunately, Hungary did not succeed in getting financed and had to refrain from joining the project.
The fourth manual was made and considered to be the final manual to be used to execute phase 4 of the project (12).

Furthermore, an international report format was made (13), as well as a first approach of an analysing strategy of all the data after Phase 4.

.<u>Phase 4: IAQ audit project</u>, in which the 6 selected buildings were investigated as described in the manual (12). Detailed studies on ventilation and source identification were done by BBRI (Belgium) and SBI (Denmark), respectively. The experimental part of Phase 4 was executed mainly in the months February/March 1994, except for the detailed investigation on source identification by SBI.
The fourth meeting was held in Athens (Greece) in April (14) were the results of the auditing and the detailed ventilation measurements were presented. The University of Athens was the host. After the presentations of the results of the Audit, a proposal was made by Bluyssen to distribute the tasks for the data-analysis (15). The following working groups were agreed upon (for more information see ref.14):

- Working group 0: Data collection
- Working group 1: Questionnaire
- Working group 2: Sensory Evaluation
- Working group 3: Air Quality
- Working group 4: Pollution sources
- Working group 5: Ventilation and energy consumption
- Working group 6: Ventilation, Energy consumption and Source control
- Working group 7: IAQ-Audit procedure

In general, each working group was given the following tasks:

- collection relevant data of all national audit investigations
- analysis of these data
- discussion of the results

Furthermore, a draft national report was handed out by TNO (16).

At the Healthy Building '94- conference in Budapest (August 1994), each participant (except for Norway) presented their results of the Auditing with a poster, which had a common format (provided by TNO). In a workshop, a general paper on the applied EC-Audit procedure was presented by the coordination (17) and intended procedures for the international data analysis were presented by the different working groups. The workshop attracted a large audience.

Each participant made their national report (18-26). Detailed studies on source identification and ventilation performance, were specifically done by SBI (Denmark) and BBRI (Belgium), respectively. Separate reports on detailed studies were made (27, 28).

.<u>Phase 5: final reporting</u>, in which all results and findings were summarized, and correlations, comparisons, recommendations and conclusions were given.
During the fourth meeting in Athens a time schedule for the international data-analysis was presented (14). Eight working groups were formed. At the Healthy Building '94- conference in Budapest (August 1994) for each working group a meeting was held, in which the time schedule and task distribution was discussed and redefined when necessary. The minutes of these meetings were reported by TNO (29) and the final national report of TNO was distributed (18).

The last official meeting was held on October 27 and 28, 1994, in The Netherlands hosted by

TNO, were mainly the IAQ-Audit procedure and the final reporting were discussed (30). A draft final report was distributed during the meeting. Furthermore, the working groups discussed a list of topics in their own groups. This list of topics comprised: the main discussion points with respect to the IAQ-Audit procedure, methods, procedures and instruments that were used in the Audit, the contents of the draft final report, recommendations on energy consumption and source control, and their tasks, deadlines and task distribution. On the second day of the meeting these topics were discussed in the whole group.

At the Energy performance conference in Lyon (24-26 November 1994) the applied European Audit procedure was presented by the coordination (31).

All data was collected in a database, developed by Switzerland (EPFL) (32), called DREAM.

An extra meeting was held for the working group leaders to edit the final report in Delft, The Netherlands, hosted by TNO.

Four progress reports were delivered to the EU in Brussels on time and were accepted.

This report presents the final reporting, which is conform the originally set objectives.

The time schedule of the project is shown in Figure 1.1. As can be seen, the project was executed as originally planned.

A list of documents related to this project is presented at the end of this report.

Figure 1.1 WORK PLANNING

Year	1992	1993												1994												1995
Month	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1
Phase 1																										
. preparation	xx																									
. seminar	x																									
. writing manual	xx	xxxx	xxxx	xxxx	xxx																					
Phase 2																										
. preparation			xx	xxxx	xxx																					
. pilot study					x																					
. rewriting manual						xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xx														
. 3rd meeting										x																
Phase 3																										
. training team										xxx	xxxx	xxxx	xxxx													
. sel. buildings						xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx													
Phase 4																										
. preparation							xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx												
. IAQ-Audit															xxxx	xxxx										
. detailed studies															xxxx	xxxx	xxxx									
. sample-analysis															xxxx	xxxx	xxxx									
. data-analysis																xxxx	xxxx	xxxx	xxxx							
. nat. report																		xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx		
Phase 5																										
. 1st meeting																	x									
. data-analysis																		xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	
. 2nd meeting																							x			
. final report																							xxxx	xxxx	xxxx	xxxx

2. METHOD

2.1 General

The Audit procedure as described in the final manual (12) was prepared for the investigation of indoor air quality and energy consumption in European office buildings. This investigation should result in an European audit technique that provides information on office buildings to decrease energy consumption without detriment to, and even with an improvement in, the indoor air quality. By determining the pollution load (chemically and sensory), the ventilation performance and the energy consumption, and by identifying the pollution sources, recommendations can be made to avoid excessive energy consumption and ensure air quality by source control and ventilation.

The indoor environment is exposed to changes from day to day and even during the day. Specifically, ventilation and chemical/physical compounds in the air, vary enormously not only from day to day but also from room to room in one specific building. To enlarge the chance that all data required represent one environmental condition, it is therefore of utmost importance that all measurements are done at the same location and parallel to each other. The research plan was therefore concentrated on the investigation of one building per day with minimum required measurements to make objective 2 of the project possible.
To get a reasonable data base of European buildings, 6 buildings were investigated per participating country, in which in each building 5 representative locations were selected for the measurement of a.o. chemical/sensory pollution loads and ventilation.
The manual describes the field tests which were carried out in the United Kingdom, The Netherlands, Greece, France, Switzerland, Finland, Norway, Denmark and Germany. The purpose of the manual was to ensure that the field tests were carried out in the same way in each country. Only then, proper comparison between the results from each country could be made. The manual prescribes minimum requirements of the investigations.

Research plan

In each of the previously mentioned countries six office buildings were selected. Measurements were performed at five selected locations in each building. The buildings should be studied while normally occupied and ventilated to quantify the total pollution load caused by the occupants and their activities, the ventilation systems, and the sources in the spaces themselves. The investigation included physical and chemical measurements, assessment of the perceived air quality in the spaces by a trained sensory panel, and measurement of the outdoor air supply to the spaces. The physical and chemical measurements in the spaces included measurements of noise, concentrations of carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compounds (TVOC), and the thermal parameters: operative temperature, air temperature, relative humidity and air velocity. Airflows between the selected spaces and adjacent spaces were measured when necessary. Additional measurements in the adjacent spaces included measurements of CO, CO_2 and TVOC and assessments of the perceived air quality. In the mechanically ventilated buildings the perceived air quality of the supply air in the five selected spaces were assessed by the sensory panel. At one of the five selected locations of each building the measurement further comprised measurement of individual volatile organic compounds (VOC), and of airborne particulate matter. All chemical measurements were also performed outdoors. A questionnaire for evaluating retrospective and immediate symptoms and perceptions was given to the occupants of the buildings. The building characteristics were described by use of a check-list. The annual energy consumption of the buildings and the weather conditions were registered.

Season for experiments

To achieve similar conditions with regard to temperature in the buildings in the different countries the experiments in all nine countries were conducted in the heating season. Considering the one month recall period of the questionnaire, the experiments were conducted in November/December or February/March to avoid the recall period coinciding with Christmas/New Years time.

Buildings

It was desirable that the six buildings in each country represented somehow the building stock in the country in terms of age and type of construction. Public or private sector buildings were equally acceptable. To avoid high and unstable emissions in new buildings, the buildings should have been at least two years old. There was no restriction on the type of ventilation used in the buildings. The buildings should have been located in areas where the outdoor air quality was reasonably fresh.

The study population should have comprised at least 125 employees in each building, occupying offices representative of the building. It was preferable, but not a requirement, that the population in each building was a homogeneous group of white-collar/clerical workers like for instance in a bank, an insurance company or other administration offices. Furthermore, gender was also an important factor, since men typically report fewer symptoms than women. Buildings with an equal distribution of men and women were preferable.

In each building physical and sensory measurements were performed at five selected locations. The locations were all in one or more large open-plan offices, or in cellular offices. Both smoking and non-smoking work places were included. The selected offices should have been representative of the building. The main activity of the offices was general office work. Computer terminal rooms and photocopying rooms were avoided.

A location near the office spaces studied was required for refreshing the senses of the panel. The location could have been a nearby office where it was possible to open the windows or it could have been a location outside the building.

A technical survey of the building and its installations was made based on a walk-through survey with the use of a check-list and on ground plans and information from the building maintenance staff. The walk-through survey was performed before the main investigation. The check-list used in the present investigation is given in the manual (12).

Questionnaire

The questionnaire developed for the Audit project (given in the manual) included a short description of how to fill in the questionnaire, a section for personal information such as gender, occupation, employment, smoking habits, allergies etc. The main questions concerned the occupants' health and their environmental conditions during the past month, the occupants' health and their environmental conditions at this point in time and other aspects of the office environment.

The occupants surveyed should have been representative of occupants in the building as a whole. To achieve this, response rates of over 80% were needed from either whole occupant populations or from occupants randomly selected from the occupant populations. In order to obtain a valid sample of at least 100 occupants, buildings with 125 or more occupants should therefore have been selected. A procedure for selecting these is given in the manual, as well as procedures for distributing and collecting.

Sensory measurements

The perceived air quality was assessed by a panel of trained subjects assessing the air quality in decipol. A description of the sensory reference equipment for air quality assessments required is given in the manual.

A panel of 12-15 subjects should have been selected from a group of at least 50 applicants of ages ranging from 18 to approximately 30 years old. There was no restriction on distribution of gender or smoking habits. Each of the applicants should have participated in a selection test as described in the manual (12).

The 12-15 selected subjects were trained for three to five days in smaller groups of three to seven persons. Each day they received one to two hours of intensive training. The subjects were exposed to 10-15 2-propanone concentrations during the training period. The subjects were furthermore trained to assess air polluted with samples of building materials and to assess the air quality of real spaces. On the third day of training the subjects should have been exposed to a performance test with 2-propanone. After all panel members passed this individual exam, the whole panel was exposed to a second exam, based on pollution sources typically found in buildings.

Ventilation measurements

The general ventilation related information should have corresponded to the period of time during which the other evaluations were performed. The particular objective of these general ventilation measurements was to provide the necessary information for calculation of the source strength for each considered pollution source. The ventilation parameters (airflow rates) to be considered for each selected room should have consequently been the following:

- air supplied by the ventilation system (mechanical system: air delivered through the supply ducts; natural: outside air entering through purpose-provided openings);
- infiltration through building envelope (outside air entering the room directly from outdoors);
- air coming from adjacent rooms.

The measurement techniques used to measure the airflow rates are given in the manual. In addition to these minimum measurements, optional measurements were proposed.

Physical measurements

The physical measurements were made in the occupied zone of the selected spaces.

The thermal measurement included air temperature, operative temperature, relative humidity and air velocity. Air temperature and air velocity were measured at 0.1 m, 0.6 and 1.1 m above floor level, corresponding to foot, middle and head level of a seated person. Operative temperature and relative humidity were measured at 1.1 m above floor level.

At one of the selected measurement locations, continuous measurement of operative temperature and relative humidity were performed on the day of the experiment. All other measurements were allowed to be spot measurements, typically with a duration of 5-30 min. Instruments used are suggested in the manual.

The amount of respirable particulate matter should have been measured during 8 hours in one of the selected spaces. Several methods exist, but to avoid incomparability of results between the participating countries it was recommended to use a gravimetric method. Specifications on the procedure used for measuring respirable particulate matter are given in the manual.

The A-weighted equivalent sound pressure level L_{eq} was measured during at least 2 min. in each of the selected spaces during occupancy with a sound level meter.

Chemical measurement

The concentration of carbon dioxide (CO_2) (as an indicator of the number of occupants present), carbon monoxide (CO) (as an indicator of the number of smoking occupants present) and TVOC (the chemical pollution load in a building can be reflected in a TVOC index, expressed as TVOC/m^3 air) should have been measured in the selected rooms, in adjacent spaces from which air is flowing into the selected rooms and outdoors. Furthermore, the concentrations in the ventilation supply air should have been measured for mechanically ventilated buildings. It was recommended that these measurements were made with a direct reading instrument (suggestions are given in the manual). Two methods were used to measure TVOC: integrated samples on Tenax-GC followed by MS identification of the most abundant VOCs and direct measurement of infrared absorption using photo acoustical detection. All chemical measurements in spaces were made at 1.1 m above floor level. In all but one measurement location per building, the measurements were allowed to be spot measurements (duration of a few minutes). At one measurement location per building continuous (8 h) measurement of TVOC with a direct reading instrument was made.

Energy consumption

The total annual energy consumption of the audited buildings for all energy sources (oil, coal, gas, electricity, district heating, etc.) was recorded. This information was provided by the building owner or the technical manager and was collected during the preliminary survey.

2.2 Selected buildings

In this paragraph a summary of the main characteristics of the 56 selected buildings and their ventilation systems is presented in Tables 2.1 and 2.2. For more information per country see Appendix A and the national reports (18-26).

Table 2.1 Summary of main characteristics of 56 selected buildings

Characteristics	Percentage [%]	Characteristics	Percentage [%]
Situation		**Age**	
country side	14	2 years < age ≤ 5 years	29
suburbs	25	5 years < age ≤ 10 years	21
downtown	54	10 years < age ≤ 20 years	11
industrial area	7	> 20 years	39
Total floor area		**Number of floors**	
≤ 2,500 m^2	16	1 < floors ≤ 3	21
2,500 < floor area ≤ 7,500 m^2	30	3 < floors ≤ 7	48
7,500 < floor area ≤ 15,000 m^2	29	7 < floors ≤ 10	13
> 15,000 m^2	25	> 10 floors	18
Number of occupants		**Smoking**	
≤ 200 occupants	36	yes	59
200 < occupants ≤ 500	34	certain areas	23
500 < occupants ≤ 1000	16	no	18
> 1000 occupants	14		

As can be seen from Table 2.1, the majority of the selected buildings were located in towns and had less than 500 occupants. 50% of the selected buildings were older than 10 years, the majority had less than 8 floors and smoking was allowed in more than 80% of the selected buildings.

Table 2.2 Summary of information on ventilation systems of 56 selected buildings.

Characteristics	Percentage [%]	Characteristics	Percentage [%]
Ventilation system			
natural ventilation	12	design air change < 0.5 h^{-1}	0
exhaust system only	2	0.5 h^{-1} < design air change < 1 h^{-1}	18
supply system only	5	1 h^{-1} < design air change < 3 h^{-1}	51
balanced VAV system	9	design air change > 3 h^{-1}	31
dual ducts balanced	20	des. outdoor air flow rate < 7 l/s.pers.	14
induction units	18	7 l/s.pers. < air flow < 10 l/s.pers.	25
simple balanced	30	10 l/s.pers. < air flow < 20 l/s.pers.	28
other system	4	20 l/s.pers. < air flow < 30 l/s.pers.	17
		30 l/s.pers. < air flow < 50 l/s.pers.	11
		design outdoor air flow > 50 l/s.pers.	6
Cooling system		**Heating system**	
no cooling	25	no heating	0
supply of cooled air	48	hot water heating	50
local fan coil units	18	air heating	43
cooled ceilings	5	direct electric heating	7
cooling convectors	4	other system	0
Recirculation		**Heat recovery**	
no recirculation	61	no heat recovery	42
up to 25% recirculation	6	rotating wheel	27
25% < recirculation < 50%	12	plate exchanger	8
50% < recirculation < 75%	12	others	23
recirculation > 75%	10		
Openable windows		**Ventilation principle**	
can not be opened	32	no planned principle available	2
can but may not	14	displacement ventilation (incl.natural)	12
can be opened	54	mixing ventilation	87
Control of ventilation system		**Sensor controlled ventilation**	
manual on and off	23	no sensors	55
clockwork	77	temperature sensors	41
		humidity and other sensors	4

The statistical information given in Table 2.2 has been extracted from the checklists. The presented recirculation, air change and airflow rates are design values. Most of the information given is based on more than 50 buildings. It should however be noted that a rough estimate of the design air change rate was determined from 44 buildings, while the lowest outdoor air change per person is given for 35 buildings. Real values often differed from design values (in buildings measured), in particular for recirculation rates. This indicates that airflow rates seem to be of less importance to the building management in at least 35% of the audited buildings.

The majority of the selected buildings had mechanical ventilation with cooling and without recirculation. The design air change was in ± 50% of the selected buildings between 1 to 3 ach; the design outdoor airflow rate was more than 10 l/s in 60% of the buildings.

Only 12% of the investigated buildings had planned natural ventilation only. For this reason, in the analysis no comparisons are made between natural and mechanical ventilated buildings.

2.3 Equipment and methods

This paragraph gives an overview of the equipment and methods applied in each country. Difference with the general recommended methods and equipment in the manual (12) are highlighted. For more detailed information see the national reports (18-26).

2.3.1 Sensory panel

Table 2.3 presents an overview of the selection, training, training equipment, retraining, calibration and field procedures used, for each country involved. As can be seen from this table not all countries kept exactly to the recommendations in the manual (12) when it came to selecting and training of the panel members. Exam 1 was obviously a tough exam to pass, although exam 2 was found to be too easy.
The training rooms differed. Not every country kept to the recommendations. The equipment used for the training, the decipolmeters, were in general supplied by TNO. In some cases the order was placed too late, which caused planning problems for some.

It is very difficult to decide whether a sensory evaluation is valid or not since the correct answers are unknown. The correct perceived air quality in a room could be defined as the mean perceived air quality evaluated by the whole world. Another approach could be that the correct perceived air quality is the one that the persons using the room perceive. The first definition is unpractical and the last definition is not general. So what was done was to try to map the whole world by a selected panel of few people, normally 10-15 subjects. The average panel sizes are given in Table 2.3. It was stated in the manual (12) that the sensory panels should comprise 12-15 subjects. Only Greece and Denmark had the required minimum panel size for all audit days. It goes without saying that the bigger the sensory panel, the more robust the mean perceived air quality.

Not only the panel size helped to reach a valid mean perceived air quality evaluation. The individuals must also be able to evaluate the perceived air quality. In order to find out whether a panel member is capable of perceiving the air quality the subjects were put to a calibration test of 2-propanone concentration. The test concentrations were measured but kept unknown to the subject. The hypothesi was then that if a person is not able to evaluate the test concentrations then he or she would not be able to evaluate the more difficult office concentrations. An option was then to exclude such subjects for the analysis. Another reason for excluding a panel member was if the evaluation was registered as an outlier, e.g. 3 times the standard deviation above the mean value.

For more detailed information on the selection, training, retraining and calibration results, is referred to the national reports (18-26). In paragraph 4.1 a more detailed overview is given on the performance of the different panels.

In the international analysis it was however decided to keep all data as they are, since the research on performance of panels and panel members is an ongoing activity. So far, it is not correct to exclude certain data because the performance of panel members using 2-propanone has never been proved to correlate with the performance of panel members in the field. The method introduced in paragraph 4.1 is a first attempt, but definitely not the last.

Table 2.3 *Overview of selection, training, training equipment, retraining, calibration, and field procedures used, for each country involved.*

	The Netherlands	**Denmark**	**United Kingdom**	**Greece**	**France**	**Switzerland**	**Finland**	**Norway**	**Germany**
Selection	54 persons 8 levels	none	48 persons 8 levels	44 persons 8 levels	26 persons 19-40 years 7 levels	two selections non-smokers 46 and 35 persons	47 persons based on method with amylacetate	50 persons 7 levels	34 persons 6 levels
training	14 subjects 4 groups 4 days	14 subjects 2 groups 4 days	17 subjects 3 groups 3 days	12 subjects 2 groups 3 days	16 persons 3-4 groups 4 days	two panels: 14 and 15 subjects 6 days	17 subjects 3 days	15 subjects 3 groups 5 days	16 subjects 3 groups 3 days
exam 1	11 passed	12 passed	all passed	all passed	7 levels 13 passed	all passed	all passed	9 passed	all passed
exam 2	passed	not passed	passed	passed	passed	passed	passed	passed	passed
retraining	3-4 levels	5 levels	8 levels	2 levels	none	before audit day	5 levels	2-3 levels	in the building; day before audit; 4-8 levels
calibration	6 levels	8 levels	.	3 levels	in building 4-7 levels	8 levels	8 levels	7 levels; 8 persons selected for field	in the building; 4 levels
field	2 groups of 6 one after the other in spaces	2 groups of 7 7 in spaces	in groups	each location once; 1 group one by one?	2 groups of 4/5, one after the other	each location once; one after the other	one after the other and also in one group	each location once; one after the other	milestones in building; 2 groups of 8 in spaces
average panel size	11.5	13.8	11.7	12	7.8	11.1	11.5	11.2	11.7
training room	zero-decipol room (see 12)	stainless steel 100 % outdoor air; 30 ach; displacement	temperature-controlled room	natural ventilated low-polluting room	low-polluting, well-ventilated room	2-propanone < 5 ppm; 46 persons: 1 decipol	walls/ceiling: polycarbon plastic; floor: aluminium; displacement	2-propanone < 0.8 ppm; 49 persons: 1.4 decipol	low polluting room; 20 ach
decipolmeters	see (12)	cone: stainless steel covered with teflon	fan in other hole (not in cone) see (12)	see (12)	see (12)	see (12)	see (12)	see (12)	100 ml bottles for 2-propanone see (12)

2.3.2 Questionnaire

Translation

In general the questionnaire as given in the manual (12) was translated into the language required in each country and back-translated into English by an independent translation organisation. This back-translation was sent to BRE (United Kingdom) to be checked on possible mis-interpretations. Consequently, the translated versions were revised were necessary.

Except for Switzerland and Germany, all countries kept to this procedure.

The back-translation was an important exercise to establish a closer comparability of questionnaires between the countries taking part. While the translations were generally good, there were always some points at which the back-translation was somewhat different from the original. That was considered to be important only if it meant that the translation had a different meaning to the original English. BRE therefore made comments on the back-translations, so that the originator could look at the translation and check whether it had the right meaning.

The errors detected can be categorised as follows:

. a word which was (or appeared to be) a mistranslation (e.g. the Danish for 'academic' which looked like a bad translation but in fact represented the English 'professional' quite well);

. missing or added words, questions or instructions (often the instructions to tick only one box);

. small variations in expression (e.g. 'the time' rather than 'any time' at question A6, 'overall' for 'completely' at question C3);

. difficulties in achieving a good translation.

One common problem was that the word 'lethargy' was difficult to translate into some other languages, and we perhaps need to discuss exactly what it does mean and whether it can be translated or whether another word should be substituted. 'Heaviness in the head' is not an alternative since this also seems to have quite different meanings in different countries. The expanded phrase 'so tired that it is difficult to work' might be used. Alternatively, just 'tired' might be enough. Similarly there were some problems with 'blocked or stuffy nose' but these appeared to have been resolved in the final translation.

Data entry

The Netherlands double-entered the questionnaire data and United Kingdom had random checking for entering the data. The remaining 7 countries double-checked 10 questionnaires per building corresponding to approximately 10% of the questionnaires.

In the double-check it was found that every fifth questionnaire had one or more typing errors. In questionnaires with errors, the mean number of typing errors was 2. One questionnaire had 17 typing errors, but 1 to 4 errors were more common. Randomly spread over the more than 100 questions this gives an uncertainty of less than 0.5 % for each question.

2.3.3 Indoor air quality and climate

Indoor air quality

In general two type of measurements were made: spot and continuous measurements. Spot measurements of CO, CO_2 and TVOC/VOC were performed in each selected space, supply air, outdoors and in adjacent spaces when thought to be necessary. Spot measurements varied from 5 to 25 minutes. Continuous measurements of CO, CO_2, TVOC and particulate matter were made at least in one selected space. The instruments used for the measurement of the CO, CO_2, TVOC, VOC and particulate matter by each country are presented in Table 2.4. More detailed information is given below.

Volatile Organic Compounds (VOC)

Two different methods for measuring volatile organic compounds in air were used: the Tenax-GC method and direct measurement of infrared absorption using photo acoustical detection. These two methods not only use different principles of measurement but they are also sensitive for different groups of organic compounds.

Conceptually VOC's comprise any gaseous (excluding particle bound substances) organic compound in air. With the traditional method of measuring VOC's i.e. collecting volatile organic air contaminants on an adsorbing material like activated carbon (or in our case Tenax-TA) and separation by gas chromatography only the main fraction with respect to the number of compounds is analyzed. This fraction with a boiling point of about 50°C to 250°C is normally called VOC. Not included in this range of compounds are the very volatile organic compounds (VVOC) with lower boiling points that have a low tendency for adsorption on the commonly used adsorbing materials as well as those compounds with boiling points above about 250°C that are difficult to elute both from the primary sample as well as from the gas chromatographic column (=semi volatile organic compounds SVOC).

Clearly, only methods sensitive to the same set of compounds can be expected to yield comparable results. But there is yet another critical point in comparing VOC-data. Concentration values can be given in two different types of unit: $\mu g/m^3$ or mg/m^3 (= mass of VOC - individual summed up - per unit of volume of air) and ppm (≐ number of VOC-molecules per million of air-molecules). Some detectors are sensitive for mass (e.g. Flame Ionisation Detection (FID)), others "count" molecules leading therefore to molecular concentrations expressed in ppm units. A correct conversion between the two type of units is possible only if the concentration of every single compound present in the sample is known, a situation rarely found in practical VOC-analyses.

With the Tenax-GC method individual substances of the central VOC-fraction are analyzed. To get comparable results from country to country (but also because the applied methodology requires complex instrumentation and practical experience with ultra trace chemical analysis) a central laboratory (BIGA Zürich) was charged with supplying the sampling tubes and analysing the exposed samples for all participants in the project.

The instrumentation for the Tenax-GC method comprised:

- sampling/desorption: Automated thermal desorption apparatus (Perkin-Elmer ATD 400) with stainless steel sampling tubes closed by Swage-Lock caps with teflon ferrules.
- separation: Gas chromatograph (Hewlett Packard 5890) equipped with J&W DB 5 MS capillary column (1µm, 30 m x 0.25 mm).
- detection: effluents from GC were fed in parallel to a Flame Ionisation Detector

(component of the GC) for quantification and a Mass Spectrometer (Hewlett Packard MSD 5970) for identification.

. data treatment: the analogue signal of the FID was fed to a stand alone, PC-based integration system (Kontron "PC Integration Pack" Vers. 3.90). Full mass chromatograms were transferred to a DEC VAX station 4000 VLC for identification of the separated compounds using "Masslib", an evaluation system for low resolution mass spectra series (Vers. 7.2, Max Planck Inst. für Kohlenforschung, Mülhheim a.d. Ruhr, Germany). Full raw data of FID and MS were stored on disk for further evaluation.

The procedure followed in the Tenax-GC method was as follows:
The stainless steel tubes, filled with 250 mg of Tenax-TA (60-80 mesh) were cleaned on the ATD 400 and loaded with a known amount (1 µg) of d8-toluene as internal standard, diluted in ultrapure methanol.
Sets of 10 tubes per building ready for sampling (cleaned up and spiked with the internal standard) were delivered by air a few days before the planned investigation. One of the ten identical tubes served as a check for possible contamination from transport (e.g. under pressurization during the flight) and was sent forth and back without opening it. At the site of the investigation, known amounts of 3 to 5 litres of air were taken at a rate of circa 40 ml/min. with appropriately calibrated pumps (sampling teams were responsible for accuracy of volume of sampled air). After exposure, samples were returned by air again to the central laboratory for analysis.
The primary desorption from the sampling tube was executed for 5 minutes at 200°C, transfer line at 220°C, and a cold trap at -30°C packed with Tenax-TA. The secondary desorption from the cold trap was performed at 300°C. The GC-separation was performed with Helium as the carrier gas (1 ml/min.) and a temperature programme from 40 to 250°C at a rate of 8°C/min.. The detection took place with a splitted FID/MS (1:1), a GC-MS transfer line at 250°C. The mass spectra were recorded from m/z 19 to m/z 300 (1.5 scans/sec).

Sampling was done with portable pumps by all teams. Pump flow was calibrated either with bubble meters or indirectly with calibrated rotatometers. Stated accuracy ranged from 2 to 10 ml/min., resp. 1 and 5%. At first sight, it appeared that pump inaccuracy was the main source of uncertainty on the sampled volume, as is common in such applications. Time inaccuracy was in the 0.5 to 2 min. range, corresponding to no more than 2% error on the sampled volume.

Quantification of the individual compounds was done on the simplified assumption of uniform sensitivity (given as mass concentration) for all detected compounds and mass-concentrations [$\mu g/m^3$] were calculated as toluene equivalents. As a measure of the total load of VOC's the concentrations of the individually detected compounds were summed up and presented as a TVOC-index (=toluene concentration producing an FID signal equal to the sum of the FID signals in the actual sample).

In the audit program several teams measured VOC's directly with photo acoustical detection using infrared absorption, with the commercially available multigas monitor (Brüel and Kjaer, Model 1302). This method allowed on-site measurement of air components with a short time response. Typically, data were recorded every 1 to 2 minutes. As there was no separate sampling step, VVOC's were measured together with the VOC's.
Except for Greece, France, Switzerland and Finland all countries performed spot measurements

in each selected office. Some used methane as calibration gas, others used toluene. Continuous measurements of TVOC with the B&K 1302 at least in one selected office per building were also performed, except for the United Kingdom, Greece and Switzerland.

Carbon dioxide (CO_2)
Six different instruments were used for either continuous or spot measurements. Accuracy when stated ranged from 10 to 50 ppm, resp. 10%.

Carbon monoxide (CO)
Instruments used ranged from dispersive (filter) IR (infra red) to direct reading colorimetric tubes and included NDIR and colorimetric direct reading detectors. Sensitivities were at the 1 ppm level when stated, detection limits were in the 0.2 ppm (IR) to 1 ppm range.

Particulate matter
All countries used the gravimetric method to measure particulate matter and in addition Switzerland used straylight dust meters.
The apparatus used by the majority of the countries was an open faced filter holder that was set in a vertical position, i.e. with air flowing horizontally towards the filter. Norway used the cyclone method, employing two stages for fine and coarse particles. The filters used in most cases had a diameter of 37 mm, although 25 mm and 47 mm were used as well.
Various types of filters were used (cellulose ester, glass fibre, teflon) and the nominal pore size of the filters ranged from 0.5 to 5 µm. The sampling rates of the pumps ranged from 0.2 to 20 l/min.. The calibration of the flow rate was carried out using a flowmeter, a rotameter or a gasmeter. The preparation of the filters was mainly based on the method proposed in the manual (12). The airflow of the pump during sampling was approximately 3.5 l/min. and the sampling period was approximately 8 hours for all countries. The filters were weighted before and after sampling on a balance with an accuracy of 5 µg to 10 µg. Therefore, the accuracy of the method ranged from 3-6 $\mu g/m^3$.

Indoor climate
In general two type of measurements were made: spot and continuous measurements. Spot measurements were performed in each selected space, supply air, outdoors and in adjacent spaces when thought to be necessary. In general, continuous measurements were made in one selected room per building. The instruments used for the measurement of the air temperature, the operative temperature, the relative humidity, the air velocity and the noise level by each country are presented in Table 2.5.
Most countries used instruments from Bruël & Kjaer (B&K) to measure the indoor climate parameters. Some countries additionally used sensors connected to data loggers, to collect the parameters continuously.

Table 2.4 *Overview of instruments and methods used to measure indoor air quality, by each country.*

	The Netherlands	Denmark	United Kingdom	Greece	France	Switzerland	Finland	Norway	Germany
Spot									
CO [ppm]	B&K 1302	B&K 1302	B&K 1302	Dräger Multiwarn	Dräger minipac	Dräger Pac 2CO	.	B&K 1302 Telair NDIR	B&K 1302
CO_2 [ppm]	B&K 1302	B&K 1302	Horiba ABPA-210 portable	Dräger Multiwarn	Dräger Multiwarn	Arox 425A[5]	.	B&K 1302	B&K 1302
VOC	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]	Tenax-GC[1]
TVOC [ppm]	B&K 1302 (methane)	B&K 1302 (toluene)	B&K 1302 (methane)	.	.	.	.	B&K 1302 (toluene)	B&K 1302 (methane)
Continuous									
CO [ppm]	Maihak Unor-6[2]	B&K 1302	.	Dräger Multiwarn	.	Dräger AC200	B&K 1302[5]	B&K 1302	B&K 1302
CO_2 [ppm]	Horiba ABPA-250E[3]	B&K 1302	Horiba ABPA-250E	Dräger Multiwarn	Dräger Multiwarn	Binos 100[5] or Arox 425A	B&K 1302[5]	B&K 1302	B&K 1302
TVOC	B&K 1302 (methane)	B&K 1302 (toluene)	.	Horiba APHA-300E	B&K 1302 (methane)	.	B&K 1302[5] (methane)	B&K 1302 (toluene)	B&K 1302 (methane)
particulate matter	gravimetric	gravimetric	TSI Model 8510 Piezobalance aerosol mass monitor[4]	gravimetric	gravimetric	gravimetric + straylight dust meter	gravimetric	gravimetric	gravimetric

1: using tenax-tubes delivered and analyzed by BIGA, expressed in $\mu g/m^3$ toluene; sample volume 3-5 l air; VTT and France analyzed some of the Tenax-tubes themselves; the method also provides TVOC.
2: measurements at 3 locations
3: continuous measurements at all selected locations
4: was in fact a spot measurement
5: used both for spot and continuous measurements

Table 2.5 *Overview of instruments and methods used to measure indoor climate, by each country.*

	The Netherlands	Denmark	United Kingdom	Greece	France	Switzerland	Finland	Norway	Germany
Spot									
air temperature [°C]	.	B&K 1213	B&K 1213	EBRO electronic RHT 200	Dantec 54N50	Pt-100-Air probe	Dantec 54N50	DISA 54N50	B&K 1213
operative temp. [°C]	.	B&K 1212	B&K 1213	.	globe thermometer	B&K 1212	globe thermometer	.	B&K 1213
rel.humidity [%]	.	B&K 1213	.	EBRO electronic RHT 200	Novasina type MIK 3000-C	Rotronic Hygroskop DV-2 with YA-100, Air probe	Alnor Humicor, IHRT	.	B&K 1213
air velocity [m/s]	B&K 1213	B&K 1213	B&K 1213	Dantek type 54 N50	Dantec 54N50	Dantec 54 N50 Flowmaster	Dantec 54N50	DISA hot-wire anemometer	B&K 1213
noise [db(A)]	B&K 2230	B&K 2230	Castle GA108	Girrus research limited sound meter	B&K 2218	SEL sonometer	B&K 2230	B&K 2218	B&K 2230
Continuous									
air temperature [°C]	thermistor[1]	B&K 1213	thermistor probes	grant 1200 series, type 1206	thermistor	Condustrie-Met AG	B&K 1213	thermocouples[1] B&K 1213	B&K 1213
operative temp. [°C]	globe thermometer[1]	B&K 1212	.	grant 1200, type 1206	globe thermometer	B&K 1212	B&K 1213	black globe[1] B&K 1213	B&K 1213
rel.humidity [%]	Vaisala[1]	B&K 1213	vaisala sensor	grant 1200, type 1206	Vaisala	same as spot	B&K 1302	Vaisala and Rotronic[1]	B&K 1213
air velocity [m/s]	.	B&K 1213	Dantec 54R10 transducer	grant 1200, type 1206	.	.	B&K 1213	B&K 1213	B&K 1213
noise [dB(A)]	.	B&K 2230	.	.	Alean	.	.	.	B&K 2230

1: continuous measurements at all selected locations

2.3.4 Ventilation

The purpose of the ventilation measurements was to assess all the airflow rates entering the zones of interest. In each office room, air may come from mechanical supply, from infiltration of outdoor air or from adjacent spaces. Various methods were used by the different participants to assess these airflow rates (Table 2.6).

Table 2.6 Ventilation measurement methods applied by various countries.

Country	Infiltration	air from adjacent spaces	supply air
The Netherlands (NL)	tracer gas decay in one room	dP monitoring and gap area	Flowfinder or dP and air velocity measurements and induction unit characteristics
Denmark (DK)	tracer gas constant concentration and decay	smoke tests to check flow direction	Flowfinder
United Kingdom (UK)	various tracer gas techniques	smoke tests, anemometry. dP spot measurements and gap area.	Flowfinder. Tracer gas in ducts.
Greece (GR)	tracer gas decay combined with dP monitoring to assess leakage characteristics	smoke tests to check flow direction. successive tracer gas decays.	velocity traverse at grid.
France (F)	smoke tests and dP measurement	smoke tests, dP measurement and gap area	low pressure flowmeter or velocity measurement at grid
Switzerland (CH)	tracer gas constant concentration in naturally ventilated buildings. smoke test to check zero infiltration in mechanically ventilated buildings.	second tracer gas injected in room delivering air to test rooms. smoke test to check flow direction	tracer gas constant concentration or constant emission. Smoke test to check zero infiltration.
Finland (SF)	assumed to be equal to supply minus exhaust air flow rates	dP spot measurements	dP measure and grid characteristics. velocity traverse at grid or in ducts.
Norway (N)	negligible	unsuccessful tracer gas	hot wire anemometer and bag technique
Germany (D)	over-pressure in most buildings. tracer decay in naturally ventilated buildings.	smoke tests to check flow direction. negligible air flow from adjacent spaces.	tracer gas decay. no infiltration in mechanically ventilated buildings.

The reasons for this variety (or lack of uniformity) were:

- It was impossible to impose a specific technique, since the equipment of the various participating institutions was not the same. For obvious budgetary reasons, it was impossible to have all participants buy a standard equipment.
- The various measuring teams all had ventilation measurement specialists, already skilled and used to a particular technique.
- Buildings and ventilation systems varied from country to country, and measurement techniques were adapted to these systems.

Basic principles were however provided in the manual (12), and were respected as far as possible. It should be said that the conditions for measurements are not ideal in occupied buildings. Even with improved techniques for measurement and interpretation, the results can not be perfect. Therefore, in some cases results were reported with large uncertainties.

Specific comments from each country are summarised below.

The Netherlands

The ventilation measurements and methods were chosen in such a way that it was possible to perform them during the time of day that was available, and so that it was still possible to make an evaluation of the airflows of importance. Therefore, in most buildings three type of measurements were performed: continuous measurement of pressure differences between the selected rooms and the corridor (indication of airflow between corridor and room), spot measurement of mechanical air supply and exhaust and a decay measurement in at least one room (indication of infiltration from outside air).

The mechanical air supply and exhaust rate were measured using either the 'Flowfinder' with an adapter when necessary (Buildings A, B, C, D and F) or a vane anemometer with pressure flow characteristics of the induction unit (Building E).

Doors were kept closed during measurements.

Denmark

Supply air was measured with the ACIN Flowfinder. Airflows from adjacent spaces were investigated by smoke tests. Doors were kept closed during measurements and airflow from adjacent spaces were found negligible in most cases. Therefore, the constant concentration and decay tracer gas measurement were used to assess infiltration. In one building, which had recirculation, detailed measurements of infiltration, exfiltration, supply air and degree of recirculation were performed.

United Kingdom

The test zones in five buildings were open plan offices, with only a few exceptions in the case of Buildings B and C. These five buildings were air conditioned, and recirculation was present in all cases, in various ways. Building D was cellular and naturally ventilated.

Large open plan offices present problems when applying conventional ventilation measurement techniques using tracer gas, particularly with regard to achieving and maintaining an even distribution of tracer gas. Recirculation complicates the problem further, especially where the system serves a larger portion of the building than the area where measurements can be carried out, a situation faced in four buildings. These problems were approached using several tracer gas techniques, involving either constant concentration injection, concentration decay or the novel homogeneous emission method.

In all cases, with exception of the homogeneous tracer gas emission technique, the tracer measurement was intended to provide the overall ventilation rate of the test zone. The ventilation system supply rate to the zone was measured independently, either with a flowmeter or using tracer gas. Infiltration for the whole zone could then, in theory, be calculated by subtracting the ventilation system supply rate from the whole zone ventilation rate.

In all case the test zones were connected to many adjacent spaces. To overcome this problem smoke 'puffers' were used to identify whether flow entered or left the test zone at the boundary doors. If air entered, then a sensitive digital manometer was used to measure the pressure drops across the door, for a few minutes. The area of the gaps around the door was then estimated. The order of magnitude of the inflow rate was then calculated assuming the flow to be equivalent to that through a sharp-edged circular orifice. Generally, the calculated inflow rates were found to be insignificant compared to the overall ventilation rate and their influence was therefore neglected.

In most cases the ventilation system supply rate to the zone was measured using the pressure balanced flowmeter (Flowfinder, TNO). In two cases (Buildings E and F) the ventilation system supply rate was determined by releasing tracer gas (constant injection, SF_6) into the supply ducts, upstream of the supply inlet to the zone, and measuring the concentration downstream.

Greece

Five out of six buildings had mechanical ventilation. However, as it is common during winter in Greece to switch the mechanical ventilation off, three buildings were naturally ventilated. Three buildings received most of the supply air through a mechanical system.
A face velocity method using an anemometer was used to measure the air supply flow rates at the inlet grids. The direction of airflows from or to the selected rooms was checked using smoke tests. Successive decays with a single tracer gas (N_2O) allowed the determination of the general air change rate, and of airflows from adjacent spaces and from outdoor.

France

Building C was naturally ventilated (windows), building D had a mechanical exhaust ventilation system, the other buildings had a balanced system. In all cases, the investigated rooms were connected to one adjacent space (corridor) and doors were kept closed during measurements. Except Building C, all buildings had over pressure, therefore no air from adjacent spaces was entering the investigated rooms (the direction was checked by smoke tests and pressure difference measurements between room and corridor). For two rooms in Building C, it was found that air entered, but were found to be insignificant.
Supply air was measured with a low pressure flowmeter (using an adaptor when necessary). In some cases, the flowmeter could not be used, thus a face velocity method using an anemometer was applied. In addition, tracer gas decay was measured in each room. No significant discrepancy was found between both methods.
For each audited room in Building B, it was possible to separately measure the different airflow rates: outdoor air, recirculated air, return air. The difference between supply and return was assumed to be equal to exfiltration and flow from room to corridor. The degree of recirculation was derived from flow rate measurements and found higher (90%) than the design value (75%). For Building F, outdoor airflow due to the ventilation system could not be measured; thus the degree of recirculation was evaluated by CO_2 measurements and found close to the design value (65% instead of 60%).
Building C was ventilated via cracks of the envelope and through windows, which were closed during the tracer gas decay measurement. The rooms of Building D were ventilated via self-regulated air inlets above the windows. The ventilation rate was measured with the decay method, since it was not possible to measure the airflow rates at the inlet.

Switzerland

An automatised tracer gas system, the Compact Equipment for Survey of Air Renewal (CESAR) was used. It can measure airflow rates using up to three tracer gases. Up to 10 locations can be monitored successively at 50 seconds intervals. Analysis was carried out by four independent non-dispersive IR (infra red), for tracers N_2O, SF_6 and Halon R1301; and for water vapour to correct the interference. R1301 is an ozone depleting gas, and was therefore used only when necessary.
Measurements were performed under normal conditions, that is with doors closed or open according to the occupants habit. In each building, before deciding on the tracer gas injection

strategy, smoke tests were performed in openings between zones and to outdoor environment. Tracer was only injected into zones from which air flowed into the test rooms, since the scope of the measurements was to assess only airflows coming into the test rooms. The constant concentration injection technique was used when possible. In very large office rooms, however, the controlled tracer flow rate was too low, and constant injection rate technique was used. A powerful Bayesian identification technique was used to obtain airflow rates from multiple tracer time varying injection rates and concentrations.
Because of non standard design of grids in Switzerland, the Flowfinder could only be used in one building to asses supply air (Building D). In other mechanically ventilated buildings, infiltration was checked to be zero by smoke tests and tracer gas measurement allowed to assess the supply airflow rate.
Recirculation rate and other airflow rates in air handling units were measured separately using a tracer gas dilution technique at constant injection rate in ducts.

Finland
Pressure difference between room and adjacent space (corridor) and between room and outdoors (if possible) were measured in the morning and the afternoon of the audit day.
Mechanical air supply and exhaust flow (if possible) were measured with an anemometer, an anemometer tube and manufacturers calibration curves together with the measured pressure drops across diffusers (Buildings A, B, C, D and F). The exhaust flows were measured using pressure traverse (pitot tube) (Buildings B, C, D and F; exhaust point inaccessible in Building A).
The difference between supply and exhaust was assumed to be equal to either infiltration, exfiltration or both, according to the measured flow between room and adjacent space.

Norway
All buildings had mechanical ventilation systems. Supply and exhaust airflow rates were measured in each audited room. SWEMA hot wire flow meter and bag techniques were used. Measurements were performed under normal conditions, that is with doors closed or open according to the occupants habit.
Tracer gas constant concentration and constant injection rate measurements were tried without success. Variable uncontrollable conditions prevented to reach a steady state. It was assumed that infiltration was negligible.

Germany
Over pressure was observed in the four mechanically ventilated buildings. Smoke tests were used to check airflow direction to outdoor and to adjacent spaces. Tracer gas decay (N_2O) was used to measure general air change of each room. This air change was assumed to be equal to supply air in mechanically ventilated buildings and to infiltration in naturally ventilated buildings.

2.3.5 Energy consumption

Energy consumption assessment

The method described in the manual (12) aimed to assess the total yearly energy consumption of each audited building. This information can be obtained from energy bills or from data collected by the building management. If possible, information was collected separately for the various energy sources. It is necessary to mention that those sources are only commercial forms of energy. There were no plans for evaluating eventual energy coming from the environment (passive solar heating or cooling, daylighting, night ventilation, etc..) which could eventually replace other energy needs. To compare the various sources, all values in original units were converted into SI units. Lower calorific power values and conversion factors given in Table 2.7 were used for that purpose.

Table 2.7 *Lower calorific power of several energy sources.*

Energy source	Measured Unit	Calorific power	
		[MJ/unit]	[kWh/unit]
extra light oil	kg	42.7	11.9
extra light oil 850 kg/m^3	litre	36.0	10.0
heavy oil	kg	40.2	11.2
natural gas, atm.pressure	m^3	36.3	10.1
propane, butane	kg	46.0	12.8
electricity, district heating	kWh	3.6	1.0

Energy consumption index

To compare (as far it is reasonable possible) the energy use of buildings of various dimensions, an energy consumption index was calculated by:

$$\text{Energy index} = \text{total yearly energy use/gross heated floor area} \quad [\text{MJ/m}^2] \quad [2.1]$$

The gross heated floor area included all heated spaces of the considered building, calculated with external dimensions. Unheated spaces such as garage, storage, machinery rooms should not have been included, even if they were at room temperature. An electricity energy index was defined in a similar way, dividing the yearly electricity consumption by the gross heated floor area. For buildings not electrically heated, a heating index was obtained by subtracting the electricity index from the total energy index.

Comments

Many participants found it difficult to collect the energy consumption data from the building managers. These data were not always available, which indicates that the energy consumption is not always considered to be of great importance in office buildings. It should be noted that in general the energy bill in most office buildings is negligible when compared to other costs, such as capital interests or salaries. This is one more reason for a broader evaluation of the energy and the IAQ issues together under the perspective of the policy makers and not leave the solutions only for the market itself. In particular, when the energy prices of commercial energy never were so low for many years and the environment-related energy issue is not clearly understood or integrated by the market.

2.4 Time schedule

The buildings should have been visited on working days either on Tuesdays, Wednesdays, Thursdays or Fridays. Every morning during the experimental period the sensory panel should have been retrained and should have taken a performance test in a temperature controlled, well-ventilated room, which lasted 1-2½ hours depending of the available equipment. When the training was finished the panel was transported to the building where they were asked to assess the outdoor air quality. The panel was then guided to a well-ventilated waiting location where they spent at least 2 minutes between each assessment of a room. The panel should then have assessed the air quality in the selected locations, in the adjacent spaces and of the supply air in random order twice.
The employees were informed about the questionnaire survey a week before the experiments. On the experimental day the distribution of the questionnaires was suppose to start parallel to the sensory evaluations and each individual was personally asked to fill in the questionnaire and told that the questionnaire would be collected within one hour.
To perform the study six measuring teams were needed. 1-2 persons distributed and collected the questionnaires, 1-2 persons did the thermal and chemical measurements with direct reading instruments, 1-2 persons did the measurements of particulate matter and sample chemicals on the collection media, 1-2 persons did the air-exchange measurements and 1-2 persons took care of the sensory panel. Finally, one person took notes at the selected locations and in the corridors of any unusual events happening.
The measurements were performed parallel to each other. The actual time schedule used varied due to cultural differences in the participating countries. The presence of the sensory panel may influence the physical and chemical measurements and vice versa. These influences should have been minimized by careful planning of the time schedule for the measurements in the selected locations.

For each country their general time schedule can be found in their national report (18-26).

In general the different countries kept their time schedules very well to the recommendations in the manual. Some difficulties were encountered with the planning of the ventilation measurements, which took more time than originally was planned.

2.5 Detailed investigations

Two detailed investigations on source identification and ventilation performance were made by SBI from Denmark and BBRI from Belgium, respectively. The results of these investigations are reported separately (27,28). The objectives of these investigations are summarized in this paragraph and main findings are summarized in paragraph 3.8.

2.5.1 Source identification

The strength of indoor air pollution sources can determine the ventilation requirements in office buildings and therefore set a limit to reductions of energy consumption in office buildings. Activities to reduce the air pollution load in buildings need to be based on knowledge about the relative importance of different sources. This knowledge should be based on sufficiently detailed identification and proper quantification of the sources in buildings.

It may be possible to get a more detailed identification by the use of a FLEC (Field and Laboratory Emission Cell) (33). When using the FLEC it is important to consider the influence on emission rates of the environmental parameters such as temperature, humidity, specific ventilation rate and air velocity (34). The FLEC is ventilated with clean synthetic air. It is therefore also of importance to consider the primary origin of compounds emitted from a surface (35). Some compounds may be deposited or adsorbed on a surface before the FLEC has been mounted. When the FLEC is then mounted, these compounds are not longer present in the air, and may therefore be re-emitted as secondary pollution from the surface under the FLEC. The emission rates of these compounds may decrease rather rapidly, because the surface material is cleaned by the air in the FLEC.

By applying a cell to the possible sources in a room and sampling volatile organic compounds (VOCs), chemical analysis of the emissions from these sources is possible. These emissions may be compared with chemical analysis of room air to get an idea of the importance of the sources. This method is not yet fully documented regarding the influence of time and environmental parameters. Refinement and optimization of procedures may improve the precision of results and the feasibility of the method. It is therefore of importance to validate the method by characterizing the influence of the mounting of a FLEC to a surface material on emission rates, and to test whether field measurements of this type gives realistic and relevant data.

The main objectives of this study was therefore to contribute to the European IAQ database with respect to:

- The refinement of a method to identify the major air pollution sources among surface materials in an office building, without excessive disturbtion of normal work and without destroying parts of the building.

- To validate and optimize the method with respect to time before sampling chemicals and sampling parameters with FLEC mounted to surface.

- To identify and quantify major pollution sources in three offices in three selected office buildings by the developed method.

The experiments for the source identification were performed during July and August 1994 in the Copenhagen area after the comprehensive general measurements (Auditing) had been performed by other contractors in the project. When selecting offices for the study, data obtained during previous studies were used.

In one office in each of three selected buildings three Field and Laboratory Emission Cells (FLECs) were mounted to the wall, floor and desk surface on representative places. During the measurements the FLECs were supplied with clean, humidified synthetic air. Air from the FLECs were sampled on tubes with Tenax TA sorbents at four different times after application (1 h, 3 h, 6 h and 24 h). Each sample was taken during a period of 50 minutes with a flow rate of 90 ml/min giving a sampling volume of 4.5 l. Similar samples were also taken from the room air and the outdoor air.

2.5.2 Ventilation performance

Detailed measurements were carried out by BBRI in two buildings selected for the general studies: one situated in the Netherlands (Building C) and the other in France (Building E).

The general objective of the detailed ventilation measurements performed in these two buildings was double:

- To perform additional measurements which should complete and enhance the general ventilation measurements. This allows to obtain more information on the ventilation related parameters characterising these two buildings, and also to demonstrate the validity and limitation of the methods used in the general measurements.

- To apply recently developed techniques and validate their application and utility, to identify new possibilities.

Therefore several measurements were performed:

- General ventilation measurements: These measurements allow to have an overall view of the ventilation of the building. The following parameters were measured in both investigated building:
  - supply airflow rate
  - exhaust airflow rate
  - degree of recirculation
  - exfiltration and infiltration through the building envelope.

  (These measurements were also performed by the Swiss team in each of its audited buildings.)

- General outdoor airflow rate from carbon dioxide measurements: The principle of this technique is to use the carbon dioxide emitted by people as a tracer gas. In addition to the average CO_2 concentration in the building, the injection of CO_2 must be known in order to derive the total outdoor airflow rate (= infiltration + mechanical supply - recirculation). This can be evaluated from the number of people present in the building assuming an average CO_2 emission by person (about 18 l/h per person).

- Air spreading in the building - Ages of air

- IAQ related parameters: Some parameters can be measured in the exhaust ducts of the ventilation system. The value measured is then an average for the whole building. A continuous monitoring will give an indication of the parameter as function of time. This type of measurement is very helpful for the general evaluation of IAQ in an office building. This method was applied to measure CO and CO_2 in both buildings.

- Energy related parameters: Since ventilation systems supply outdoor air to the buildings they can affect the thermal balance of buildings. This can result in additional costs depending on the outdoor temperature. In winter, the cold outdoor air must be heated, whereas the night ventilation during the summer helps to cool down the building and thus decreases the cooling costs.
  The outdoor and indoor temperatures were monitored during August 94 in the French building. From these measurements and from the general air change rate, the cost or profit due to ventilation were evaluated.

3. RESULTS

3.1 Questionnaire

In this paragraph the questionnaire results are presented. More detailed information per country can be found in the national reports (18-26).

3.1.1 Response rate

The response rate regarding the questionnaire varied between 54% and 97% with a mean response rate of 79% for the 56 European office buildings. The response rate including the total number of questionnaires filled in is given for each building in each country in Table B.1 of Appendix B. The relatively high response rate should first of all be seen as an outcome of the procedure for handing out and collecting the questionnaires. Absent employees and employees too busy to participate in the survey did in most cases not receive a questionnaire.

3.1.2 Population

Information of the population in the audited buildings, including sex, age, smoking habits, allergic diseases and work function, is given in Tables B.2 to B.6 of Appendix B. The sex distribution is furthermore shown in Figure 3.1. The figure shows that the sex distribution varied from country to the country, but only significantly for the buildings in The Netherlands.

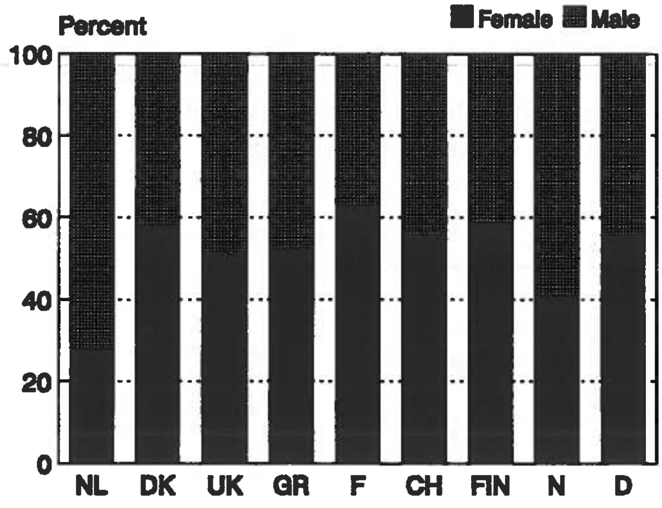


Figure 3.1 *Sex distribution in the audited buildings shown as mean for the participating countries.*

The reverse is seen for the mean age, which was for all countries approximately 39 years (Table B.3). The highest percentage of smokers was found in the investigated buildings of Greece (48%). The mean percentage of smokers ranged in all other investigated buildings per country from 22 to 37%, with an average of 31% (Table B.4).
In the investigated buildings of Finland the percentage of occupants who ever had eczema is 51%, while in the buildings of Greece this was only 8%. The average of all investigated buildings was 27% (Table B.5).
The average of occupants who experienced asthma was 10%. The buildings in Finland score again the highest with 18%; all other investigated buildings per country had percentages between 7 and 13%. Hay fever was experienced on average by 25% of the occupants, with a range of 17% (Germany) to 31% (France).

The work function distribution varied considerably from country to country (Table B.6).

3.1.3 Environmental perceptions

Tables B.7 to B.10 in Appendix B present the mean response rate of the occupants' perception of indoor air quality for the retrospective (last month) and immediate response (here and now). The acceptability of indoor air quality, air dryness, air stuffiness, and odour perception are furthermore shown in Figures 3.2 to 3.5 for the buildings investigated in each country considering the here and now response. Acceptability of indoor air quality last month and here and now is shown for the occupants in the buildings investigated of the nine different countries in Figure 3.6, presented in percentage of dissatisfied.
In this figure all occupants who voted below zero on the scale from -5 to 5 are taken as being dissatisfied with the air quality.

The average air dryness ratings did not show a lot of difference between the investigated buildings per country (Figure 3.3 and Table B.8). The same can be said for the average air stuffiness and odour ratings, although the variation of ratings of buildings per country was reasonable (Figures 3.4 and 3.5; Tables B.9 and B.10).

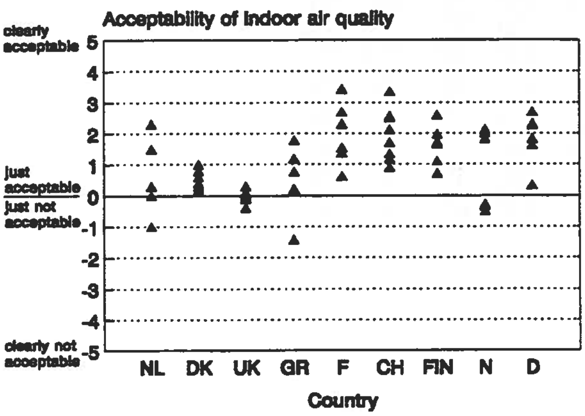


Figure 3.2 *Indoor air acceptability, now, on a scale from -5 to +5.*

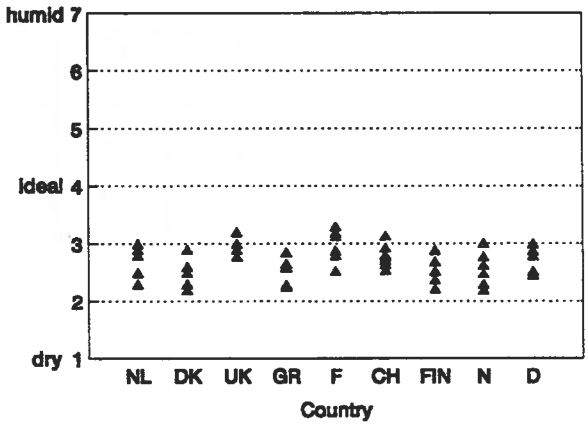


Figure 3.3 *Air dryness, now, on a scale from 1 to 7.*

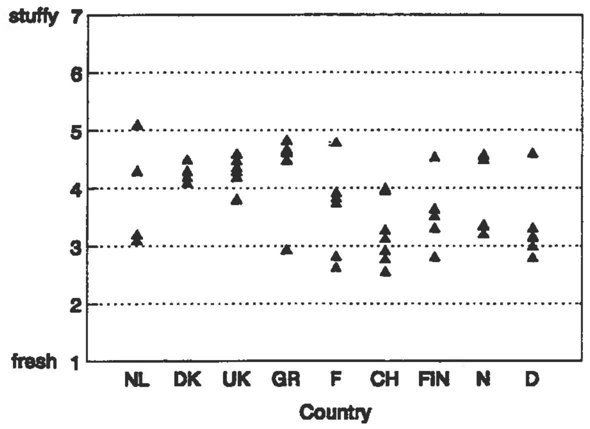


Figure 3.4 *Stuffiness, now, on a scale from 1 to 7.*

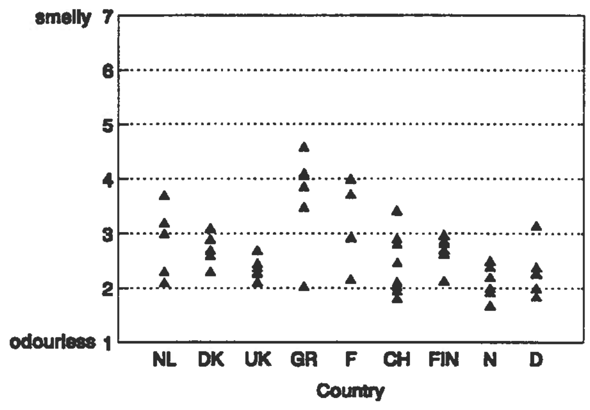


Figure 3.5 *Odour, now, on a scale from 1 to 7.*

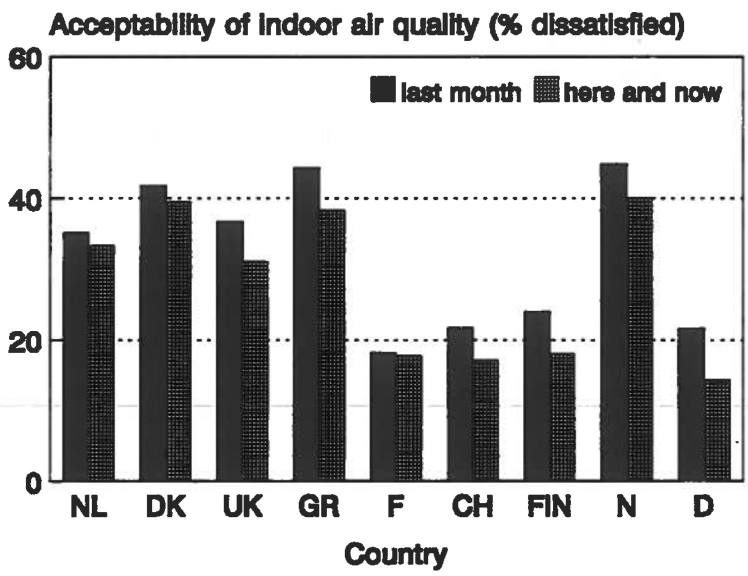


Figure 3.6 *Indoor air acceptability rated by the occupants in the European IAQ Audit buildings presented in percentage of dissatisfied.*

Figures 3.7 and 3.8 show the thermal comfort rate and noise satisfaction for the here- and-now response. Thermal comfort rating, light satisfaction, noise satisfaction, control of ventilation and cleanliness of office are listed in Tables B.11 to B.14 of Appendix B.
In general the levels of noise and light were rated acceptable, the level of thermal comfort was often slightly warm, but for most buildings acceptable. The general opinion among occupants was that they had little control over the office environment.

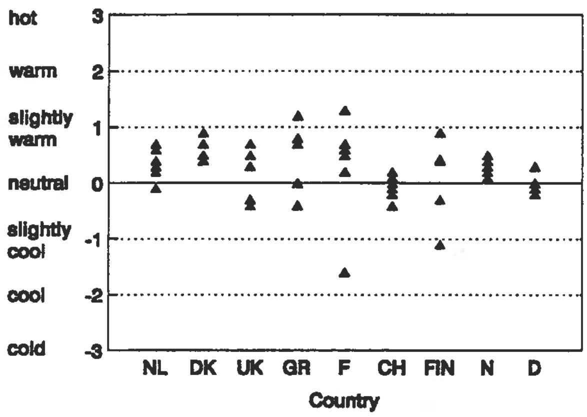


Figure 3.7 *Thermal comfort rate, now, on a -3 to 3 scale.*

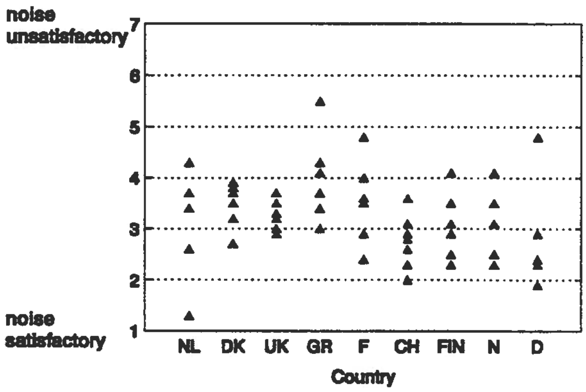


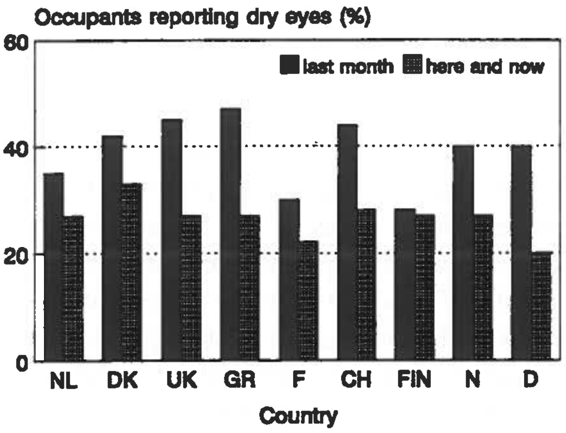
Figure 3.8 *Noise satisfaction, now, on a 1 to 7 scale.*

3.1.4 Building-related symptoms

For each of the questions on symptoms of the past month, two answers could be given: how many days do you experience the symptom and if a symptom experienced was better on days away from the office. In this case a symptom is considered relevant when the first answer was 1-5 days or more and when the second answer was yes. For each of the questions on symptoms now, three answers could be given: are you experiencing the symptom, if yes did this symptom got better or worse since you arrived and how severe is this symptom. In this case a symptom is considered relevant when the first answer was yes, the second answer was no change or worse and the third answer was larger then 0 (the severity is not weighted here. The number of building-related symptoms are given for all investigated buildings per country in Tables B.15 to B.23 of Appendix B. The most reported symptoms were lethargy, headache, dry eyes, dry skin, blocked or stuffy nose and dry or irritated throat. It should be noticed that the most reported symptoms past month were lethargy and headache for most of the 56 Audit buildings. Whereas the most prevalent building-related symptoms here and now varied between dry eyes, dry skin, dry and irritated throat, stuffy nose, lethargy and headache. The mean prevalence of building-related symptoms for all investigated buildings per country are listed in Table 3.1. The mean number of occupants reporting dry eyes and lethargy last month and here and now are given for all investigated buildings per country in Figures 3.9 and 3.10, respectively.

Table 3.1 *Building-related symptoms for all of the buildings.*

Country	NL	DK	UK	GR	F	CH	FIN	N	D	Mean
Symptoms past month										
• dry eyes	35%	42%	45%	47%	30%	44%	28%	40%	40%	39%
• watering eyes	10%	12%	22%	21%	30%	19%	18%	10%	15%	17%
• stuffy nose	25%	23%	50%	31%	41%	39%	28%	25%	38%	33%
• runny nose	11%	13%	27%	17%	32%	19%	16%	10%	18%	18%
• dry throat	29%	30%	42%	36%	47%	42%	24%	31%	41%	36%
• chest tightness	12%	5%	14%	30%	26%	16%	8%	8%	12%	15%
• flu-like symp.	18%	14%	31%	33%	38%	27%	16%	14%	31%	25%
• dry skin	16%	23%	24%	27%	29%	26%	22%	33%	28%	25%
• irritated skin	6%	5%	14%	14%	22%	8%	11%	9%	12%	11%
• headache	33%	42%	58%	55%	54%	39%	21%	38%	36%	42%
• lethargy	37%	42%	61%	61%	63%	49%	41%	59%	52%	52%
• other symptoms	11%	11%	15%	6%	15%	14%	13%	11%	11%	12%
Symptoms here and now										
• dry eyes	27%	33%	27%	27%	22%	28%	27%	27%	20%	26%
• watering eyes	3%	3%	6%	7%	16%	7%	9%	5%	3%	7%
• stuffy nose	26%	27%	36%	21%	28%	36%	37%	29%	38%	31%
• runny nose	7%	9%	12%	10%	18%	13%	14%	9%	10%	11%
• irritated throat	27%	29%	30%	27%	31%	35%	30%	31%	24%	29%
• chest tightness	8%	3%	6%	20%	19%	11%	7%	7%	7%	10%
• flu-like symp.	11%	7%	9%	14%	15%	19%	18%	10%	25%	14%
• dry skin	21%	39%	30%	21%	25%	34%	51%	39%	29%	32%
• irritated skin	10%	10%	12%	9%	15%	11%	19%	12%	9%	12%
• headache	17%	24%	27%	23%	23%	15%	13%	17%	13%	19%
• lethargy	22%	29%	41%	31%	31%	27%	28%	48%	24%	31%
• other symptoms	8%	9%	10%	6%	8%	9%	8%	10%	5%	8%



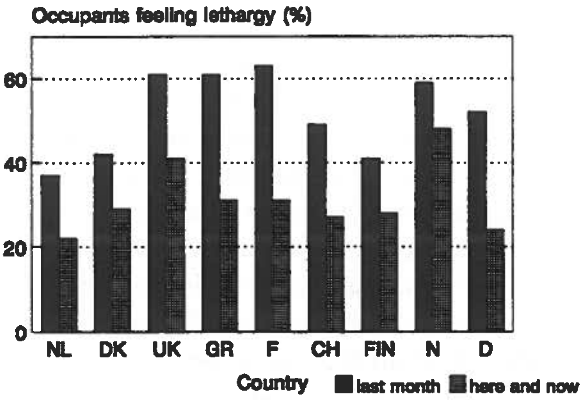


Figure 3.9 *Occupants reporting dry eyes, for the different countries.*

Figure 3.10 *Occupants feeling lethargy, for the different countries.*

Tables B.24 and B.25 (Appendix B) give the mean number of building related symptoms, BSI. The definition of the BSI symbols used were:

- BSI fs: (f) based on the frequency scale (s) with a short list of symptoms
- BSI ff: (f) based on the frequency scale (f) with the full list of symptoms
- BSI ss: (s) based on the severity scale (s) with a short list of symptoms
- BSI sf: (s) based on the severity scale (f) with the full list of symptoms

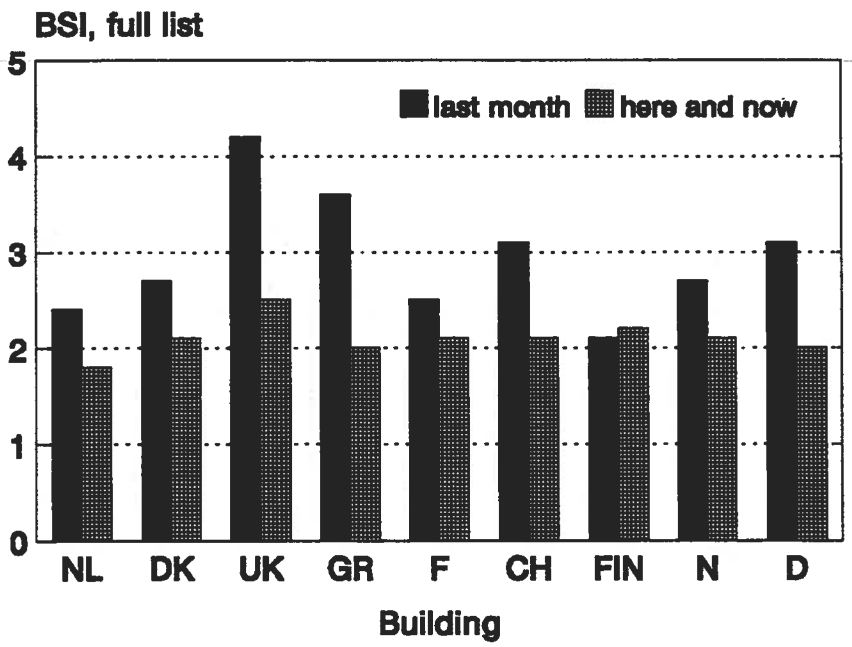


Figure 3.11 *Mean number of building-related symptoms, full list, for the European IAQ Audit buildings.*

A frequency scale was used in the retrospective part of the questionnaire whereas a severity scale was used for the here and now response (see manual (12)). The mean BSIsf (here and now) and BSIff (last month) are given for all investigated buildings per country in Figure 3.11.

A correction on BSIs can be made using the sex and work function distributions in the buildings investigated. However, from Figure 3.1 can be seen that correction for sex does not seem to add much more information, since only in investigated buildings of The Netherlands the sex distribution seemed to be significantly different. Concerning work function, a correction was not made since a correction assumes that the environment is the same for the different categories of occupants. It could well be the case that employees in lower work categories have poorer indoor environment than managers.

3.1.5 Symptoms and adverse perceptions

In this paragraph some of the questionnaire responses are compared. All correlations that were found significant are significant at a 5% level.
The analysis of the correlation between building related symptoms and adverse perception is given in Figure 3.12. The figure shows the number of building related symptoms, here and now, full (BSIsf) versus acceptability of indoor air quality here and now. A correlation between the number of symptoms and the acceptability of the indoor air was found.

Some of the most prevalent symptoms were lethargy and dry eyes. Thus, the number of occupants reporting dry eyes, here and now, are shown versus acceptability of indoor air quality in Figure 3.13. In Figure 3.14 the number of occupants feeling lethargy is given as a function of the indoor air acceptability rated by the occupants. In both cases a significant correlation was found.

To investigate whether the occupants include thermal sensation in their rating of indoor air acceptability, the acceptability here and now versus thermal sensation here and now is given in Figure 3.15. No correlation seemed to be present.

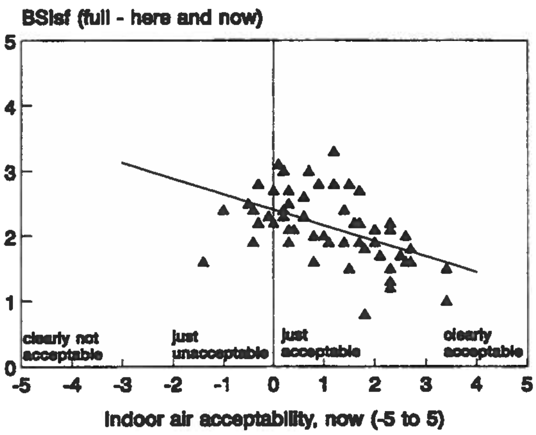


Figure 3.12 *BSIsf versus indoor air acceptability, now.*

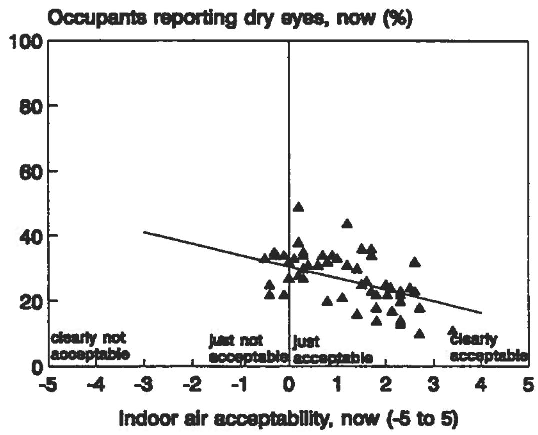


Figure 3.13 *Occupants reporting dry eyes versus indoor air acceptability, now.*

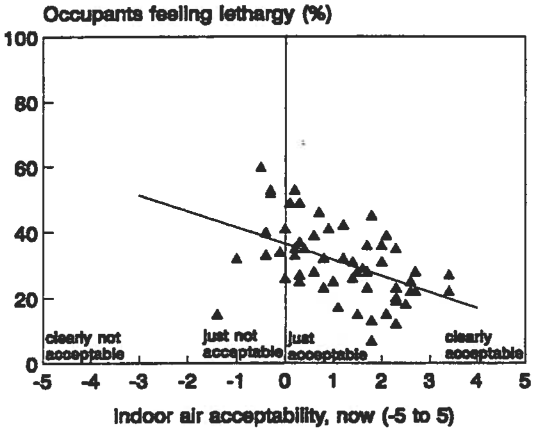


Figure 3.14 *Occupants feeling lethargy versus indoor air acceptability, now.*

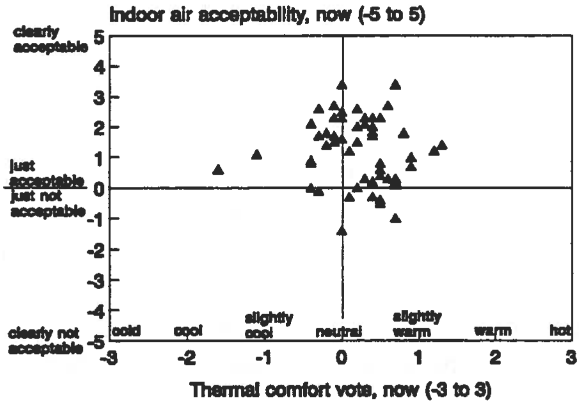


Figure 3.15 *Indoor air acceptability versus thermal sensation vote, now.*

The correlation between the immediate response and the retrospective response is illustrated in Figure 3.16, where BSIff is shown versus BSIfs. In Figure 3.17 the acceptability of indoor air quality last month is given versus indoor air acceptability here and now. In both cases a clear relation was present. Both for symptoms and adverse perceptions the retrospective response was worse than the immediate response. Thus, BSIff was higher than BSIsf and the indoor air acceptability rate (-5 to 5 scale) last month was lower than the indoor air acceptability here and now.

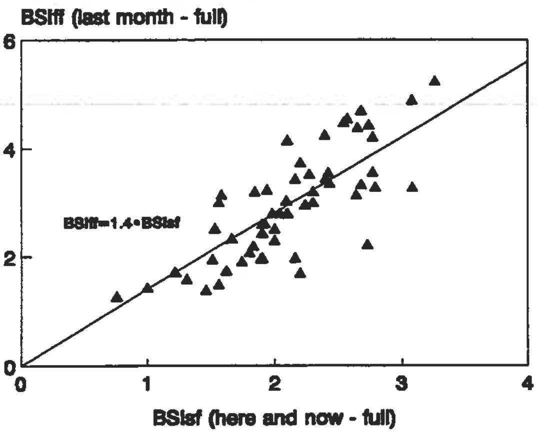


Figure 3.16 *BSIff versus BSIsf.*

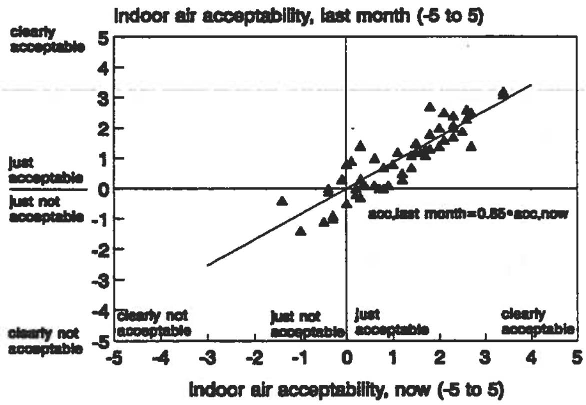


Figure 3.17 *Indoor air acceptability, last month, versus indoor air acceptability, now.*

The perception of air quality is compared in Figures 3.18 and 3.19, where indoor air acceptability is given versus air stuffiness and air odour, respectively. Both stuffiness and odour were significant correlated with indoor air acceptability. As the figures show, stuffiness seemed to be the best indicator of the occupants perception of indoor air acceptability.

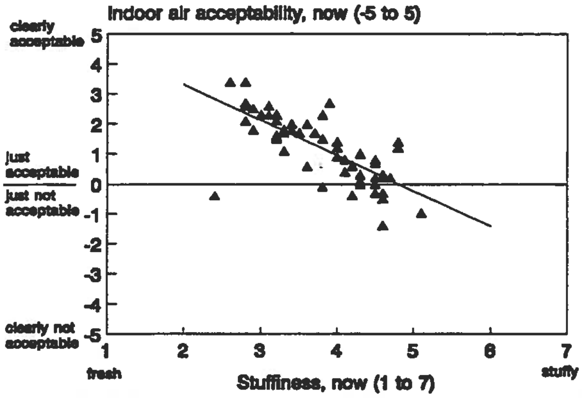


Figure 3.18 *Indoor air acceptability versus air stuffiness.*

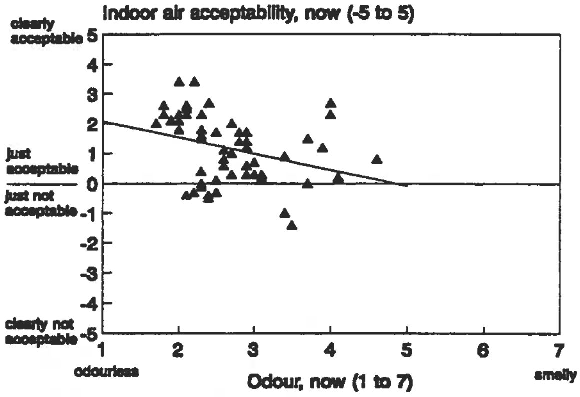


Figure 3.19 *Indoor air acceptability versus indoor air odour.*

3.1.6 Summary

From the questionnaire results it can be concluded:

- The average response rate of all occupants in 56 audited buildings for the questionnaires was 79%. The relatively high response rate should first of all be seen as an outcome of the procedure for handing out and collecting the questionnaires.

- Sex distribution differed from building to building (Figure 3.1). The building with fewest women had 16% women whereas the building with most women had 87%. The mean distribution for all the 56 buildings occupants were half women half men.

- The mean number of smokers for all buildings was 31%. A total of 10% of the occupants suffered from asthma.

- Indoor air quality was overall rated just acceptable corresponding to approximately 30% of the occupants dissatisfied with the indoor air quality (Figures 3.2 and 3.6). 8 of the 56 buildings had a negative indoor air quality rating implying that more than 50% of the occupants rated the indoor air quality unacceptable.

- In all buildings the air was found to be dry by the occupants (Figure 3.3). On a scale from 1 to 7 with 1 being dry and 7 humid the mean rate for all buildings was 2.7.

- In half of the buildings the air was perceived on the stuffy side on a scale going from fresh to stuffy indoor air (Figure 3.4).

- The indoor air was not perceived strongly odorous by the occupants (Figure 3.5). On a scale from 1 to 7, with 1 being odourless and 7 being smelly, the mean odour rate for all of the 56 buildings was 2.7 rated at the time the audit was performed.

- The mean thermal comfort was rated between slightly cool to slightly warm in all but 4 buildings (Figure 3.7). In general the buildings were perceived to be slightly warm.

- Noise and lighting conditions were generally found to be satisfactory (Figure 3.8).

- The occupants generally rated control of ventilation as little.

- Most reported building related symptoms were (Table 3.1): lethargy, headache, dry eyes, dry skin, stuffy nose and dry throat. 52% of all occupants felt lethargy during the past month and 31% felt lethargy during the building audit. The corresponding numbers for dry eyes were 39% last month and 26% at the time of the audit. The 3 most reported symptoms last month were dry eyes, headache and lethargy whereas the 3 most reported symptoms at the time of the audit were stuffy nose, dry skin and lethargy.

- The mean number of building-related symptoms last month (BSIff) ranged from 1 to 5 symptoms (Figure 3.11). The mean number of symptoms for all 56 European IAQ Audit buildings was 3.

- The building-related symptoms monthly were generally more prevalent than the health symptoms at the time of the audit, which can be expected since there are about 20 working days in a month, and a symptom experienced only twice a month was already counted.

- The number of building-related symptoms last month and at the time of the audit showed a significant correlation (Figure 3.16). Indoor air acceptability last month and at the time of the audit were also significantly correlated (Figure 3.17).

- The uncorrected BSIs are the observed responses. Correction of BSIs was not done because sex correction did not have a major impact on the results and work function correction was not done since it assumes that the environment is the same for the different categories of occupants.

- A correlation between building-related symptoms and adverse perception regarding air quality rated by the occupants was shown (Figures 3.12-3.14).

- The occupants rating of indoor air quality did not correlate with the occupants perception of the thermal environment (Figure 3.15).

- The indoor air quality rating clearly correlated with the stuffiness rating (Figure 3.18).

3.2 Sensory evaluation

The mean sensory evaluations performed by trained sensory panels are given in Table C.1 (appendix C) for the audited buildings. The mean perceived air qualities for the investigated buildings per country are given in Figure 3.20. Furthermore, the perceived air quality in the selected spaces is shown in Figure 3.21 for all the buildings. Figure 3.21 shows the variation of buildings within countries as well as between countries.

The investigated buildings in Greece and Germany had the poorest perceived air quality. The best perceived air quality in the selected spaces (offices) was found in buildings of The Netherlands and Norway. The perceived air quality in offices varied between 2.7 decipol in a Norwegian building up to 9.2 decipol a Greek office building.

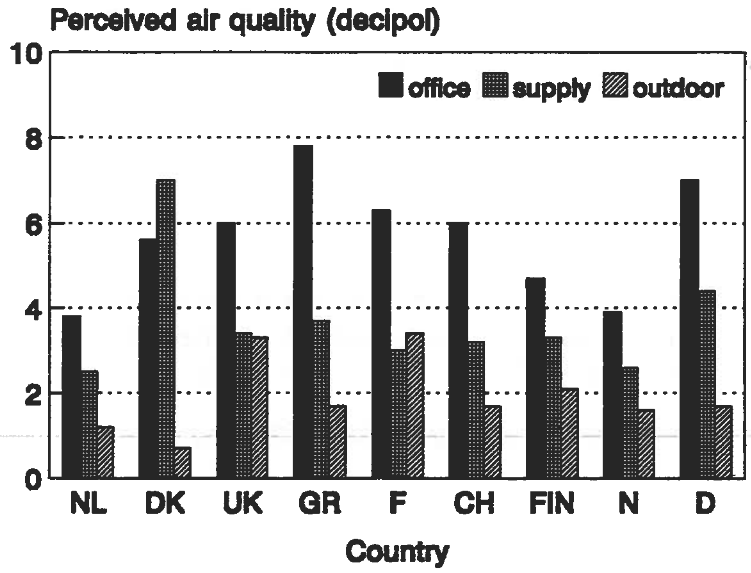


Figure 3.20 *Mean perceived air quality (decipol) in the selected offices, the supply air and the outdoor air.*

The poorest perceived outdoor air quality was found in France with a perceived air quality of 7.8 decipol (Building A). The best outdoor air quality was found in Denmark with a mean perceived air quality of 0.2 decipol (Buildings C and E).

For some of the buildings the outdoor air quality was perceived poorer than the perceived air quality for the selected space. The supply air from the ventilation system was sometimes perceived poorer than the air in the selected space.

The mean perceived air quality for all 56 European IAQ Audit buildings was approximately 6 decipol for office air, 4 decipol for supply air and 2 decipol for outdoor air. This corresponds to roughly 50, 40 and 25% dissatisfied visitors with the perceived air quality (36).

A statistical test showed that the variation between countries was significantly greater than the variation within countries at a 5% level regarding the perceived air quality in the selected offices.

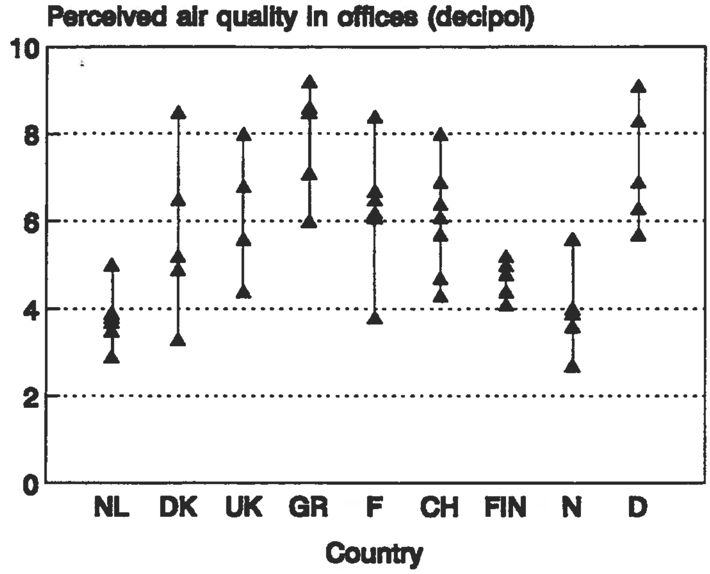


Figure 3.21 *Mean perceived air quality (decipol) in the selected offices in the 56 European IAQ Audit buildings.*

Figure 3.22 shows that no correlation between the perceived air quality in the offices and the perceived air quality outdoor seemed to be present. Also, the perceived air quality in offices did not correlate with the perceived air quality in the ventilation supply air.

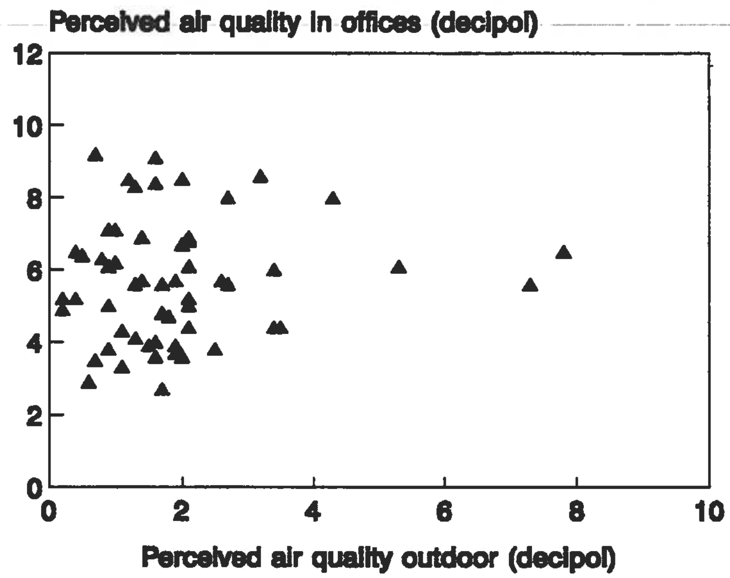


Figure 3.22 *The perceived air quality in offices versus the perceived air quality outdoor, both in decipol.*

3.3 General indoor air quality

The results of the indoor air quality measurements, comprising VOC, CO_2, CO and particulate matter, are presented for each country in Appendix D. More detailed results can be found in the national reports (18-26). Additional comments are given below.

3.3.1 Volatile organic compounds

The Tenax-GC results

The average TVOC-concentrations expressed in $\mu g/m^3$ toluene found in buildings per country is presented in Table 3.3. Average TVOC indices per building in the investigated rooms ranged from 40 to 1840 $\mu g/m^3$ with a median of 202, a geometric mean of 228 and a geometric standard deviation of 2.4. Outdoor air samples ranged from 10 to 420 $\mu g/m^3$, with a median at 80, a geometric mean of 86 and a geometric standard deviation of 2.5. Both office building averages and outdoor air levels were lognormally distributed with a rather high geometric standard deviation, which confirms a finite probability of hitting samples far above the great majority of usual values.

The most abundant compounds are presented for each building per country in Appendix D. Typically, 50-100 compounds were detected in the FID mode in each sample. Mass spectral results were retrieved and evaluated for one investigated room sample in each building and the 15 most abundant compounds (expressed in toluene equivalent index) were identified. With only 15 compounds per sample, more than half of the TVOC index could be accounted for in 90% of the buildings. Pooling all samples resulted in a comparatively short list of 66 partially or completely identified compounds. An overview of the most abundant compounds in all buildings is given in paragraph 4.4.3. No single instance of a concentration hazardous to human health was identified. Levels for individual VOCs and even the cumulative TVOC indices all ranked orders of magnitude below current workplace exposure limits.

Interlaboratory quality control on Tenax-GC method

A total of 31 double samples were taken (12 before, 19 during the actual audits) and analyzed in parallel at BIGA and in one of two other laboratories (CSTB France and VTT Finland), equipped with similar instrumentation and using - with slightly variations - the same methods. TVOC-values ranged from 50 to 10,000 $\mu g/m^3$. The results gave no indication of a systematic deviation for one of the three involved laboratories. Excluding 5 samples with obviously wrong values, the average relative difference was about 25%. This degree of uncertainty is satisfactory, considering e.g. differences in FID detectors and in baseline computation algorithms for integration.

B&K gas analyzer results

The TVOC measurements with the B&K 1302 analyzer are not presented, because they were not used in the international analysis.

Table 3.3 Average TVOC, CO_2 and CO concentrations found in buildings per country.

	NL	DK	UK	GR	FR	CH	SF	N	D
CO_2 [ppm]									
offices	656	736	516	587	778	744	737	628	674
supply air	437	.	.	544	550	523	535	448	386
outside air	418	382	327	400	344	382	473	440	402
CO [ppm]									
offices	0.5	0.6	0.7	.	1.9	<1	0.8	1.4	0.7
supply air	0.5	.	.	.	2.5	<1	0.6	1.4	0.5
outside air	0.5	0.5	.	.	1.5	<1	0.9	1.3	0.5
Particulate matter [$\mu g/m^3$]	72	88	20	149	76	181	51	20	61
TVOC [$\mu g/m^3$]									
offices	179	135	436	495	413	518	118	528	146
supply air	88	38	329	137	306	310	82	148	228
outside air	79	33	128	158	82	251	62	155	155

3.3.2 Carbon dioxide and carbon monoxide

Carbon dioxide

Considerable differences between reported spot and averaged continuous carbon dioxide levels were frequent and in some audits excerpts from the continuous records were used as spot values to avoid the problem. In 9 out of 56 cases, the reported spot readings were above, in 7 below, the range of the reported values in continuous measurements. The difference does not originate from the use of different instruments for spot measurements.

Reported outdoor CO_2 levels ranged from 250 to 570 ppm, with 51 out of 54 reported values in the usual 300 to 520 ppm range. The average was 390 ± 60 ppm. No evidence of geographic differences could be found along North-South or East-West axes or between maritime and more continental settings.

Averages and standard deviations from continuous measurements should be considered as indicative values, since most of the variation was generally caused by non-random perturbations, including the presence of the audit team and visits by the sensory panel, which were not removed in a uniform manner by all teams.
As shown on several continuous records of different countries (18-26), the time profile was influenced not only by the persons present, but could also have incorporated variations in the outdoor air concentration, particularly at low levels. Most of the buildings investigated in this project had quite high ventilation rates per person, exceeding the 10 l/s.person. Downward drifts extending over several hours were observed in many cases, illustrating the fact that people may not have been the only major contributors over long periods of time. For accurate measurement including weak contributions, it seems therefore necessary to register the outdoor CO_2 concentration as well. At present, CO_2 has not been considered a priority outdoor air contaminant, except in long term averages as a greenhouse gas. Short term variations seem to be largely unexplored.
The average measured concentrations of CO_2 per country are presented in Table 3.3.

Carbon monoxide

Considering the variability of CO outdoors and the generally weak variations observed in the audited buildings, measurements outdoors would also be recommendable for reliable interpretation of indoor air studies. Also, resolution to ±0.2 ppm or better seems to be a prerequisite if fine detailed measurements are desirable. A correlation between CO concentration and number of cigarettes smoked may work fine in closed experimental rooms with CO-controlled air supply or short experimental times. It was confirmed during this audit that, under field conditions, such a correlation may not be observed unless possibly in very poorly ventilated buildings submitted to quite heavy smoking.

Available time profiles or records were in most cases rather flat or showed moderate fluctuations or drifts (± 1 ppm). Some peaks were observed, with CO values up to 7 ppm. Explanations may be sought for such episodes. No single value approaching the current workplace exposure level (25-30 ppm time-weighted average) was observed even during short-term episodes.

The average measured concentrations of CO per country are presented in Table 3.3.

3.3.3 Particulate matter

The concentration of total suspended particulates was measured in one room in each audited building. The values were lognormally distributed, with a geometric mean of 66 $\mu g/m^3$, a large geometric standard deviation of 2.71 and a median at 62 $\mu g/m^3$. As for the TVOC, this indicates a finite probability of findings samples far above the great majority of usual values, so that gravimetric determinations remain justified, even if low values can be expected in most cases.

In Table 3.3 the mean particulate concentration for the audited buildings per country are given (see also appendix D). In general the particulate concentration stayed below 120 $\mu g/m^3$ (37) except for several buildings in Greece and Switzerland.

3.4 General indoor climate

The results of thermal and noise measurements in selected offices of the audited buildings are presented in Appendix E. For more detailed information see national reports (18-26). Additional comments are given below.

The average results of the thermal and noise measurements per country are shown in Table 3.4.

Table 3.4 The average results of the thermal and noise measurements per country.

	NL	DK	UK	GR	FR	CH	SF	N	D
Air temperature [°C]									
. offices	22.3	23.7	22.9	23.5	23.5	22.9	22.3	23.4	21.7
. supply air	19.5	25.1	.	31.2	22.5	.	21.9	20.2	.
. outside air	6.6	5.6	10.4	14.7	12.4	7.2	.	-0.6	.
Operative temp. [°C]									
. offices	22.3	23.5	23.1	.	21.9	21.4	22.4	23.6	22.0
Rel. humidity [%]									
. offices	31	29	36	33	44	39	19	17	41
. supply air	34	.	.	27	42	.	15	.	.
. outside air	57	71	74	40	54	68	.	.	.
Air velocity [m/s]									
. offices	0.10	0.07	0.11	0.08	0.07	0.12	0.08	0.07	0.06
Noise [dB(A)]									
. offices	48	46	55	54	46	45	39	42	51

The mean air temperatures measured in the buildings per country were in general in the upper limit of the recommended values given in the CEN 27730 (38) for the winter (20-24°C). Small differences between operative and air temperature were generally observed (except for France), which indicated low difference between radiant and air temperature.

The measured operative temperature (mean 22.5°C) and air velocities (mean 0.08 m/s) met in general recommendations in the thermal comfort standard (38) and requirements in prENV 1752 (36).

The Nordic countries (Denmark, Finland and Norway) had a relative humidity indoors below 30%, which is not uncommon in these countries. Highest relative humidities indoors were found in France and Germany.

The average noise level was 47 dB(A).

3.5 Ventilation

The results of the ventilation measurements of the 56 audited buildings are presented in Appendix F. More detailed information on room level can be found in the national reports (18-26).
Measurements of airflow rates of the whole building were not mandatory, hence were performed only in a few countries and are reported in paragraph 3.8. Within this project, only airflow rates coming from ventilation, by infiltration or from adjacent spaces in audited rooms were measured. Note that measured supply airflow rate included recirculation when present. The results shown below are based on measurements of 226 rooms from 56 buildings. Since some rooms were equipped for one person only, and others were large open offices, airflow rates in rooms varied by several orders of magnitude. To be able to compare the airflow rates, specific airflow values rates were calculated for each audited room (Figure 3.23). The volume of the room was calculated as the product of floor area and room height.

Outdoor airflow rate (Qo) is most interesting from the point of view of both energy consumption and indoor air quality. This is obtained by summing the outdoor airflow rates caused by infiltration (Qor) and supply (Qvr):

$$Qo = Qor + (1-R)Qvr \qquad [3.1]$$

where R is either the measured value or the planned value of the recirculation rate.

Figure 3.24 shows the cumulated frequencies of recirculation rate. This figure does not include the eight naturally ventilated buildings. Nearly 60% of the mechanically ventilated buildings had no recirculation. Among those with planned recirculation, recirculation rates of 50% or higher were the most frequent.

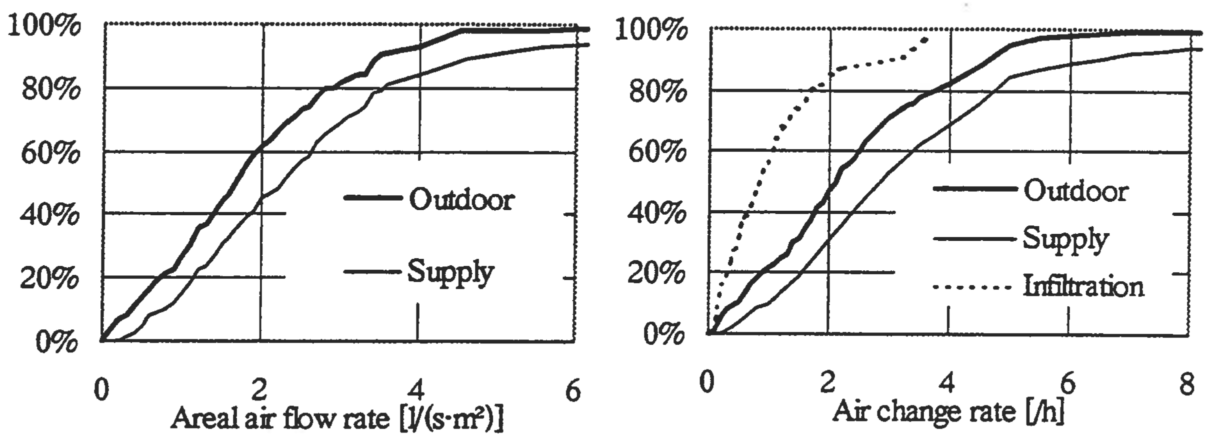


Figure 3.23 Cumulated frequencies of specific airflow rates in 226 audited rooms of 56 buildings. In naturally ventilated buildings, ventilation comprises infiltration rates.

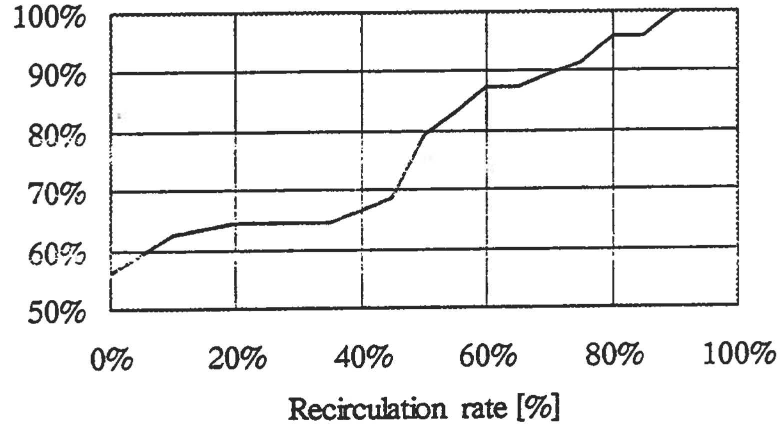


Figure 3.24 *Cumulated frequencies of recirculation rates in 48 audited buildings with mechanical ventilation.*

Planned recirculation rates do not necessarily relate to real ones. In fact, measured recirculation rates differed significantly from planned ones, as shown in Figure 3.25. Recirculation rates differed from zero in 22 of them.

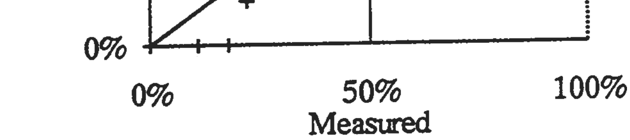


Figure 3.25 *Comparison of planned and measured recirculation rates in 48 buildings with mechanical ventilation.*

Frequencies of areal airflow rates in the 226 audited rooms are shown in Figure 3.26. The distribution was nearly homogeneous up to 3 $l/(s.m^2)$. The higher frequencies for outdoor airflow rate in some classes came from naturally ventilated buildings.

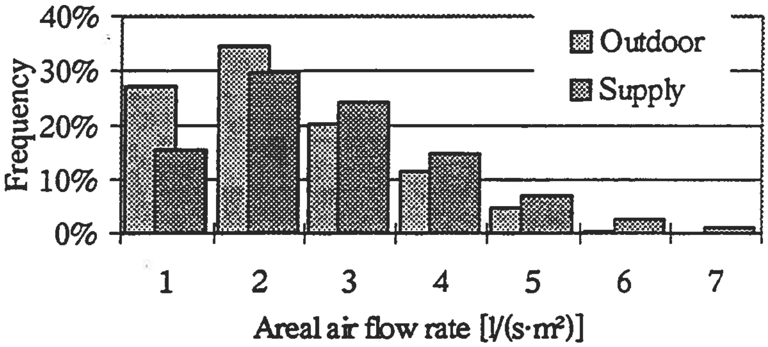


Figure 3.26 *Frequencies of areal airflow rate in 226 audited rooms. On x-axis, numbers are the upper limit of each class.*

The same information is presented as cumulated frequencies of specific outdoor and supply airflow rates in Figure 3.23. On the average, the outdoor airflow rate was 1.9 l/(s.m^2), while the total supply airflow rate was 2.7 l/(s.m^2). Outdoor air change rate was 0.4 h^{-1} or less in 8% of the audited rooms, and larger than 3 h^{-1} in 30% of rooms. The average outdoor air change rate was 2.5 h^{-1} but the median was about 2.1 h^{-1}.

Naturally ventilated rooms present generally a low air change rate (Figure 3.27). Their average outdoor areal airflow rate is 1 l/(s.m^2), while it is 2.1 l/(s.m^2) in mechanically ventilated rooms. Eighty percent of mechanically ventilated buildings have more than 1 l/(s.m^2), while only 20% of naturally ventilated buildings overpass this limit.

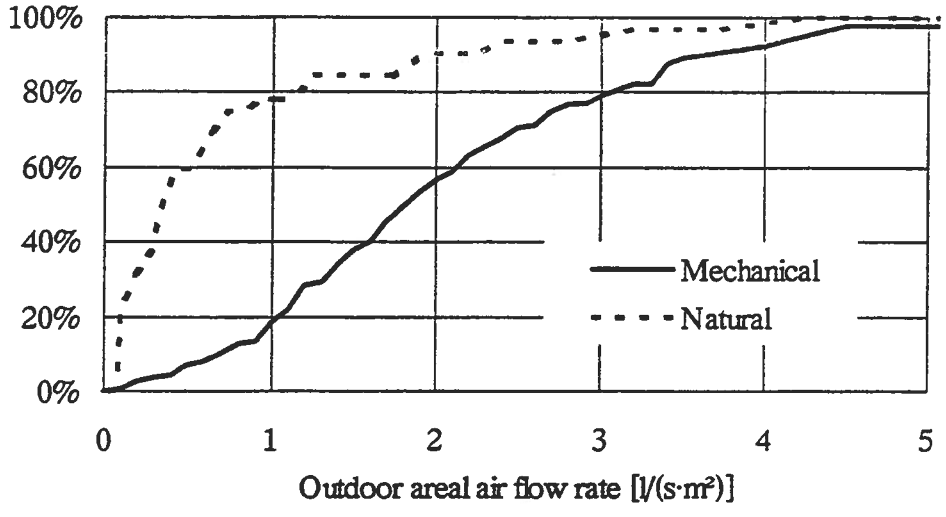


Figure 3.27 *Cumulated frequencies of areal outdoor airflow rates in audited rooms split into two populations: 30 naturally ventilated rooms, and 196 mechanically ventilated rooms.*

3.6 Weather conditions

A description of weather conditions during period of time that the measurements in the audited buildings took place is given for each country in appendix G.

3.7 Energy consumption

The results of the energy consumption collected of all countries are summarized in Tables 3.6 and 3.7. Detailed energy consumption data per investigated building of each country are given in appendix H.

Table 3.6 *Statistics on floor area and energy use (in MJ) of audited buildings.*

	Floor area [m^2]	**Heating oil [GJ]**	**Natural gas [GJ]**	**Electricity [GJ]**	**District heat [GJ]**	**Total [GJ]**
mean	15,000	8,600	9,500	9,700	7,800	18,000
st.dev.	16,000	25,000	11,000	16,000	6,100	23,000
maximum	69,000	98,000	34,000	89,000	20,000	98,000
minimum	2,400	230	230	380	62	960

Table 3.7 *Statistics on yearly energy indices of audited buildings.*

	Energy Index			**Energy per person**		**Specific power**
	Total [MJ/m^2]	**Electric [MJ/m^2]**	**Fuel [MJ/m^2]**	**Total [MJ/person]**	**Electricity [MJ/person]**	**[W/(m^2.K)]**
mean	1,100	540	570	31,000	15,000	4.7
st.dev.	470	400	370	26,000	17,000	2.6
maximum	2,500	1,700	1,800	150,000	86,000	12.6
minimum	370	75	0	8,000	2,300	1.2

The Energy Index is often used to compare energy consumption of different buildings. This index is obtained by dividing the yearly energy use by the gross heated floor area. When separate information is available, the energy index can be split into electricity index and fuel index. The fuel index is obtained by subtracting the electricity consumption from the total energy use. It then includes light oil, natural gas and district heat. Table 3.7 shows the mean individual indices and Figure 3.28 shows the individual indices per building of each country.

The specific power, given in the last column of Table 3.7, is the energy index divided by the accumulated temperature difference (degree-seconds). It is the average power per square meter area divided by the average indoor-outdoor temperature difference during the heating season.

What appears at a first glance is the huge variation in values. There was a 7:1 ratio in total energy index between the highest and the lowest. And a 20:1 ratio between the highest and the lowest energy use per person. This clearly shows a large theoretical economy potential. Since buildings can be operated with less than 500 MJ/m^2 total energy use and less than 100 MJ/m^2 for electricity, why did the other buildings perform so inefficiently?

The main source of energy for audited buildings was electricity (circa 48%) (Figure 3.29). The remaining was more or less equally distributed between district heat, heating oil and natural gas, each for 15 to 19%. The discussion of those results show how difficult it is to compare buildings from different countries with different design strategies and different managing conditions regarding energy. In fact the number of buildings audited per country was not sufficient to refer to a representative sample. Neither was the uniformity of the energy consumption values for the different buildings in the same country. With respect to the energy forms used, different country conditions were reflected (Norway used almost only electricity) and make it therefore difficult to compare any type of energy. On the contrary, the knowledge of the energy consumption levels together with the IAQ conditions allow to reach conclusions that respond clearly to some of the questions raised at beginning before the project was presented.

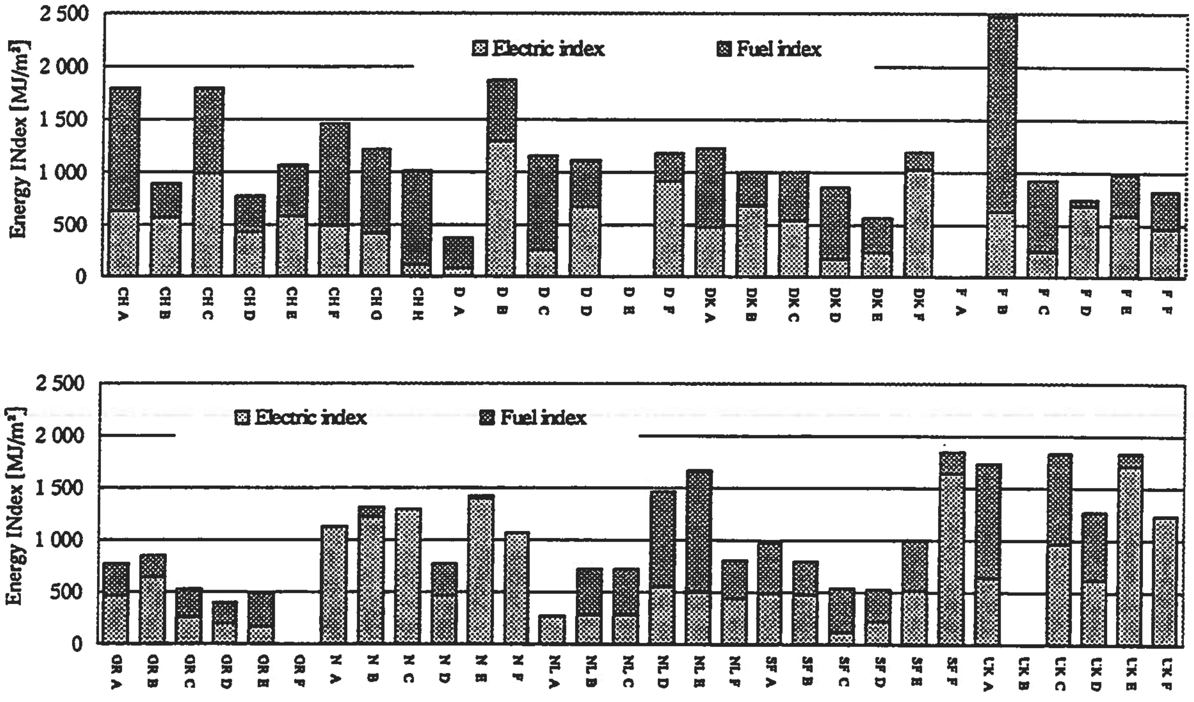


Figure 3.28 Energy index of each of the audited buildings.

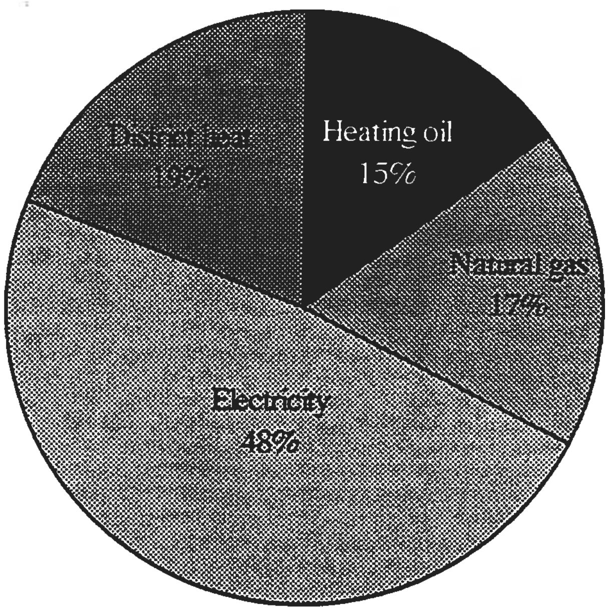


Figure 3.29 ***Distribution of energy sources in audited buildings.***

3.8 Detailed investigations

In this paragraph the main findings/conclusions of the detailed investigations are given. More detailed information can be found in Appendix I and references 27 and 28.

3.8.1 Source identification

- Among the investigated office buildings the walls were estimated to be the major emitter of VOCs to the room air in the newly built or renovated office building while the floor was the major air pollution source in older buildings.

- Emissions rates calculated on the basis of FLEC measurements and surface areas were only indicative of the actual air pollution source strengths. But the simplified method used gave a good indication of the origin of emitted volatile organic compounds in indoor air.

- The changes in emission rates during 24 hours after application of the FLEC were mostly small. A great deal of these changes might have been associated with uncertainties in the method. The best time for sampling chemicals seemed to be after the FLEC had been running for one hour.

- More research is needed on the causes of the temporal changes and the influence of typical variations in temperature, humidity, ventilation rate and other environmental parameters on emission rates and resulting room air concentrations.

3.8.2 Ventilation performance

- Ventilation related parameters were evaluated with tracer gas measurements. It turned out that measured values can vary significantly from designed values.

- A simplified technique based upon CO_2 measurements was tested. It appeared that knowing the daily occupation and the daily average of CO_2 concentration in the building, one can derive the general outdoor airflow rate (accuracy about 20%). Furthermore, recirculation rate can also be evaluated from CO_2 measurements.

- Tracer gas technique allows also to estimate the mean age of air in buildings. In case of buildings equipped with several exhaust units, this measurement will also provide an indication of the air and possible pollutants spreading in the building.

- Knowing ventilation rates, the balance of the building can be determined for parameters measured in supply and exhaust. Measurement of enthalpy (humidity and temperature) will yield the energy consumption or increase due to ventilation. The same can be done for water vapour, determining the sources and/or sinks in the building. This can be extended to every parameter that could be measured in both supply and exhaust (VOCs, pollution,..). Furthermore, the measurement of a pollutant concentration in the exhaust provides an average concentration for the building which might be of help to identify IAQ problems.

4. ANALYSIS

4.1 Sensory evaluation

4.1.1 Performance

A panel of subjects can be trained to improve its performance in sensory evaluation. But the question is: When is a panel member or the whole panel trained? Which criteria have to be followed to determine when a person or panel is trained. Depending on the training procedure and test forms, several criteria to describe the performance of a panel member or the whole panel have been used (39,40).

In the current training procedure of panel members to evaluate perceived air quality in decipol, the training level of a panel or panel member is tested with unknown 2-propanone concentrations in air and several other unknown air pollution sources, which each panel member has to compare with four known 2-propanone concentrations in air (2, 5, 10, and 20 decipol).

The training level can be determined by using the given votes compared to correct votes for the 2-propanone levels and by using the repeated votes and/or the standard deviation on the panel vote for the unknown sources. Some methods are available to calculate an index, which presents the performance. The disadvantage of all these methods is the dependency on the chosen perceived air quality (PAQ) level and the number of unknown (2-propanone) sources.

To get a good impression of the quality of a panel or a panel member, some error limits have to be known. In the current project exam's were used to select a panel member and a whole panel (40). The limits in these exam's are level dependent. If the voted error is compared with the error limits assumed, an indication of the performance can be established.

A comparison of different calibration tests and panels can only be made if the chosen levels are comparable. So there is a strong need for a new method which is :

- independent of number of samples;
- independent of chosen PAQ levels;
- the result (value) has to be a relative or absolute error .

Three performance factors were therefore defined. For the new performance method the ideal vote (voted=correct) as index = 0 is taken. Besides that an allowed maximum and minimum error (both level dependent) are defined as index +1 and -1. With this approach the index should theoretically be independent of the chosen level (if the error limits are chosen correctly), and result in information about the voted error related to the allowed error (0 = perfect; $< |1|$ = allowed ; $> |1|$ = bad).

. *Individual performance factor*

The individual performance with 2-propanone concentrations can be described by the Individual Performance Factor (IPF). The method to calculate the IPF is related to exam 1 as described in the manual (12). Based on experience the required precision for an individual panel member was determined (see Figure 4.1).

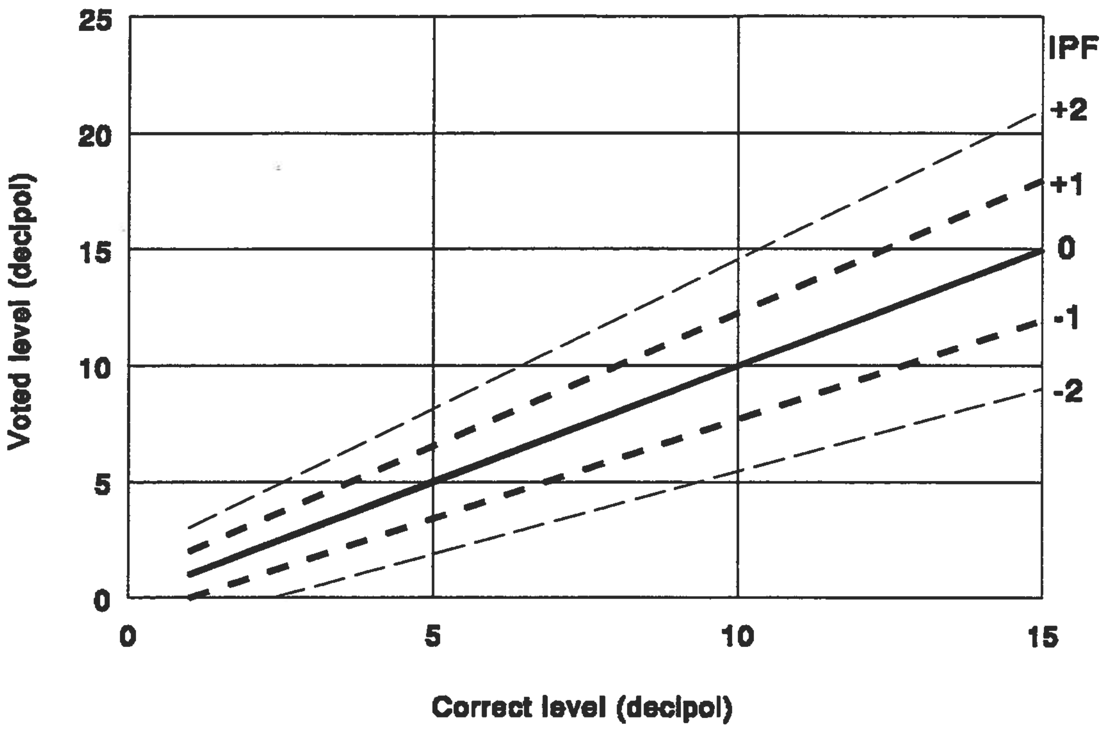


Figure 4.1 *Required precision of an individual panel member vote when assessing the perceived air quality of 2-propanone concentrations (exam 1).*

Description of exam 1 :
Votes in the area between the fat line and the fat dashed line are accepted. One on four votes is accepted in the area between the fat dashed line and the thin dashed line. One on the eight is accepted for other votes.

The Individual Performance Factor is defined as :

IPF = voted error / allowed error [4.1]

with:

voted error	=	voted minus correct
allowed error	=	allowed difference between voted en correct

To determine the formula and to calibrate the IPF = +1 line and IPF = -1 line the exam 1 criteria were used. The IPF formula is then defined as:

IPF = (voted - correct) / (2/14 * correct + 12/14) [4.2]

with:

IPF	=	individual performance factor
voted	=	voted PAQ level [decipol]
correct	=	correct PAQ level [decipol]
2/14	=	tangent of angle difference between lines
12/14	=	intersection with Y-axis

The mean value of the IPF and the standard deviation of the IPF give an indication of the quality of the panel member related to 2-propanone concentrations. If the allowed errors change, the coefficients in the formula change as well. Note that the IPF is not the numerical error, which means that a too high vote and a too low vote may result in a mean IPF index of zero. Therefore, the deviation on the IPF must be considered too and should be as small as possible.

. *Panel performance factor*

The same approach is possible for the whole panel. The mean IPF value of the performance for the whole panel is called the Panel Performance Factor (PPF). The mean value of the PPF and the standard deviation give an indication of the quality of the whole panel related to 2-propanone concentrations.

. *Deviation performance factor*

The panel performance of other pollution sources then 2-propanone can be described by the Deviation Performance Factor (DPF). This method is related to exam 2 as described in the manual (12). Based on experience the required precision of the mean vote of a whole panel was determined (see Figure 4.2, dashed line).

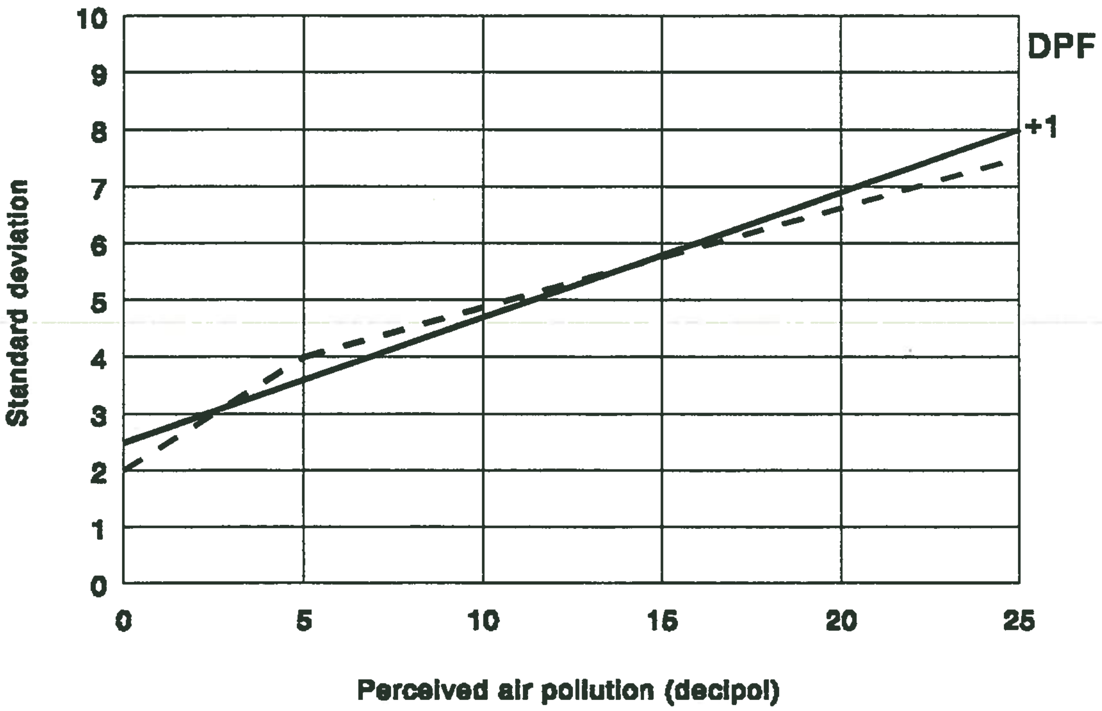


Figure 4.2 *Required precision of the mean vote of the whole panel when assessing the perceived air quality of pollution sources other than 2-propanone (exam 2).*

Description of exam 2:
Standard deviation of a whole panel in the area between the dotted line and X-axis (Figure 4.2) is accepted.

The Deviation Performance Factor is defined as:

$$DPF = \text{standard deviation} / \text{allowed standard deviation} \quad [4.3]$$

where

DPF	=	deviation performance factor
standard deviation	=	calculated standard deviation [decipol]
allowed standard deviation	=	allowed stand. dev. for the whole panel (Fig 4.2) [decipol]

To create a simple formula the allowed standard deviation is changed to a linear dependency on the decipol level (see Figure 4.2, fat line). To determine the formula and to calibrate the DPF = +1 line, the exam 2 criteria were used. The DPF formula is then defined as:

$$DPF = (\text{standard deviation}) / (0.22 * \text{perceived} + 2.5) \quad [4.4]$$

where

perceived	=	perceived air pollution (mean panel value) [decipol]
0.22	=	tangent of angle between line and X-axis
2.5	=	intersection with Y-axis

The mean value of the DPF and the standard deviation of the DPF give an indication of the quality of the whole panel related to pollution sources typical to be found in buildings. If the allowed errors change, the coefficients in the formula change as well.
The DPF assumes that panel size lies around 12 to 15 persons. The standard deviation is the deviation on a single vote and not the deviation on the mean vote (standard error). In future calculations this should be included.

4.1.2 Performance of IAQ-Audit panels

The three new performance factors were used to calculate the performance of eight panels: Germany, Denmark, Finland, France, Greece, The Netherlands, Norway and United Kingdom. Switzerland was excluded, since no retraining or calibration data were available. For the calculation of the IPF and PPF the retraining data were used for the United Kingdom, France, Greece and Germany, and the calibration data were used for Norway, Finland, Denmark and The Netherlands. This because not each country had executed the calibration and retraining.

Individual Performance Factor
The individual performance indices of each panel of persons can be found in TNO-report 94-BBI-R1664 (41). The mean IPF of all panels per PAQ level is presented in Figure 4.3. The figure shows that the IPF value between 0 - 5 decipol is still level dependent. To compensate this influence the error limits as described in exam 1 should be adjusted.

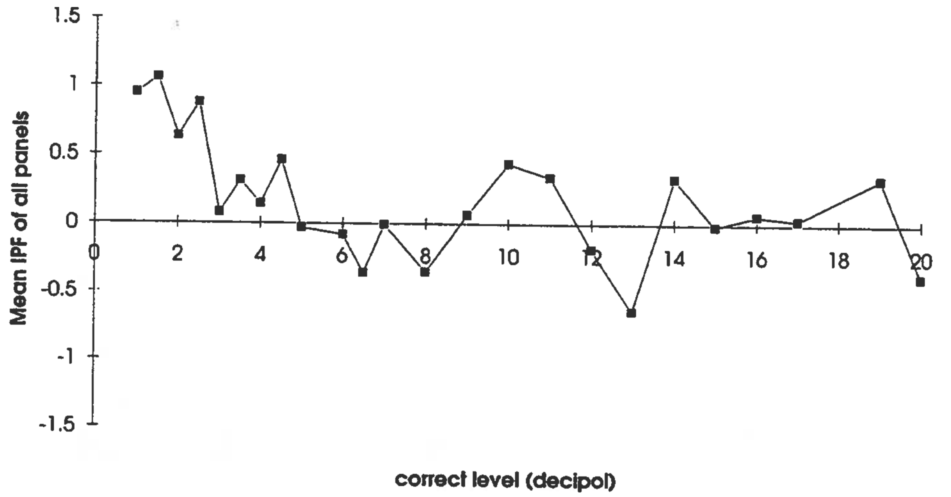


Figure 4.3 *The mean Individual Performance Factor per perceived air quality level of eight sensory panels.*

Panel Performance Factor
The PPF of each of the eight panels is presented in Figure 4.4. As can be seen from this figure, the PPF ranges differed from 0.04 to 0.60.
The standard deviation on the PPF for the eight panels, which presents the spreading in IPF values of the panel members, are shown in Figure 4.5. The majority of the panels (seven on eight) had a standard deviation between 0.4 and 0.5.

Deviation performance factor
The DPF for each panel can be found in TNO-report 94-BBI-R1664 (41). Unfortunately these results show that the DPF is dependent on the perceived air quality (PAQ). Linear regression on the DPF versus PAQ gives an indication of this dependency. The regression lines for each panel is presented in Figure 4.6. As can be seen five out of eight panels showed a similar DPF dependency on PAQ and therefore seemed to have a similar vote behaviour. To create a level independent DPF this 'average vote behaviour' has to be included in the limits as described in exam 2.

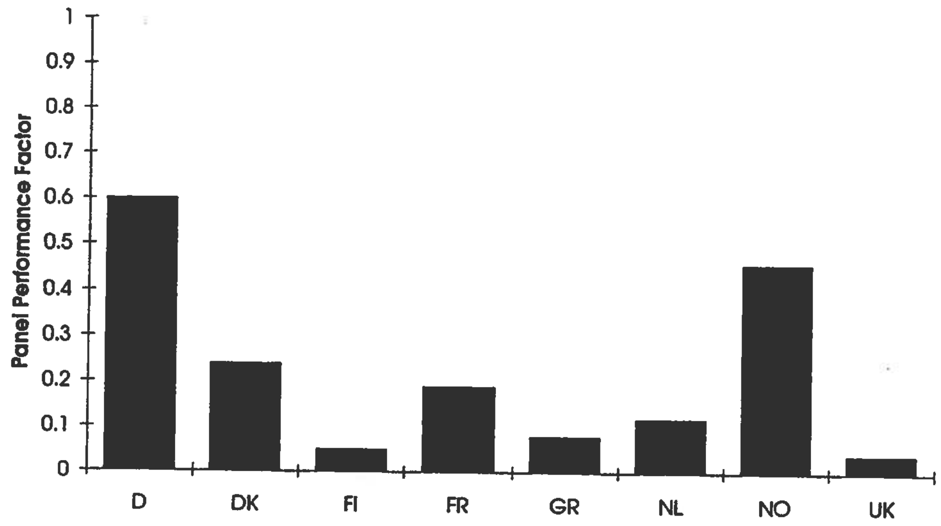


Figure 4.4 *The Panel Performance Factor of each of the eight panels of the IAQ-Audit project.*

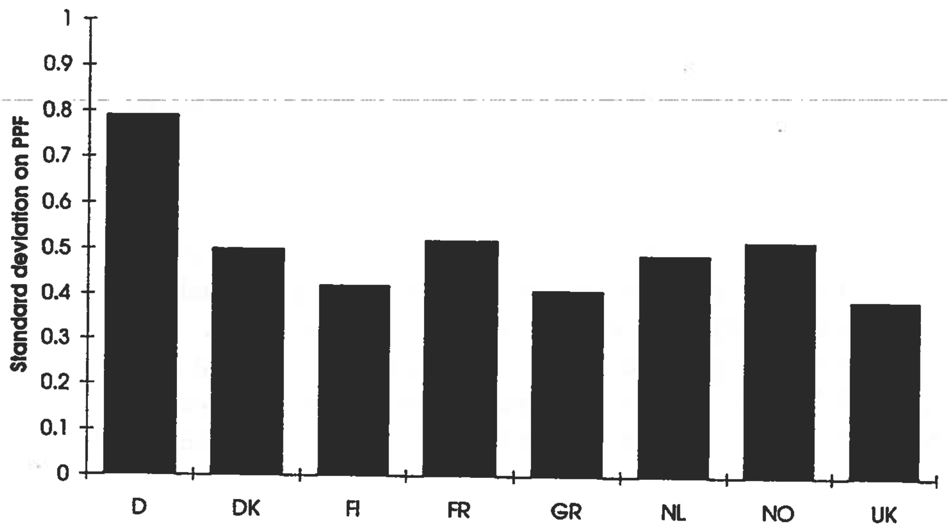


Figure 4.5 *The standard deviation on the Panel Performance Factor of each of the eight panels of the IAQ-Audit project.*

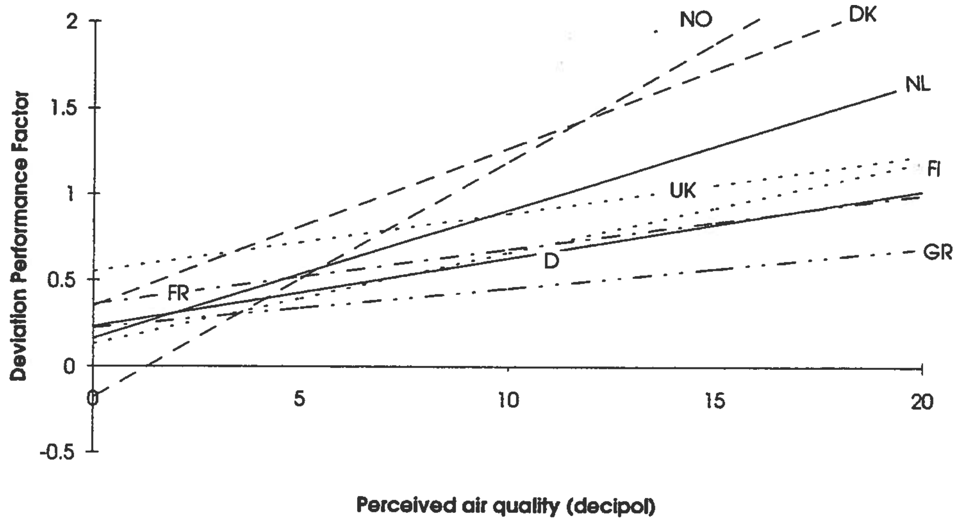


Figure 4.6 *The Deviation Performance Factor versus the perceived air quality of each of the eight panels of the IAQ-Audit project.*

4.1.3 Revision exam criteria

<u>2- propanone (exam 1)</u>
To create a performance method which is independent of the number of samples and the chosen decipol level the vote behaviour of a panel member or whole panel has to be included in the method. In this new approach the performance is related to the maximum allowed error (limits) so the vote behaviour has to be included in the limits.
As was concluded in paragraph 4.1.2 the IPF depends on the PAQ level, therefore, the error limits have to be adjusted.

The mean IPF for each PAQ level is determined by taking all the panel votes. In Figure 4.3 this mean IPF value is presented. The IPF value at 1 decipol is twice as high compared to the values in the area between 5 - 20 decipol. To compensate this the error limits in the area between 0 - 5 decipol have to be adjusted. A proposal of the new error limits is shown in Figure 4.7. The allowed error at 1 decipol is doubled. In the area 5 - 20 decipol the allowed error has not changed.
The result on the mean IPF value after correction is shown in Figure 4.8 (white dots). With the new error limits the mean IPF value for each PAQ level ranges between +0.5 and -0.5. The new error limits also influence the IPF formula, which is defined as:

$$IPF = (voted - correct) / (A * correct + B) \qquad [4.5]$$

with:

IPF	=	individual performance factor
voted	=	voted PAQ level [decipol]
correct	=	correct PAQ level [decipol]
A	=	tangent of angle difference between lines
B	=	intersection with Y-axis

The coefficients A and B are now depending on the PAQ level. The values for A and B are given in Table 4.1.

Table 4.1 *IPF coefficients: A and B.*

PAQ range [decipol]	A	B
< 5	- 3/28	+ 59/28
>= 5	+ 4/28	+ 24/28

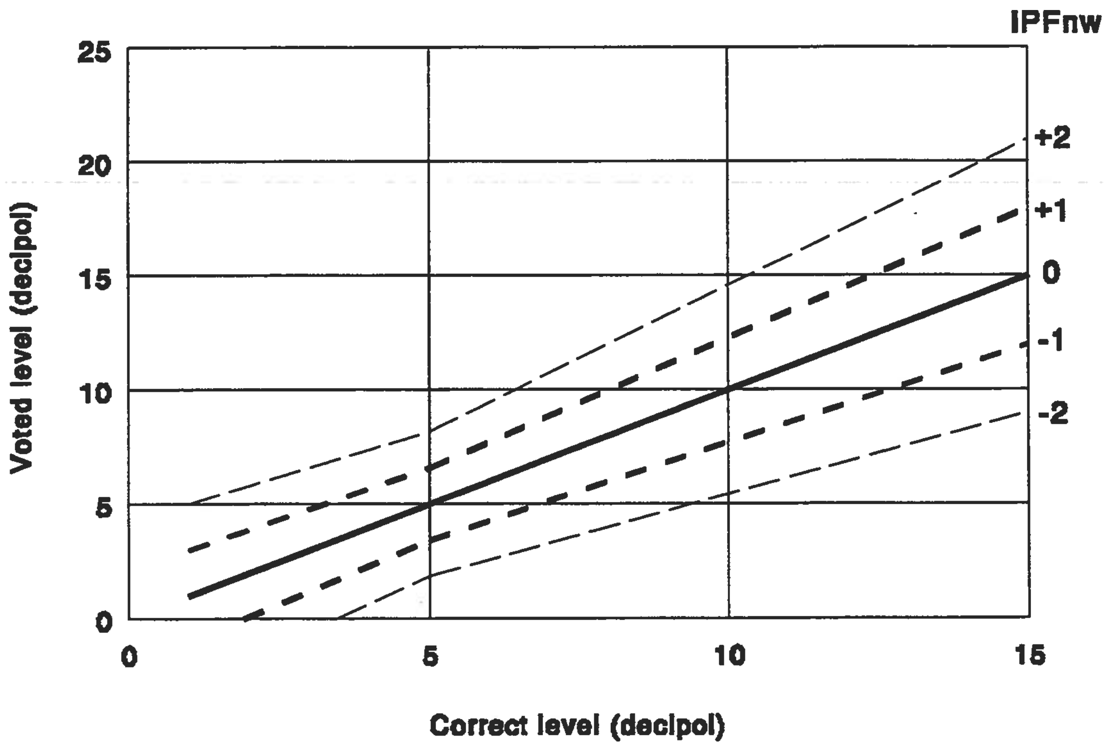


Figure 4.7 *Corrected required precision of an individual panel member vote when assessing the perceived air quality of 2-propanone concentrations.*

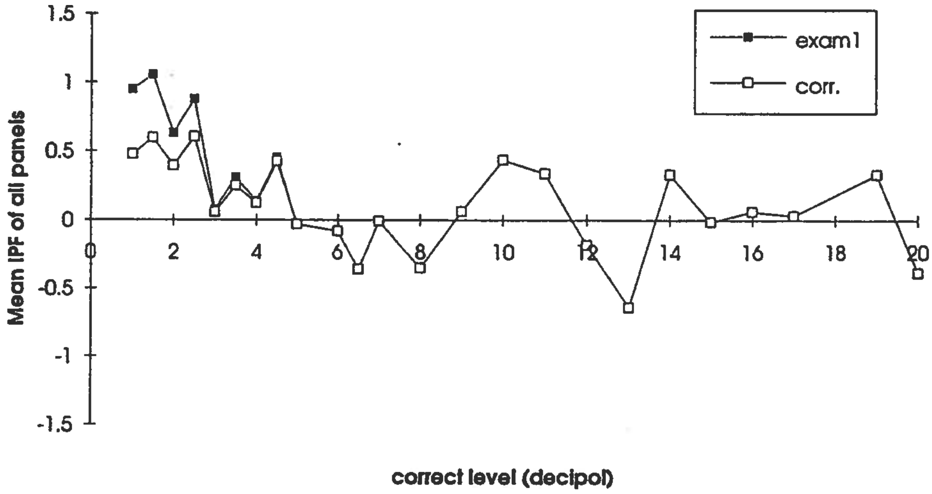


Figure 4.8 *The mean Individual Performance Factor of all IAQ-Audit panel data (using exam 1 and corrected error limits).*

Taking the new error limits (exam 1) into consideration the IPF and PPF values of the eight panels were recalculated.
The corrected individual performance factor of each panel of persons is presented in Appendix C. As can be seen the maximum IPF value in the area < 5 decipol has about the same value as the higher PAQ levels. The IPF-definition has improved.

The PPF of each of the eight panels is presented in Figure 4.9. The PPF ranges from -0.05 to +0.50. Compared to the uncorrected values (Figure 4.3), all mean PPF values have decreased.
The standard deviation on the PPF for the eight panels, which presents the spreading in IPF values of the panel members, are shown in Figure 4.10. The majority of the panels (seven on eight) have now a standard deviation between 0.3 and 0.45.

Other pollution sources (exam 2)
For the moment no correction is made for the allowed standard deviation as described in exam 2.
It must be bared in mind however that a restriction of panels on basis of the standard deviation is still a matter of discussion.

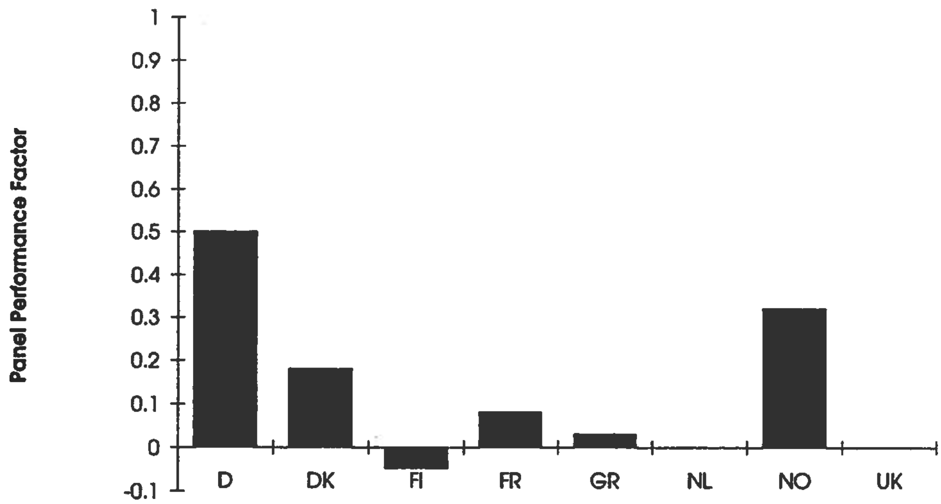


Figure 4.9 *The Panel Performance Factor of each of the eight panels of the IAQ-Audit project (including error limit correction).*

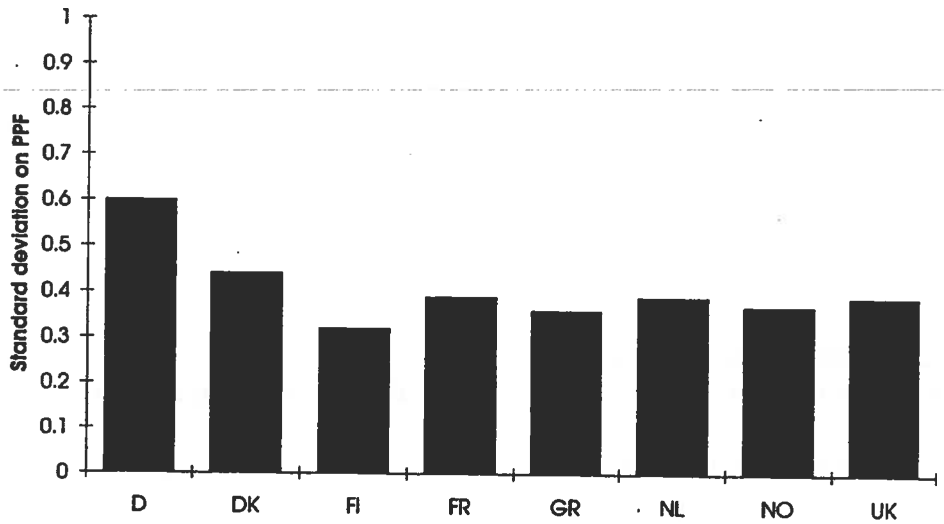


Figure 4.10 *The standard deviation on the Panel Performance Factor of each of the eight panels of the IAQ-Audit project (including error limit correction).*

4.1.4 Conclusions

This discussion was a first attempt to analyze the behaviour of different trained panels all over Europe, using the same method.

In the future it will be possible to compare new sensory panel data with the data established in this project. For that purpose the new method to describe the performance of sensory panels based on both a 2-propanone test (PPF) and performance regarding other sources than 2-propanone can be applied (DPF). Am important criterion was not included in this project, namely the reproducibility of a panel and/or panel member. Reproducibility can be defined as the standard deviation around the mean of two or more replicas of a source divided by the mean vote of that source. An additional performance factor for the reproducibility could be the Reproducibility Performance Factor defined as the standard deviation around the mean divided by the allowed standard deviation around the mean.

The DPF assumes that panel size lies around 12 to 15 persons. The standard deviation is the deviation on a single vote and not the deviation on the mean vote (standard error). In future calculations this should be included.

Furthermore, the question can be risen whether the DPF should at all be a measure of panel performance. For perceived air qualities other than 2-propanone it is common that panel members vary in their judgement. Some panel members find the smell of tobacco for example very annoying while others do not. For sources other than 2-propanone, the correct answer is not known and an evaluation of the vote is not yet possible as such.

4.2 Questionnaire - sensory measurements

In this chapter the occupants' health and comfort are compared with the sensory measurements performed by the trained sensory panels.

The occupants' perception of the indoor air was among other things given as overall acceptability of the indoor air quality on a scale from clearly not acceptable to clearly acceptable. Between the clearly not acceptable and clearly acceptable was a border between just not acceptable and just acceptable.

The occupants' health at the time of the building audit is described as the mean number of building related symptoms at the time of the audit (BSI_{sf}).

Figure 4.11 shows the occupants' rating of indoor air acceptability versus the perceived air quality measured in the offices, where as Figure 4.12 presents BSI_{sf} as a function of the perceived air quality in the offices. The occupants acceptability rating and number of building related symptoms did not show statistically significant correlation with perceived air quality in the offices evaluated by the sensory panel.

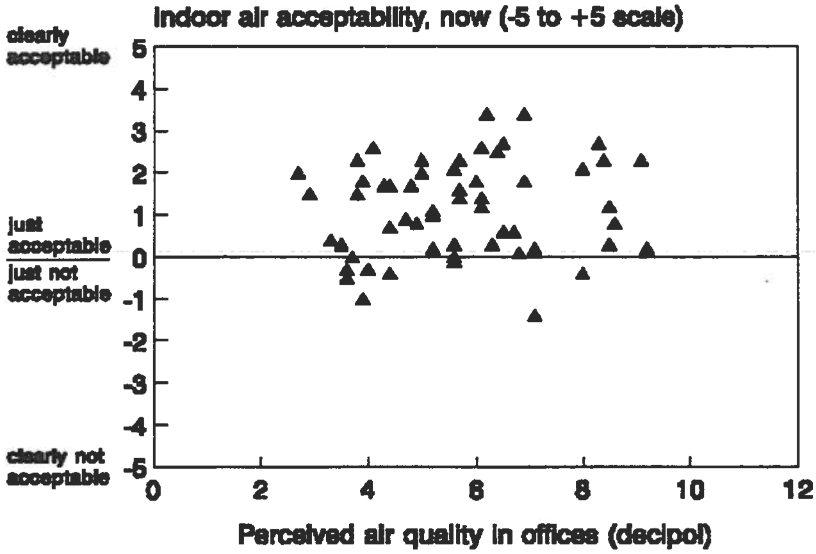


Figure 4.11 *Indoor air acceptability at the time of the audit rated by the occupants versus the mean perceived air quality in the building evaluated by a trained sensory panel.*

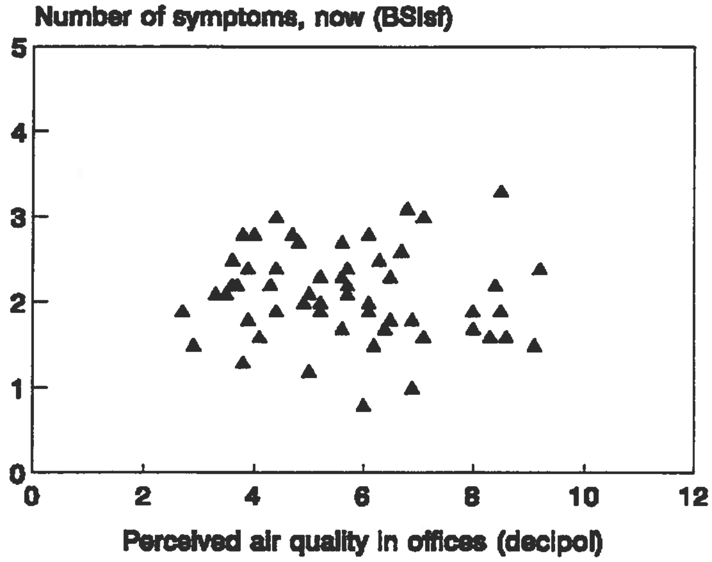


Figure 4.12 *The mean number of building related symptoms at the time of the audit (BSIsf) versus the mean perceived air quality in the building evaluated by a trained sensory panel.*

It could be discussed whether a relation between the perceived air quality and the occupants perceptions and symptoms was to be expected.

First of all it is important to remember that the occupants and the sensory panel did not evaluate the same air. The perceived air quality was measured by a trained sensory panel at five locations in a building with approximately 200 to 500 occupants, whereas the occupants evaluated the air quality in their own office room. The sensory panel gave the initial impression of the air quality at the five selected locations in the building in contradiction to the occupants who gave the adapted perception of the air quality in their own office room.

A relation between the perceived air quality and the building-related symptoms at the time of the audit was not necessarily expected, since most odorous pollutants are not necessarily a health risk and most individual measured and identified compounds were far below the health risk limits (see chapter 3.3). Poor indoor air quality is not necessarily a hazard to the occupants' health. The perceived are quality is first of all related to the comfort of the occupants, and especially to the initial impression of a guest visiting the building.

In some cases the perceived air quality within a building differed a lot, hence the mean perceived air quality for the office air in a building may have been irrelevant information. In these cases the mean value was not representative of the building. Also the selected spaces may not always have been representative for the building, as these had to be close to the refreshment location for the sensory panel.

Furthermore, it is important to remember that the audit study was not specially designed to

prove any dose-response relations. It were not the same sources, not the same sensory panels and not the same occupants that have been studied and the buildings were not selected to be either especially "sick" or "healthy".
In this paragraph questionnaire responses are compared with the sensory measurements performed by the trained sensory panels.

4.3 Sensory/chemical pollution load

For each country the mean sensory and chemical pollution loads were calculated with the formula presented below.

Sensory pollution load

The following equations were used to calculate the sensory pollution loads:

- *in the selected spaces (offices)*

$$Gs = 0.1((Cpr-Ca)Qar + (Cpr-Cpv)Qvr + (Cpr-Cpo)Qor) \text{ (olf)} \quad [4.6]$$

- *by ventilation system*

$$Gsv = 0.1(Cpv-Cpo)Qvr - 0.1.R(Cpr-Cpo)Qvr \text{ (olf)} \quad [4.7]$$

- *by occupants*

$$Gsp = 3600((CCO2r-CCO2a)Qar + (CCO2r-CCO2v)Qvr + (CCO2r-CCO2o)Qor)x10^{-6}/P_{CO2p} \text{ (olf)} \quad [4.8]$$

- *by tobacco smoking*

The number of cigarettes smoked was calculated with the following equations:

$$nc = 3600x10^{-6}((CCOr-CCOv)xQvr)+(CCOr-CCOo)xQor)+(CCOr-CCOa)xQar))/P_{CO}x10^{-3} \text{ (cig./h)} \quad [4.9]$$

The sensory pollution from smoking is then:

$$Gss = ncx4.2 \text{ (olf)} \quad [4.10]$$

- *other sources in space (materials, etc..)*

$$Gsm = Gs-Gsp-Gss \text{ (olf)} \quad [4.11]$$

Furthermore, a revised version of equation 4.6 was used to calculate the total pollution load in the audited offices:

$$Gt = 0.1(Cpr-Cpo)xQo \text{ (olf)} \quad [4.12]$$

where:

Gs	= sensory pollution load in the selected space (olf)
Gsv	= sensory pollution load caused by ventilation system (olf)
Gsp	= sensory pollution load caused by occupants (olf)
Gss	= sensory pollution load caused by smoking (olf)
Gsm	= sensory pollution load caused by other sources in space (olf)
Gt	= total sensory pollution load in the selected space (olf)

Cpr	= perceived air quality in space (decipol)
Ca	= perceived air quality in adjacent space (decipol)
Cpv	= perceived air quality of supply air (decipol)
Cpo	= perceived air quality outdoors (decipol)
Qvr	= mechanical supply flow rate (l/s)
Qor	= infiltration ventilation rate (l/s)
Qar	= flow rate from adjacent space (l/s)
Qo	= total outdoor air supply (l/s)
R	= degree of recirculation (fraction)
CCO2v	= measured CO_2-concentration in supply air (ppm)
CCO2r	= measured CO_2-concentration in space (ppm)
CCO2a	= measured CO_2-concentration in adjacent space (ppm)
CCO2o	= measured CO_2-concentration in outdoor air (ppm)
PCO2p	= production of CO_2 per olf = 18 (l/h.olf)
nc	= number of cigarettes per hour
CCOv	= measured CO-concentration in supply air (ppm)
CCOr	= measured CO-concentration in space (ppm)
CCOa	= measured CO-concentration in adjacent space (ppm)
CCOo	= measured CO-concentration in outdoor air (ppm)
PCO	= production of CO per cigarette = 44 (ml/cigarette)

Chemical pollution load

The chemical pollution load was calculated using the TVOC values measured with the Tenax-GC method (TVOC measured in $\mu g/m^3$ (toluene)):

$$Gc = 10^{-3}(CTVOCr-CTVOCa)Qar + (CTVOCr-CTVOCv)Qvr + (CTVOCr-CTVOCo)Qor) \quad (\mu g/s) \qquad [4.13]$$

where:

CTVOCr	= TVOC-concentration in space	($\mu g/m^3$)
CTVOCa	= TVOC-concentration in adjacent space	($\mu g/m^3$)
CTVOCv	= TVOC-concentration in supply air	($\mu g/m^3$)
CTVOCo	= TVOC-concentration outdoors	($\mu g/m^3$)

For calculation of pollution loads for ventilation system and total, a similar approach as in the sensory load calculation can be applied.

Uncertainty calculation

The uncertainties on each value used in the above equations is required to determine the total uncertainty on the calculated pollution loads. The following uncertainties were therefore required:

- total uncertainty of CO/CO_2 (with B&K)
- total uncertainty of TVOC-measurement (Tenax GC)
- total uncertainty of determined airflows
- total uncertainty on mean perceived air qualities

The total uncertainty for each calculated pollution load was determined by using the following equation:

$$uncertainty^2 = (\Sigma((\delta Z/\delta Xi).dXi)^2) \quad [4.14]$$

with: Z = pollution load
Xi = parameter to calculated pollution load
dXi = uncertainty of parameter

for example: if Z = (A-B).C + (A-D).E + (A-F).G

then:
$$uncert.^2 = ((\delta Z/\delta A).dA)^2 + ((\delta Z/\delta B).dB)^2 + ((\delta Z/\delta C).dC)^2 + ((\delta Z/\delta D).dD)^2 + ((\delta Z/\delta E).dE)^2 + ((\delta Z/\delta F).dF)^2 + ((\delta Z/\delta G).dG)^2$$

$$= (C+E+G)^2.dA^2 + (A-B)^2dC^2 + (A-D)^2dE^2 + (A-F)^2dG^2 + C^2dB^2 + E^2dD^2 + G^2dF^2 \quad [4.15]$$

The different calculated sensory and chemical pollution loads per m^2 office floor area and calculated uncertainties are presented in Appendix J. In this appendix only the total pollution load conform equation 4.12, the pollution load from the ventilation system conform equation 4.7, the pollution load caused by occupants conform equation 4.8 and the pollution load in the investigated rooms conform equation 4.6 are presented. The reasons for this are first of all that the CO measurements were considered to be too inaccurate to use to calculate pollution load from tobacco smoking. Second, the pollution loads calculated showed large uncertainties, which is caused by the fact that the equations used, comprise a sum of terms with differences of values multiplied by the airflow rate. If the difference in values is close to the uncertainty of the value itself (as was often the case for the perceived air quality), and also the uncertainty of the airflow rate is high, the total relative error becomes very high. Large uncertainties are possibly also caused by taken the assumption that steady state occured, while in practice this never does. Subtracting two values from another value, as is done in equation 4.11, with each of them having large uncertainties, will create an even larger error.
The average sensory pollution load from the investigated rooms was 0.4 olf/m^2, while the average sensory pollution load from the ventilation system and the occupants was respectively 0.3 and 0.1 olf/m^2. The total average sensory pollution load (using equation 4.12) was 0.6 olf/m^2.
The average chemical pollution load from the investigated rooms was 0.23 μg/s.m^2, while the average chemical pollution from the ventilation system was 0.05 μg/s.m^2. The total average chemical pollution load was 0.33 μg/s.m^2.
In the calculation of the averages unlikely values were skipped (f.e. values > 3 olf/m^2 and values > 6 μg/s.m^2) and values from buildings with recirculation where the recirculation factor was not measured.

Volatile organic compounds may have an odour and irritation potential. Therefore the relation between the sensory pollution load and the chemical pollution load was investigated.
The correlation between sensory and chemical pollution load was poor as is shown in Figures 4.13 to 4.15. Some specific components (VOCs) have a high sensory effect, others have not. Total volatile organic compounds might therefore not correlate with the sensory evaluations. Different mixtures of VOCs (with different odour and irritation potential) may however lead to the same TVOC-value. Furthermore, as is stated in paragraph 2.3.3, the TVOC measured with the Tenax-GC method did not include all VOCs present.

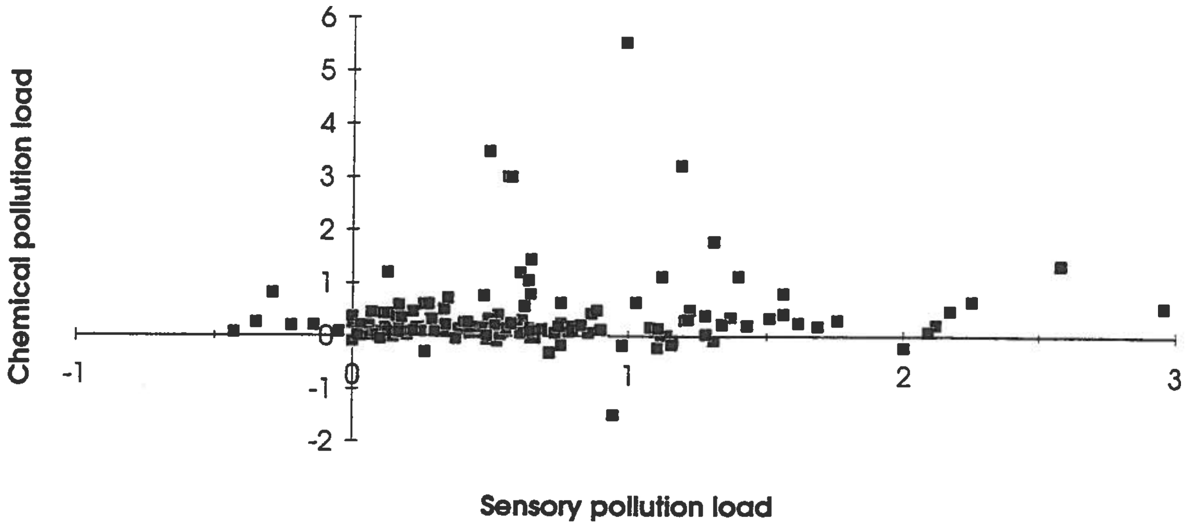


Figure 4.13 *Comparison between chemical and sensory pollution loads for the total pollution (Gt) in 165 audited rooms, expressed in μg/s/m² and olf/m² respectively (equation 4.6/4.13).*

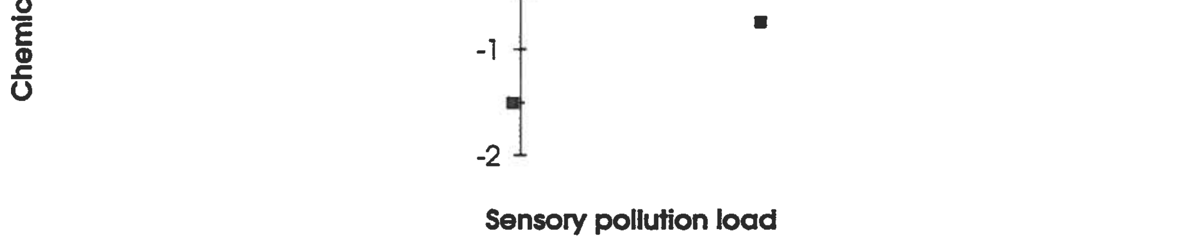


Figure 4.14 *Comparison between chemical and sensory pollution loads for the ventilation system (Gsv) in 143 audited rooms, expressed in μg/s/m² and olf/m² respectively (equation 4.7).*

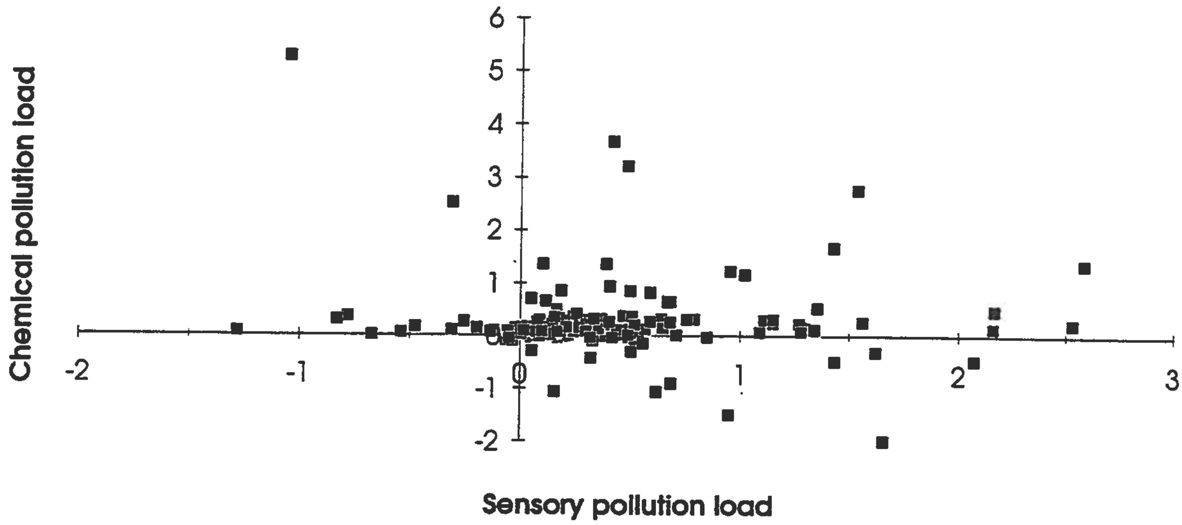


Figure 4.15 *Comparison between chemical and sensory pollution loads (Gs) from the rooms of 174 audited buildings, expressed in μg/s/m² and olf/m² respectively (equation 4.12).*

4.4 Identification Pollution sources

The pollution sources have been identified by means of calculation formulas given in paragraph 4.3, using the measured values for perceived air quality, TVOC, CO, CO_2 and airflow rates. These calculation procedures permit estimation of source strength in the broad categories indicated in Table 4.3. However, the ranking was based on professional judgements, since the large uncertainties on the pollution load calculations did not allow to only use the calculated pollution load values.

Table 4.3 *Categories of pollution sources resulting from sensory and chemical measurements.*

From sensory measurements	From chemical measurements
outdoor pollution (traffic, industry)	
ventilation system (filters)	ventilation system
people in the office	all sources in the room including materials, furnishing, people and tobacco smoking
materials and other sources in the office (tobacco smoking, furnishing, photocopying, laserprinters, renovation works)	

From the numerical values obtained, the source categories can be placed in order of magnitude. The results are presented below.

4.4.1 Sensory pollution sources

The numerical values of source strength were put in order of magnitude. The actual perceived air qualities (in decipol) for outdoor air were compared with the indoor air values. The most important sensory pollution sources are presented in Figure 4.25.

The sources were ranked according to the percentage of offices where the named source was the main source (276 rooms were included in the analyses).

Tobacco smoking is in general considered as the most dominating source of sensory pollution when it takes place. In this investigation where the source strength was evaluated through the Carbon monoxide concentration, the results showed that only in 12% of all rooms or 30% of rooms were smoking had been taking or took place, was tobacco smoke calculated to be the main source. However, sensory pollution due to tobacco smoke persists after smoking stops, whereas the CO production stops immediately. This is due to desorption effects and also due to decomposition of tobacco compounds adsorbed on surfaces. The outcome is that CO concentrations underestimate sensory pollution due to smoking.
Therefore, in Figure 4.16 tobacco smoke as a source is included in the category materials and other sources.

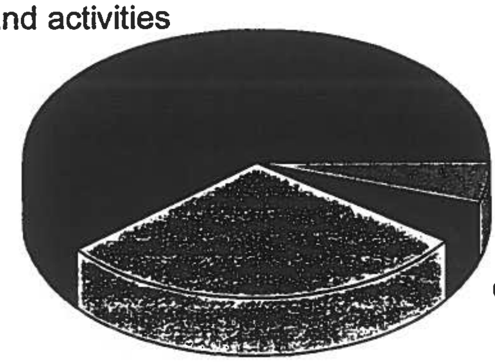


Figure 4.16 Most important sensory pollution sources estimated in audited buildings.

It can be seen that the materials and activities, closely followed by the ventilation systems were likely to be identified as the first pollution source. Among materials and activities, furnishing was mentioned most often as a source, also photocopying and building renovation. In the 50% of the situations where ventilation was identified as the prime source, filters and air recirculation from other rooms were specifically mentioned equally often. Adsorption effects of bioeffluents, CO_2 being the indicator, may result in underestimation of the sensory pollution caused by occupants. It must furthermore be noted that the ventilation systems, which were the most important source in 29% of all rooms, were equivalent to 32% of those mechanically ventilated.

4.4.2 Chemical pollution sources

The TVOC data enabled chemical pollution sources to be divided into two main categories, the ventilation systems and the office which included materials, the occupants and all their activities. Rooms without mechanical ventilation systems were excluded from this analysis, since there was only one category of source in those cases.
The results presented in Figure 4.17 are based on 211 rooms.
The office, its occupants and their activities were identified as the most important source of chemical pollution in about two thirds of the rooms.

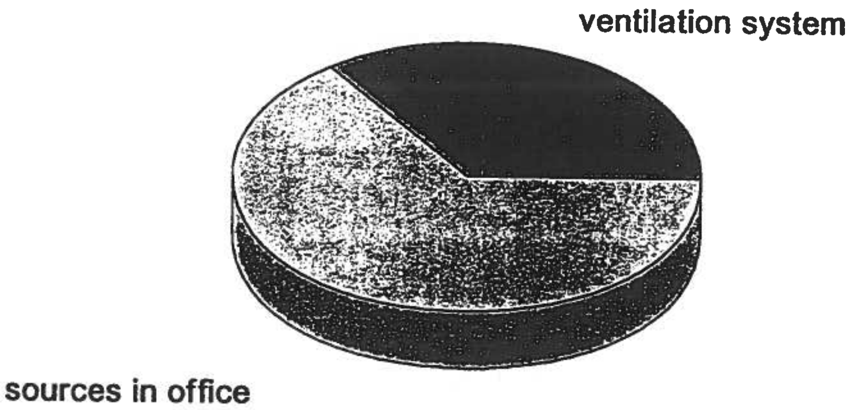


Figure 4.17 Most important chemical pollution sources estimated in audited buildings.

4.4.3 VOC sources

The number of VOCs measured in each audited building by the Tenax-GC method was in general higher than sixty. However, the most abundant compounds for each building were selected and the possible sources for these compounds were noted. Table 4.4 shows the possible sources for the most important compounds found, These sources can be divided into 6 categories:

- outdoor sources (O): traffic, industry
- tobacco smoke (T)
- building materials (B): insulation, plywood, paint, etc..
- furnishing (F): furniture (particle board), carpet, wall covering, drapes, etc..
- consumer products (C): cleaning products, hygienic products, personal care products
- equipment (E): laserprinters and other office equipment

Ventilation systems as a source were not included since no knowledge is available on which VOCs originate from the ventilation systems as such.

As it is shown in Table 4.4, most of the compounds may have been produced by more than one source. Therefore, it was difficult to identify the sources of individual VOC in each single building. The most important sources of VOC for each building have been determined by using the occurrence frequency of each source and by the information supplied through the checklist (e.g. outdoor air sources, smoking, no. of laserprinters in the room,..). The most important source of VOCs was furnishing, the second most important source was consumer products and the third was outdoor air. Figure 4.18 presents the number of buildings that each source was the first, second, third, fourth or fifth important source. It must be noted that tobacco smoke, which is ranked here as the fifth most important source of only volatile compounds, also contributes many more compounds in less volatile or non-volatile fractions, so that its effect on indoor air quality could not properly be assessed by this analysis.

Comparison of these data with the ranking of sources by sensory measurements, did not show a good correlation. This was not unexpected, since the identification of VOC sources determine the most important sources that emit VOCs. Ranking based on sensory measurements included sources that emit or produce other compounds than the compounds measured with Tenax-GC method.

It is important to note that a number of individual VOCs were highly intercorrelated. Using a regression matrix, it was revealed that the correlation coefficients r between a number of individual VOCs found in different buildings were higher than 0.7 and sometimes reached values up to 0.99. This indicates that a number of compounds were emitted from similar sources with a similar pattern of concentrations in different buildings. Therefore, individual VOCs could be classified into groups according to the intercorrelation between them. Two of the most important groups are presented in Table 4.5.

The TVOC concentrations in all rooms and the concentrations of the compounds included in groups 1 (with and without toluene) and 2 in one room, were correlated with a number of variables derived from the checklist. These variables included situation, traffic within 200 m, near sources of pollution, year of building completion and modification, furniture material, wall covering, flooring and ceiling material, and smoking. None of the parameters gave a significant relation, except for smoking. Analysis of the variance of the average TVOC levels in buildings where smoking was allowed, not allowed and allowed in separate rooms was carried out. A significant relation between the average TVOC concentration and smoking was found.

Table 4.4 Possible sources of most important VOCs found in the audited buildings.

		O	T	Materials			
	Source			**E**	**B**	**F**	**C**
(CF2)n	propellant						x
1,1,1-trichloroethane	carpets glues, aerosol sprays, cleaners, dry cleaned clothes					x	x
C2C13F13	refrigerators, propellants						x
tetrachloroethylene	dry cleaned clothes						x
dichloromethane	sprays, paint removers, polyurethane foam				x		x
dichlorobenzene	room fresheners, toilet bowl deodoriser, anti-moth crystals						x
butane	traffic	x					
n-hexane	carpet glues, wallpaper, chipboard, insulation foam, smoking, gasoline	x	x		x	x	
aliphatic C7H16	glass cleanser, traffic	x					x
n-heptane	glass cleanser, traffic	x					x
octane	paints, tobacco smoke, traffic	x	x		x		
aliph. C9H20	floor adhesives and waxes, paints, cleaners				x	x	x
nonane	floor adhesives and waxes, paints, varnish, cleaners				x	x	x
decane C10H22	floor adhesives and waxes, paints, cleaners				x	x	x
undecane	floor adhesives and waxes, paints, cleaners				x	x	x
dodecane	waxes and polishes of floor						x
tetradecane	waxes and polishes of floor						x
pentadecane	waxes and polishes of floor						x
2-methylboutane	traffic	x					
2-methylpentane	traffic	x					
3-methylpentane	traffic	x					
2,4-dimethylhexane	traffic, glues	x				x	
2-methylhexane	traffic, glues	x				x	
nonane/o-xylene	carpets					x	
nonane/styrene	carpets, tobacco smoke					x	
dimetylcyclopentane	solvent based glues and waxes					x	x
methylcyclopentane	solvent based glues and waxes					x	x
methyl-cyclohexane	solvent based glues and waxes					x	x
cyclo-hexane	solvent based glues for carpets, paint and varnish remover					x	x
2-methyl-1,3-boutadiene	rubbers,oxidation of VOC					x	
benzene	paints, carpet glues, particleboard, tobacco smoke , traffic	x	x		x	x	
C3-alkylbenzenes	floor/wall covering, paints, floor varnishes/waxes, chipboard, smoking, traffic	x	x		x	x	x
m-xylene	floor covering, adhesives, wall paper, paints, smoking, traffic	x	x		x	x	x
o-xylene	as m-xylene	x	x		x	x	x
p-xylene	as m-xylene	x	x		x	x	x
toluene	paints, adhesives, lacquer parquet, cleaners, tobacco smoke, traffic	x	x		x	x	x

Cont. Table 4.4 *Possible sources of most important VOCs found in the audited buildings.*

		O	T	Materials			
	Source			E	B	F	C
naphthalene	anti-moth products						x
phthalate compound	carpet					x	
1-butanol	floor covering (linoleum, lacquer), chipboard, paints, resins				x	x	x
1-ethanol	cleaners, varnish, floor covering(linoleum, lacquer)					x	x
1-ethoxy-2-propanol	paint				x		
2-butoxy-ethanol	floor cleaners, paints, wax strippers and varnish removers				x		x
2-phenoxy-ethanol	paint, varnish				x		x
C5-alcohol	cleaners, paints				x		x
ethoxy-ethoxy-ethanol	cleaner, paint				x		x
4-methyl-2-pentanone	floor/wall covering, tobacco smoke		x			x	
acetone	glues, carpets, particleboard, drapes, bioeffluents					x	
cyclohexanone	resins, waxes						x
benzaldehyde	cleaners, chipboard,photochemical oxidation of VOC, Tenax			x		x	x
ethanal	cleaners, tobacco smoke, photochemical oxidation		x	x			x
nonanal	cleaners, photochemical oxidation of VOC, artefact of Tenax			x			x
decanal	cleaners, fabric, photochemical oxidation of VOC, artefact of Tenax			x		x	x
acetic acid butyl ester	floor covering (parquet, PVC flooring)					x	
acetic acid ethyl ester	floor covering (parquet, PVC flooring)					x	
C5H2O8 ester							
methyl methacrylate	acrylic paint				x		
butoxy-ethoxy ethylacetate	plastics, resins, lacquer solvents					x	
acetic acid	varnishes, silicon sealant				x	x	
benzoic acid	floor detergent						x
dodecanoic acid	wood glue, varnish					x	x
a-pinene	cleaners, air fresheners, wood products					x	x
isoprene							
l-limonene	lemon scented cleaners, air fresheners, polishes, waxes						x
terpene compound	cleaners, air fresheners, polishes						x

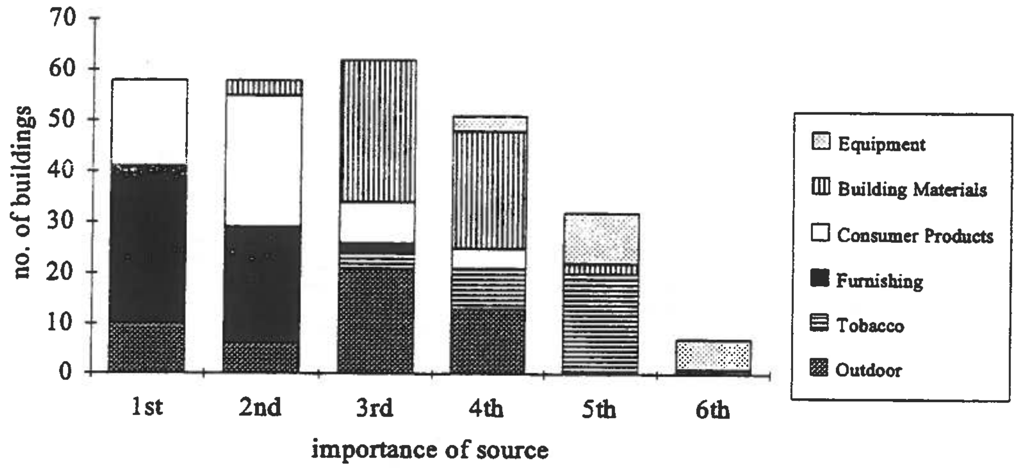


Figure 4.18 *Ranking of pollution sources according to their importance based on individual VOC measurements.*

Table 4.5 *Grouping of correlated VOCs in buildings.*

1 st group	2nd group
n-hexane	nonane + aliphatic C9H20
n-heptane	decane
aliphatic C7H16	C3-alkyl-benzene
3-methylpenane	m-xylene
2-methylpenane	p-xylene
methyl-cyclopentane	o-xylene
dimethylcyclopentane	terpene
cyclohexane	alpha-pinene
benzene	
toluene	

The compounds included in the first group probably originated from outdoor sources, while the compounds included in the second group were probably emitted by materials. Figures 4.19 and 4.20 show the variation of the compounds included in the first and second group in the various buildings of all countries. To identify the possible common sources for these compounds, it is necessary to compare them with a number of variables such as traffic, smoking, furnishing, building materials, etc..

Other correlations between compounds were found. Benzaldehyde and acetic acid showed a good correlation in a number of buildings, as is shown in Figure 4.21. Furthermore, 2,4-dimethylhexane, nonanal and C5-alcohol were found in a number of buildings in Denmark and France in proportional concentrations.

Some compounds were found together. For example, 2-phenoxy-ethanol and ethoxy-ethoxy-ethanol were found in one building in Norway (probably resulting from paint) and tetradecane, 1-ethoxy-2-propanol, 4-methyl-2-pentanone and acetic acid ethyl ester in one building in United Kingdom. These correlations do not mean necessarily that these compounds were emitted from the same source, since the number of buildings where these compounds were found together was not significant.

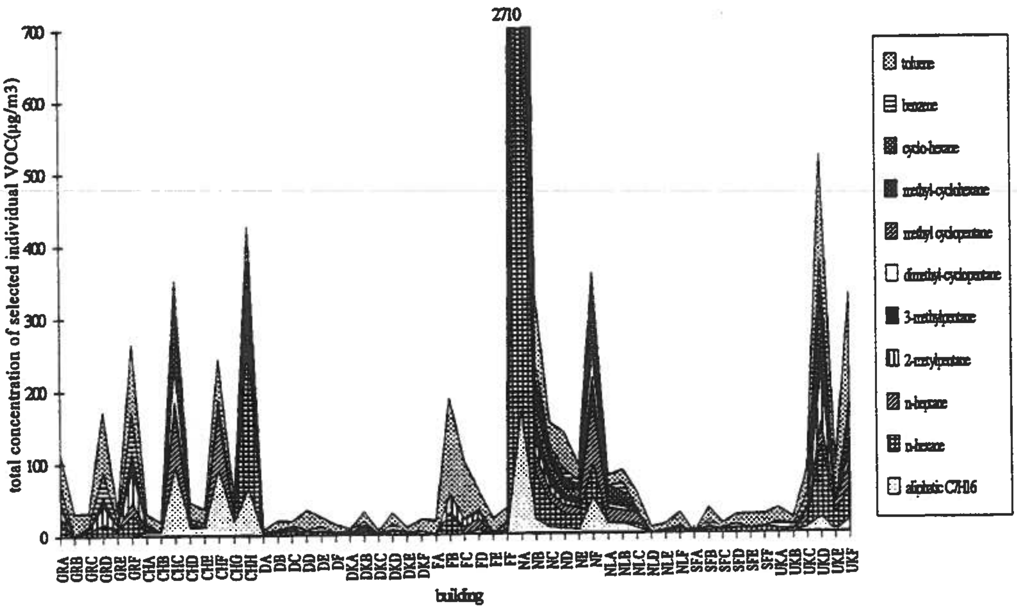


Figure 4.19 Variation of VOCs included in the first group for the audited buildings.

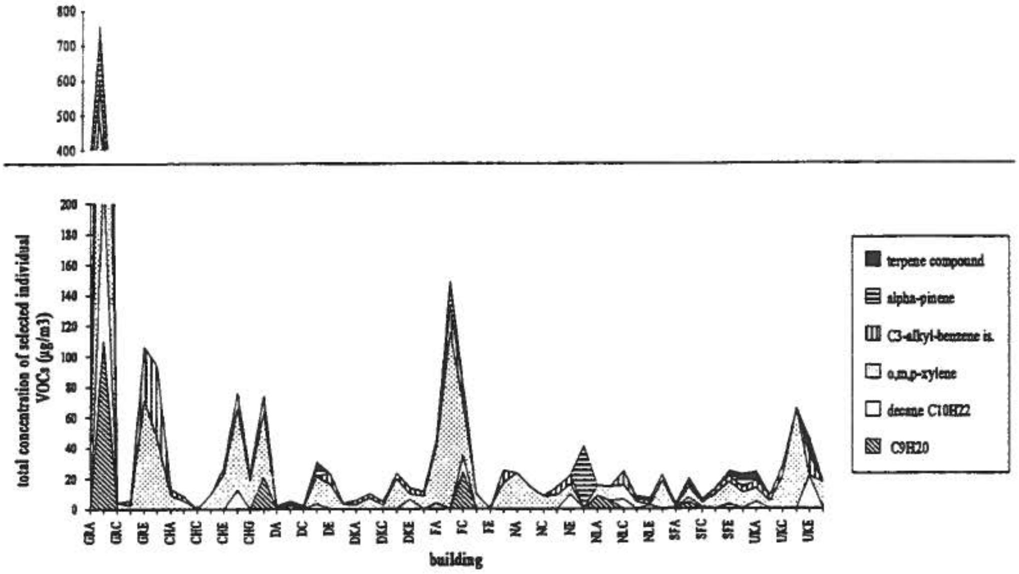


Figure 4.20 *Variation of VOCs included in the second group for the audited buildings.*

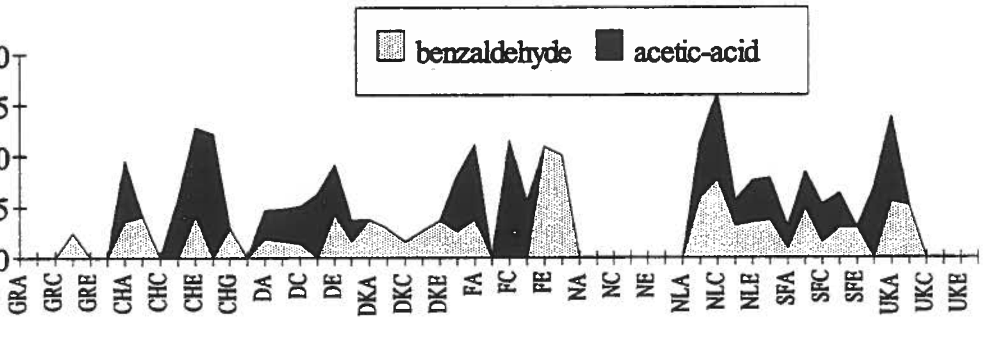


Figure 4.21 *Variation of benzaldehyde and acetic acid for the audit buildings.*

The remaining compounds that were found in the audited buildings were probably emitted separately by independent sources. These compounds did not seem to depend on outdoor sources or common materials, since they were not related to the common compounds emitted by these sources. They were mainly chlorinated hydrocarbons, which were found in a small number of buildings, and also compounds such as alkanes, a number of oxidized hydrocarbons and limonene that were found in various buildings. Limonene can originate from fruits, scented household products, soaps or wood-products; alkanes can originate from the outdoor traffic; and oxidized hydrocarbons can be emitted by for example linoleum.

In conclusions: An attempt was made to correlate the concentration patterns in different buildings, using a correlation matrix. It was found that almost all buildings had at least a small correlation with the other buildings, since there was a certain number of compounds that were ubiquitous and were found in all the buildings. Furthermore, it was shown that there was a certain number of buildings that had a similar concentration pattern. Therefore, it is possible to create groups of buildings that had similar concentration patterns.

4.5 Ventilation performance

4.5.1 Requirements

Ventilation performance can be assessed only by comparison to accepted requirements. The purpose of the ventilation in audited buildings is to ensure an acceptable indoor air quality and, in some buildings, to condition the indoor climate. This second requirement is treated in the comfort section (paragraph 3.4). This section will hence concentrate on the ventilation performance related to indoor air quality, as assessed by carbon dioxide concentration and perceived air quality, and compares the ventilation rates with the recommendations of a new prENV standard.

This prENV 1752 standard is issued by CEN (36), proposes the figures shown in Table 4.6 for required ventilation rates in office buildings. These figures are based on air quality as perceived by persons coming from fresh, clean air and entering the room.
Category A corresponds to 15% dissatisfied only, while categories B and C correspond to 20% and 30% respectively, as given in the informative annex of the prENV 1752. Airflow rates given in Table 4.6 are valid only for low polluting building materials and furnishings, and for a ventilation effectiveness of 1.

Table 4.6 *Ventilation rates recommended by prENV 1752 (36).*

Type of room	Occupancy per m^2 floor area [person/m^2]	Category	Required ventilation rate		Total when smoking allowed	
			[l/s.m^2]	[l/s.person]	[l/s.m^2]	[l/s.person]
single office room	0.1	A B C	2.0 1.4 0.8	20 14 8		
landscaped office	0.07	A B C	1.7 1.2 0.7	24 17 10	2.4 1.7 1.0	34 24 14

Carbon dioxide is a good indicator of bioeffluents. If occupants are the exclusive pollution source, the perceived air quality is related to carbon dioxide above outdoors by (36):

$$PD = 395*\exp(-15.15\ CCO2^{-0.25}) \qquad [4.16]$$

This relation is shown in Figure 4.22 together with the related categories.
Since the CO_2 production per person having an office activity is about 18 l/h, the airflow rate required to maintain the carbon dioxide concentration below a given level is given by:

$$Qvo = PCO2/(CCO2r-CCO2o) \qquad [4.17]$$

where:

PCO2 = CO_2 production per person
CCO2r and CCO2o are the CO2 concentration in room and outdoors.

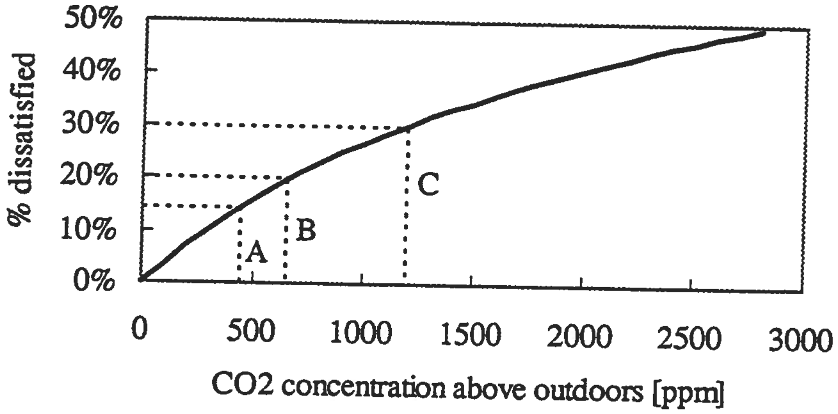


Figure 4.22 *Relation between percentage of dissatisfied and carbon dioxide concentration. This relation is valid when occupants are the only sources of pollution.*

Note that this estimate assumes steady state and known number of persons. Assuming this, the values given in Table 4.7 can be calculated. By comparison with Table 4.6, it can be seen that the latter values are twice the figures of Table 4.7. This is because a source strength of 0.1 olf/m^2 is added in Table 4.6 to take the materials and furnishings into account.

In Table 4.7 the percentage of dissatisfied and the perceived air quality in decipol corresponding to each category is also presented.

Table 4.7 *Required airflow rate related to CO_2 concentration limits.*

Category	Percentage Dissatisfied [%]	Perceived Indoor Air Quality [decipol]	CCO2r-CCOo [ppm]	Qvo [l/s.person]
A	15	1.0	450	10
B	20	1.4	680	7
C	30	2.5	1200	4

4.5.2 Airflow rates in office rooms

Supply and outdoor airflow rates per floor area and air change rates are presented in paragraph 3.5. Figure 4.23 shows the outdoor airflow rate and total air supply per working place in the audited rooms. The average value for outdoor air was about 25 l/s.person with the median at 21 l/s.person.

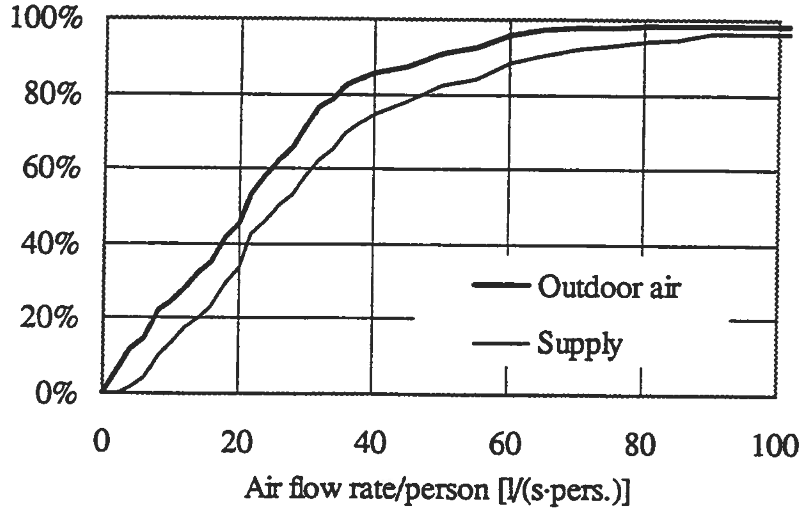


Figure 4.23 Cumulated frequencies of total and supply airflow rate per working place.

Table 4.8 provides the percentage of audited rooms which comply with the recommendations of the prENV 1752 standard. Since most audited buildings contained single office rooms, it can be said that the ventilation rate in a large majority of rooms was higher than the minimum requirements.

Table 4.8 Percentage of rooms complying to the recommendations of prENV 1752 (36).

Type of room	Category	Required ventilation rate		% of rooms complying with prENV standard
		[l/s.m²]	[l/s.person]	
single office room	A	2.0	20	55
	B	1.4	14	67
	C	0.8	8	78
landscaped office (smoking)	A	2.4	34	21
	B	1.7	24	42
	C	1.0	14	67

The figures for outdoor air are given with some uncertainty, since the recirculation rate in about one third of the buildings was not well known. Therefore, it could be worth to study the ventilation performance by considering the carbon dioxide concentration.

4.5.3 Outdoor airflow rate from CO_2

Carbon dioxide concentration measured in audited rooms is shown in Figure 4.24, together with limits corresponding to the three categories, and statistical values are given in Table 4.9.

Table 4.9 *Statistics of CO_2 concentrations (above outdoor concentrations) for 234 audited locations.*

	CO_2 [ppm]
mean	299
standard deviation	191
maximum	1500
minimum	4

It can be seen that the CO_2 concentration in all but one room was below the category C level. Respectively 96% and 84% of the rooms complied with categories B and A (Table 4.7), as far as only CO_2 concentration is concerned.

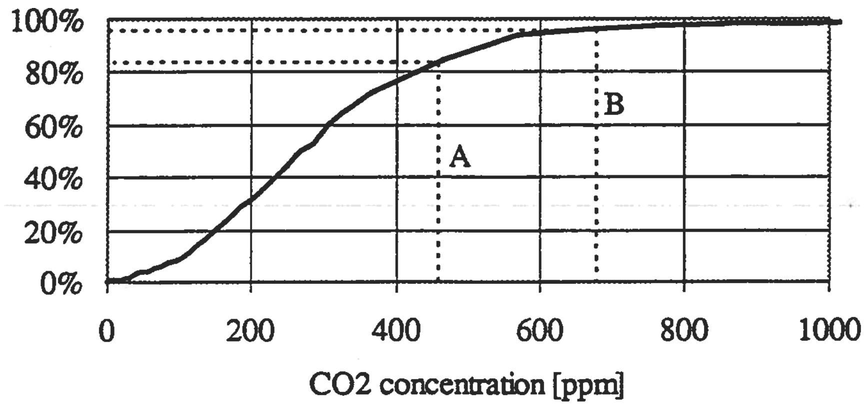


Figure 4.24 *Cumulated frequency distribution of carbon dioxide concentration above outdoors measured in the audited rooms.*

It can be concluded that outdoor airflow rate was sufficient to maintain CO_2 below acceptable levels in most audited buildings.

4.5.4 Perceived indoor air quality

Perceived indoor air quality corresponding to the three categories (as shown in Table 4.7) can be applied only to clean outdoor air. This was not the case for the outdoor air of most audited buildings, as shown in Figure 4.25. Category A could clearly not be reached in 80% of buildings without outdoor air cleaning.

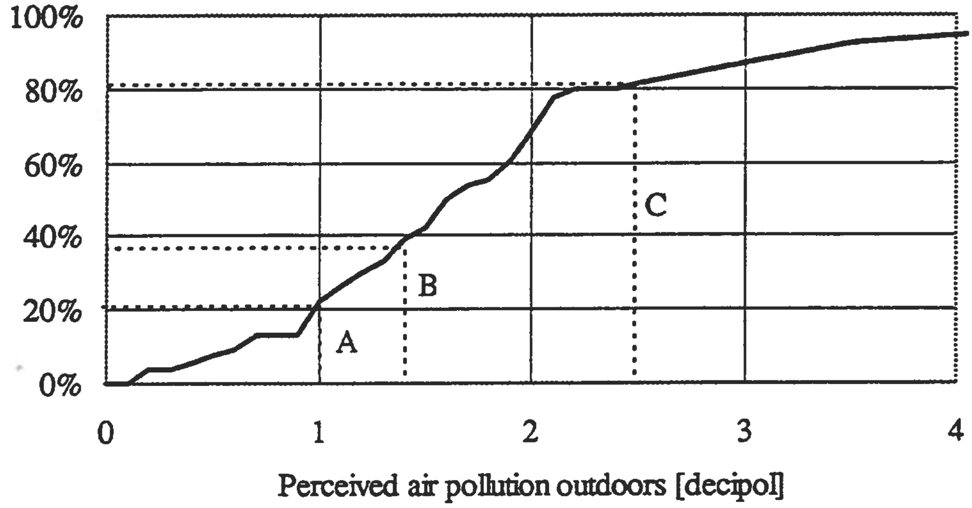


Figure 4.25 *Cumulated frequency distribution of perceived air pollution outdoors in the audited buildings.*

In order to compare the ventilation performance in audited buildings to the prENV standard recommendations (informative annex), the perceived indoor air pollution "above outdoors" was calculated for all audited rooms. The cumulated frequency distribution of this quantity is shown in Figure 4.26, together with limits corresponding to the three categories.

It can be seen that very few locations would satisfy the prENV standard recommendations as given in the informative annex.

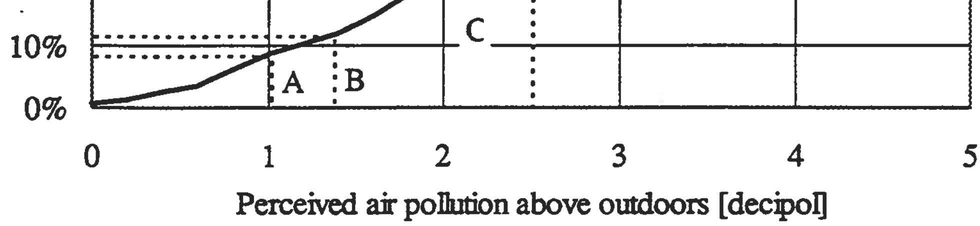


Figure 4.26 *Cumulated frequency distribution of perceived air quality above outdoors in the audited buildings.*

It follows that outdoor airflow rate was not sufficient to eliminate the pollution generated in and by the buildings, including the ventilation systems.

4.5.5 Conclusions

Table 4.10 shows the percentage of audited locations which would comply with the various recommendations given in the prENV 1752 standard.

Table 4.10 *Percentage of rooms complying to the recommendations of prENV 1752 (36).*

Requirements for	Category	Percentage of rooms complying with prENV 1752 related to		
		Ventilation rate	CO_2 concentration	Perceived IAQ
single office room	A	55	84	9
	B	67	96	12
	C	78	99.6	32
landscaped office room (smoking)	A	21	84	9
	B	42	96	12
	C	67	99.6	32

It follows that in nearly all buildings, the ventilation rates were large enough to maintain the carbon dioxide concentration, and therefore the bioeffluents concentration, below the proposed limits. For this respect, the ventilation performance was generally good.

In a majority of the rooms, the outdoor airflow rates were large enough to eliminate the bioeffluents and some other emissions coming from materials and furnishing in a reasonable amount. Therefore, if the outdoor air and the buildings were cleaner than they were, the requirements for at least category C would have been reached in a large majority of buildings.

This was however not the case when perceived air quality is considered. No location was found below 2 decipol, and less than 3% reach the category C level of 2.5 decipol. Even if outdoor air was clean, only 32% of the rooms would reach category C, and less than 9% would attain category A.

The following comments can be made:

- As said at several places in this report, buildings are main sources of contaminants, which results in an increment of the perceived air pollution. A big effort should therefore be given towards cleaner materials and equipment. For this respect, the approach in the prENV 1752 standard is correct.

- It should be noted however that in general the audited buildings were not known to be sick or a problem building. The indoor air quality was found acceptable by a majority of occupants in most buildings (approximately 30% dissatisfied).

- From the measurements performed within this project, it is shown that, if the outdoor air of more than 80% of the audited buildings is classed in category C, only 22% of the rooms comply with category A.

- However, the figures given in prENV 1752 assume that buildings are designed using low-pollution materials and furnishing. In that case, the mean outdoor air supply measured in the audited buildings (25 l/s.person) did meet category A (20 l/s.person for single offices and 24 l/s.person for landscaped offices).

4.6 Energy consumption

4.6.1 Global analysis

Cumulated frequencies of energy indices for 1993 are presented in Figure 4.27. This Figure shows that the lowest quartile of the audited buildings had an index not greater than 800 MJ/m^2, and the limit for the highest quartile was 1400 MJ/m^2. The median value was little above 1000 MJ/m^2. Only two buildings were above 2000 MJ/m^2. If only electricity is taken into account, 25% use 299 MJ/m^2 or less, the median was at about 500 MJ/m^2, only two buildings were above 1500 MJ/m^2. It is difficult to see any relation between building year and energy use (Figure 4.28). Average values for buildings constructed before and after the oil price crisis (1973) did not differ significantly. High energy indices were even more frequent among recent buildings.

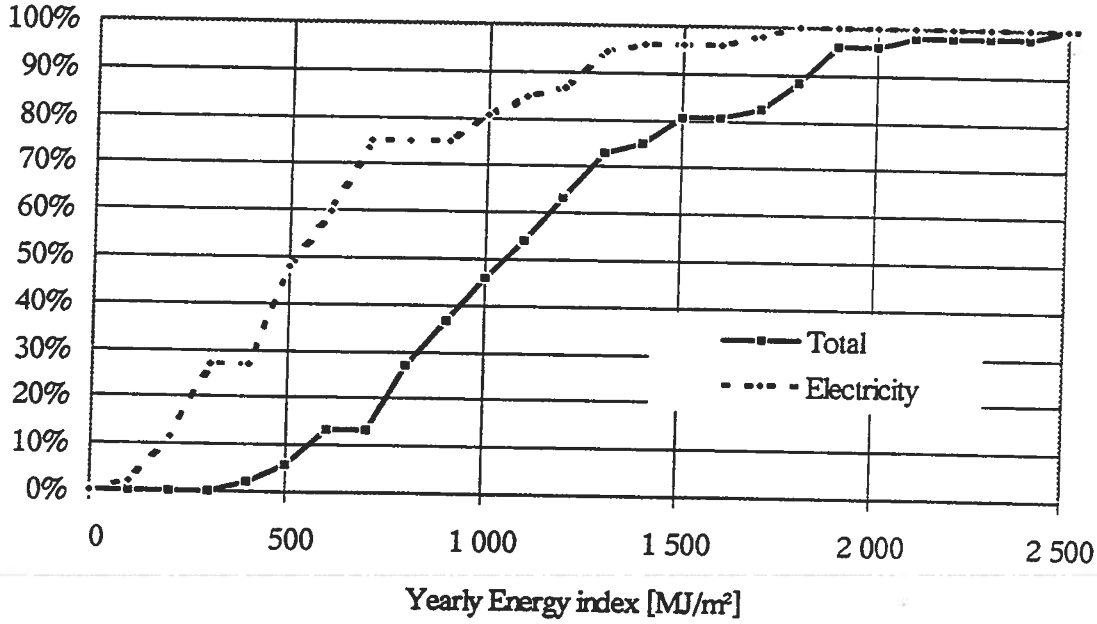


Figure 4.27 Cumulated frequencies of energy indices of audited buildings.

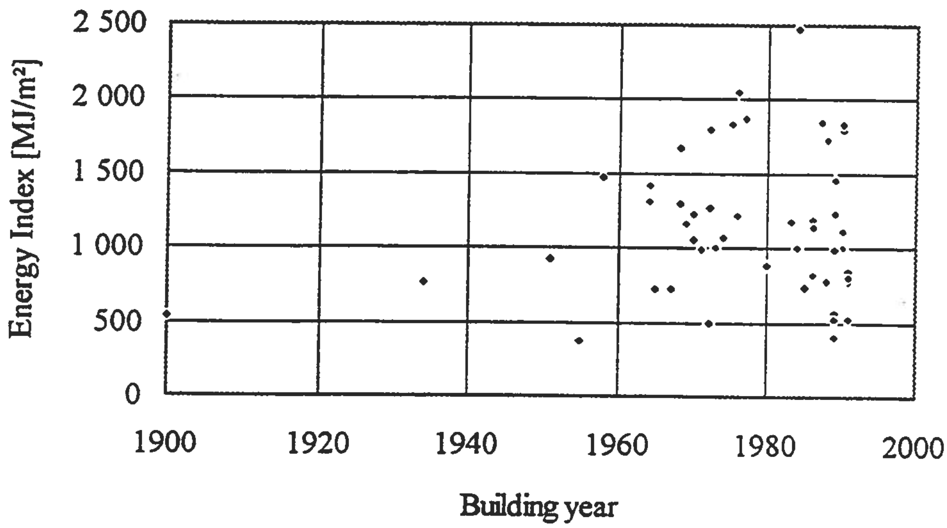


Figure 4.28 Energy index and building year.

No clear relation was found between degree days and energy use (Figure 4.29). There are two reasons for this. First the energy use for heating is a relatively small part of the total energy use. Some energy is used for cooling in warm climates and these energy consumptions were not measured separately. Second, there are various national definitions of degree days.

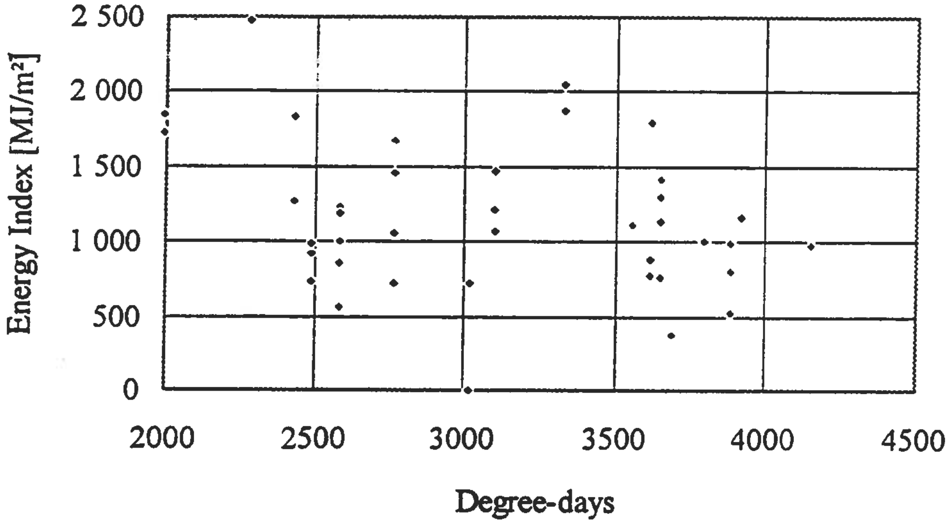


Figure 4.29 Total energy index and degree days.

A specific average power, in W/(m^2.K), is obtained by dividing the energy index by the accumulated temperature difference (in K.s or 86,400 degree days). It is the annual average used power per square meter heated floor area, for 1 K indoor-outdoor temperature difference. If the heating system efficiencies were all the same and if energy were mainly used for heating, this parameter would be independent of climate. Figure 4.30 shows the frequency distribution of this specific power, which had a median at 4 W/(m^2.K), and 60% of buildings between 2.5 and 6 W/(m^2.K).

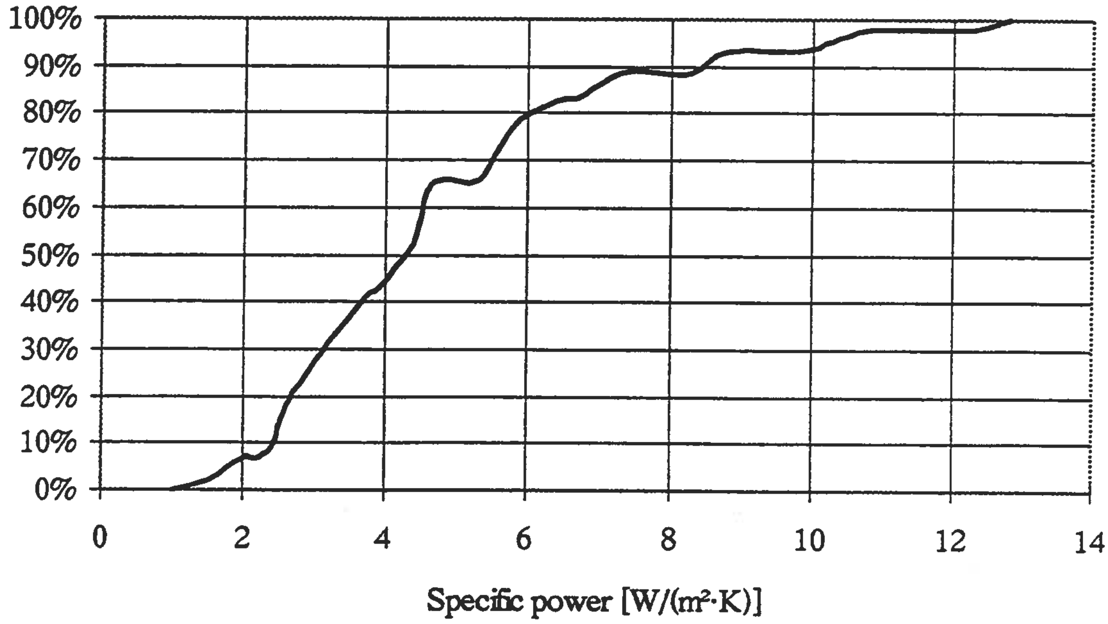


Figure 4.30 Frequency distribution of specific power.

4.6.2 National particularities

National averages of energy indices and energy use per person are presented in Figures 4.31 and 4.32. It should be stated that these are averages of the audited buildings, which are certainly not representative of the national office building stock.

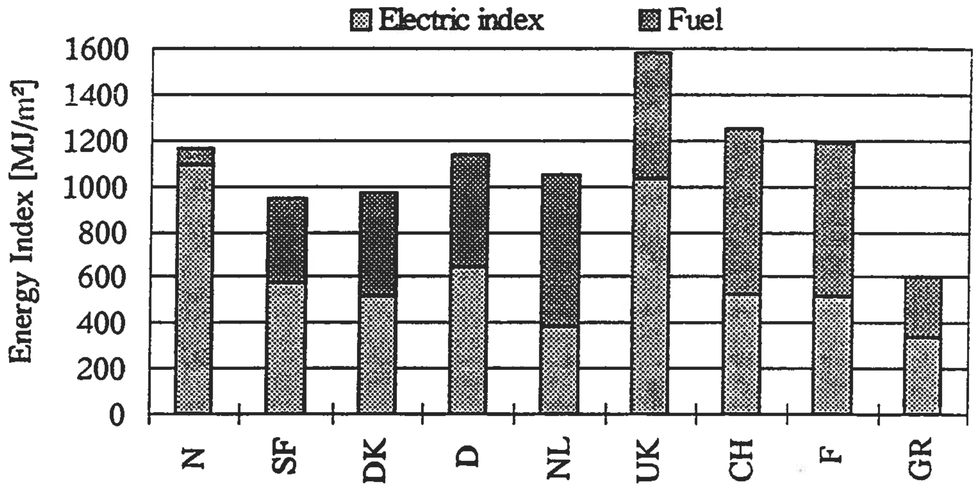


Figure 4.31 *National averages of energy indices of audited buildings. Countries are approximately ranked from North to South.*

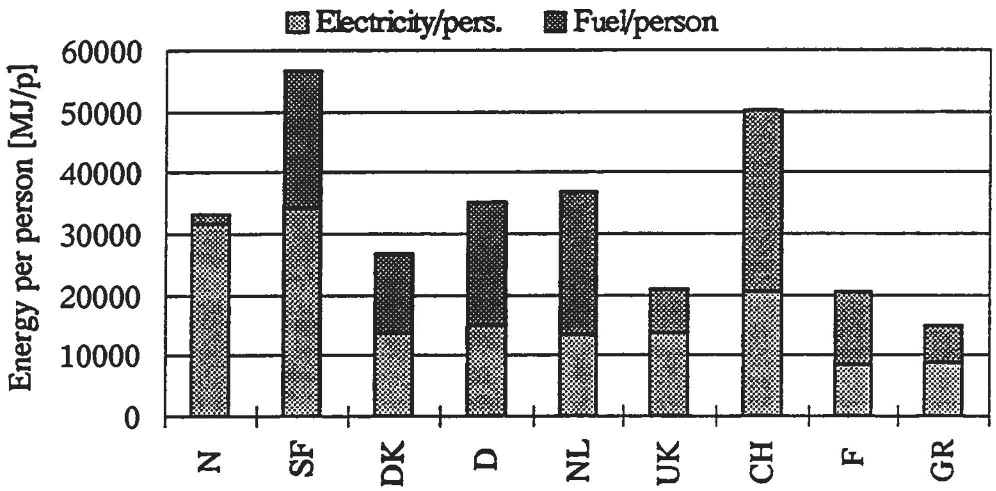


Figure 4.32 *National averages of energy use per employee.*

All audited Greek buildings had a low index. A high energy index average was found in the buildings audited in United Kingdom and Switzerland, but UK buildings showed the second smallest use per person, while the Swiss audited buildings also presented a large energy use per person. The UK energy efficiency office quote typical data from 2250 MJ/m^2 for prestige air conditioned office buildings, reducing to 1420 MJ/m^2 with "good practice". These values are 1530 MJ/m^2 for standard air conditioned office buildings reducing to 840 MJ/m^2 with "good practice". Such high limits may explain the average of the UK audited buildings. However, a recommendation generally accepted in Switzerland since 1980 proposes an upper limit to the fuel energy index at 385 MJ/m^2. Only two buildings among those audited in Switzerland complied with this recommendation.

Except for Greece, the climate did not seem to have an influence on the total energy consumption. UK and French audited buildings presented on the average a large energy index and a small energy use per person. This reflects the high occupant density observed in open plan offices, as were most of the buildings investigated in France and UK.

The part of energy used for electricity was between 40 and 65% for most countries, the exception being Norway, using 95% electricity. The reason is that this country has a large production of hydraulic electricity. The second largest user was United Kingdom, with 65% electricity.

4.6.3 Energy and airflow rate

Energy is required to heat or cool and to moist or dry the outdoor air to ensure a comfortable indoor climate. Therefore, a relationship between the outdoor airflow rate and energy use might be present. However, it is not expected to see this relationship from inspection of the total energy use, which is significantly affected by many other aspects of building use. In fact, such a relation can not be seen in Figure 4.33, in which each dot represents a building. In this figure the energy index (see paragraph 2.3 for definition) is related to the measured outdoor air change rate. Planned air change rate, given as legend of series, was provided by the planning engineers or by the building management.

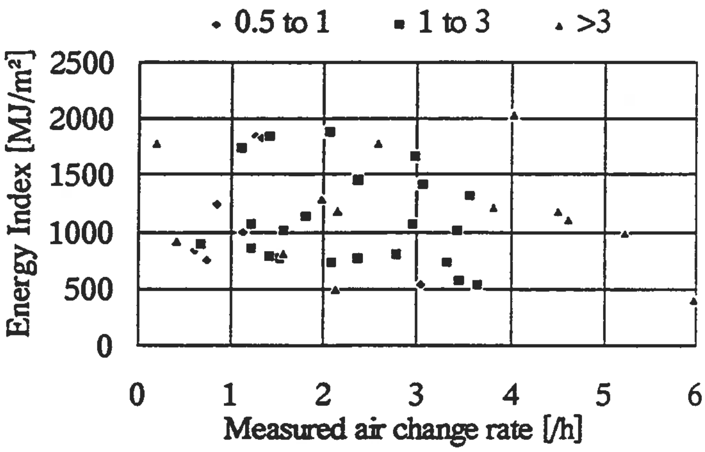


Figure 4.33 *Energy index related to air change rate in audited buildings. Legends in the figure indicate planned air change rates (volumes per hour).*

This lack of correlation has two reasons:

- Energy is used for many other purposes in buildings as well, and the amount required by air conditioning is usually much less than 50% of the total. On the other hand, there is a large dispersion in energy consumption, resulting from the wide variety of buildings and uses. The differences in energy consumption caused by ventilation seem therefore to get lost in the variations of energy consumption resulting from other causes.

- It is not necessary to use a lot of energy to ensure a good indoor climate and a good ventilation. First heating and cooling can be ensured by other means than air (e.g. water radiators, cold ceilings, cooling building structure, etc.). Second, a large part of the enthalpy contained in exhaust air can be recovered by convenient devices. Such heat exchangers are installed in a number of audited buildings.

It is also seen in Figure 4.33 that there was no relation between the air change rate and the planned airflow rate per person.

4.6.4 Energy and ventilation system

Table 4.11 shows several statistics of energy index for various groupings of buildings, according to their design air change rate, their ventilation system, the presence of cooling, and the type of heat recovery. As already seen, there was no relation between energy index and design air change rate. One more reason for lack of correlation is that design air change rate was not much related to real air change rate.

Table 4.11 *Statistics of energy index for various groupings related to ventilation system.*

			Energy index [MJ/m^2]			
		number	mean	st.dev.	max	min
Design air change rate [h^{-1}]	0.5 to 1	8	1183	499	1850	525
	1 to 3	22	1087	413	1872	526
	> 3	13	1172	486	2045	400
Ventilation system	natural	8	879	306	1267	372
	supply	3	1036	234	1220	772
	VAV	5	1340	412	1789	813
	dual duct	10	1046	522	1835	400
	induction	10	1375	579	2476	720
	other	16	1041	411	1872	525
Cooling	no	14	1007	360	1664	372
	yes	38	1168	498	2476	400
Heat recovery	none	17	1087	449	1872	400
	wheel	14	1047	400	1850	525
	plate	4	1239	355	1730	881
	other	11	1365	610	2476	536

Among the audited buildings, the eight buildings with natural ventilation, on the average, had the lowest energy index. In this group also the smallest energy consumer was found. However, two buildings of this group had an energy index larger than 1200 MJ/m^2.

The buildings with mechanical ventilation presented similar average energy consumption and included the largest consumers. In each group there were buildings with a relatively low energy index.

The presence of cooling or heat recovery did not seem to have a large influence on the average energy index, except that the largest consumers were also cooled buildings. Here again, there were low energy buildings in all groups. Note that "other" heat recovery systems was often recirculation.

4.6.5 Energy and perceived air quality

The aim of ventilation is to ensure a good indoor air quality. There is no particular reason to have a relation between energy consumption and perceived air quality. In fact, a good perceived indoor air quality can be achieved by first avoiding contaminant sources and second ensuring a minimum airflow rate to dilute pollution present. In paragraph 4.5 was shown that this minimum airflow rate was achieved in most buildings. As already said, the amount of energy required for ventilation can be very small if enthalpy recovery is applied.
It is therefore not surprising that Figure 4.34 does not show any relation. There were several buildings with a low energy index and an acceptable indoor air quality, and also buildings using a lot of energy and showing a poor indoor air quality.

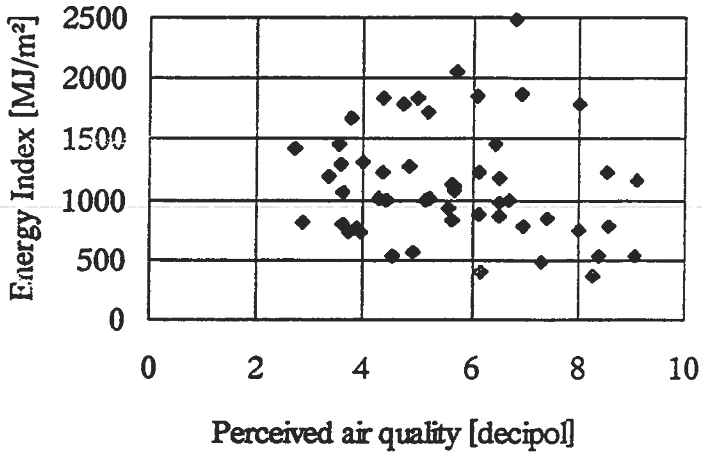


Figure 4.34 Energy index related to air quality as perceived by the sensory panel.

4.6.6 Energy and comfort

The main purpose of an office building is (or should be) to provide a comfortable working environment to occupants. This includes thermal comfort, acoustic comfort, an acceptable indoor air quality and proper lighting. Let us consider thermal comfort, which depends, among several other parameters, on air temperature. Air heating or cooling requires some energy and therefore a relation between temperature and energy use, might be present. Figure 4.35, however, does not show any correlation between air temperature, as averaged over the investigated rooms, and energy consumption. This absence of correlation has the same reasons as for air change rate: the small variation of energy consumption resulting from an increment in temperature (about 5% per K) is hidden by variations in energy use resulting from other causes. Moreover, the air temperature lies within a very small range: 64% of buildings had an indoor air temperature between 21.9 and 23.7 °C, and all of them ranged from 21 to 24.5 °C.

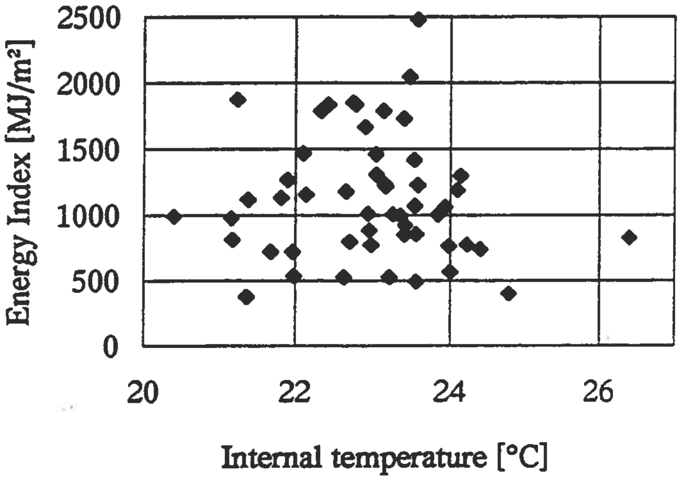


Figure 4.35 Energy index related to air temperature.

4.6.7 Energy and health

Basically, office buildings should be planned, built and managed to offer an environment in which workers feel well. It can be expected that people reporting sickness symptoms will have a lower productivity, or even may go back home. Since a lost working hour costs as much as about 1000 kWh (enough to heat between 2 and 7 m² of office space for one year), it seems natural that occupants well-being should be considered as more important than energy use in office buildings.

For this reason, managers are ready to spend a lot of money in equipment and energy to ensure a good indoor climate. Several audited buildings were indeed equipped with costly HVAC installations for that purpose. The results seemed however deceiving. Figure 4.36 shows that large energy consumption did not necessarily result in better health. The correlation was in fact 0.43 with a 95% probability to be between 0.05 and 0.70; there was a significant and positive correlation between the BSI and the energy index. On the average, the higher the energy consumption was, the larger were the number of building related symptoms.

The link between these two variables could be common causes such as:

- poor temperature control or a lack of control on climatic conditions is energy wasting and is not well accepted by occupants.
- air conditioning often uses a lot of energy and is often not well accepted by occupants.
- well-designed buildings should provide a very good indoor environment quality (hence a low BSI) together with a rational use of energy.

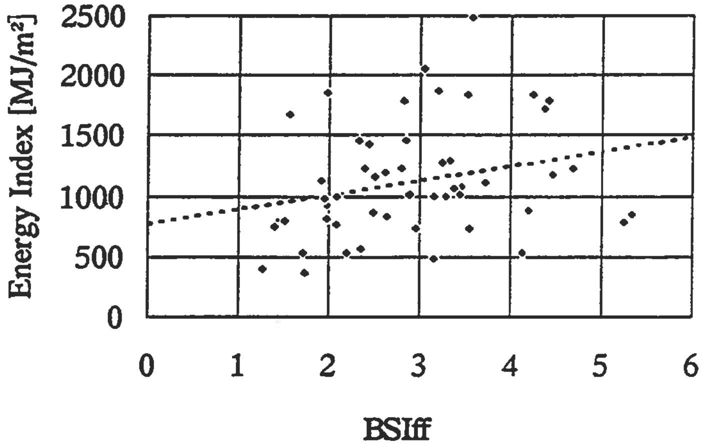


Figure 4.36 Energy index related to Building Symptom Index.

4.6.8 Extreme cases

The buildings with the lowest energy indices are listed in Table 4.12, while those with large indices are listed in Table 4.13. The factor 3 between average energy indices and the factor 3 between average energy use per person of these tables should be noticed.
Common to low energy buildings were the low specific power (except building F D) and the low energy use per person (except building CH D). Three of the eight natural ventilated buildings were in this category.
Ventilation systems included or did not include cooling and heat recovery. All ventilation systems except variable air volume (VAV) were represented in the low-energy building group.

Building D A hosted a public administration. There was a very small number of electrical devices, which were used only for short periods, within a short working time. The very low electric consumption could hence be attributed to occupants behaviour.
The low energy consumption of Greek buildings could be attributed to climate and maybe also to the fact that ventilation and cooling was used scarcely.
Building SF C, erected in 1898, was not specifically insulated but very massive. It was totally renovated in 1991. In buildings SF C and SF D, heating radiators were equipped with individual thermostats.
Building DK E was planned as a low energy, prestige building, with a relatively large budget.
Buildings NL B and NL C are very similar. Their energy consumption was considered as normal according to Dutch standards for buildings of the sixties. It would however be considered as "low" or "good practice" by UK standards.
Building F D was a relatively recent building with exhaust mechanical ventilation and self-controlled air inlets, with a radiator heating. Heat from computers was recovered by the heating system. This explains the very low fuel index.
Building N D was a high standard office building, recently renovated (1990) and adapted to modern standards.
Building CH D was planned by an energy conscious building owner and HVAC engineer. The building was only half occupied (economic crisis), therefore the indices per person were high.

Table 4.12 *Buildings with the lowest energy consumption (total energy index below 800 MJ/m²).*

Building	Built in	Energy indices [MJ/m²]			Energy/person [GJ/person]		Spec.power [W/(m².K)]	Ventilation system	Cooling	Heat recovery
		Total	Electr.	Fuel	Total	Electr.				
D A	1955	372	75	297	14	3	1.2	natural	no	none
GR D	1989	400	191	209	8	4	.	dual ducts	yes	none
GR E	1972	488	170	318	10	4	.	dual ducts	yes	none
SF D	1989	525	213	312	25	10	1.6	balanced	yes	yes
GR C	1991	526	253	272	13	6	.	dual ducts	yes	none
SF C	1898	536	117	419	10	2	1.6	balanced	no	yes
DK E	1989	563	228	334	14	6	2.5	balanced	no	yes
NL B	1965	696	273	422	17	7	2.8	induction	yes	yes
NL C	1967	668	262	406	17	7	3.0	induction	yes	none
F D	1985	740	673	67	9	8	3.4	natural	no	none
N D	1934	764	465	299	20	12	2.4	balanced	yes	yes
CH D	1991	771	417	353	41	22	2.5	natural	yes	yes
GR A	1988	772	458	313	23	14	.	supply	yes	none
mean	1970	602	292	309	17	8	2.5			

Table 4.13 *Buildings with the highest energy consumption (total energy index > 1600 MJ/m²).*

Building	Built in	Energy indices [MJ/m²]			Energy/person [GJ/person]		Spec.power [W/(m².K)]	Ventilation system	Cooling	Heat recovery
		Total	Electr.	Fuel	Total	Electr.				
NL E	1968	1665	495	1169	62	18	7.0	induction	no	none
UK A	1988	1730	643	1086	25	9	10.1	VAV	yes	yes
CH C	1990	1789	984	805	57	32	5.7	VAV	yes	yes
CH A	1972	1789	623	1166	55	19	5.7	dual ducts	yes	none
UK E	1975	1835	1703	132	24	22	8.8	dual ducts	yes	yes
UK C	1990	1837	966	871	18	10	8.8	induction	yes	yes
SF F	1987	1850	1643	206	97	86	10.8	balanced	yes	yes
D B	1977	1872	1296	576	37	26	6.5	balanced	yes	none
D E	1976	2045	.	.	81	.	7.1	induction	yes	yes
F B	1984	2476	626	1850	38	10	12.6	induction	yes	yes
mean	1981	1889	998	873	49	26	8.3			

On the higher side, the following comments can be given:
As expected, these buildings presented a high specific power and a large consumption per person. All ventilation systems except natural ventilation and exhaust only were represented. Except one, all these buildings were also cooled, but most of them were equipped with some heat recovery system.
Building NL E was characterised by a large fuel index. It was the highest energy consumer among the Dutch buildings.
As said above (paragraph 4.6.2), UK A, C, and E were fairly typical for the UK air conditioned office buildings.
CH A presented a very high requirement for heating. This old building was not tight and a complete retrofit is planned. CH C was, at the contrary, brand new. Its high electricity use did

not come from heating, but from a high demand for cooling (closed building without shading) and for office machines and computers.
High values for SF F, D B and E were not explained. Building F B was a highly glazed building, without solar protection. The operational control of the HVAC system was not optimal and the energy index for cooling was included in the energy index.

4.6.9 Conclusions

The following conclusions related to energy can be deduced for this survey:

- Energy consumption varied strongly from building to building. In practice, it depended more on planning, construction, and management than on climate, building type or HVAC systems.

- It is hence possible to make low-energy buildings with different architectures and various HVAC systems.

- If planning, construction, and management are performed by energy conscious persons, the result will be a low energy consumption together with a good indoor environment quality. Several examples were found throughout this survey.

- On the contrary, one single weak step (e.g. poor management or poor planning) may destroy the qualities of a building or the effects of a conscious management.

- If permissive energy regulation leads to high energy consumption (see buildings in UK), strong rules not necessarily result in low-energy buildings (see building CH C).

There are then some arguments showing that healthy buildings do not require necessarily a lot of energy. Smart managers, architects and engineers make and operate buildings in a way that both good indoor environment and low energy consumption can be achieved. At the contrary, some expensive ways aiming to improve indoor environment seem to be counter productive. Even when requirements on physical parameters (temperature, airflow rates, etc.) are met, occupants do not feel well.

4.7 Comparison IAQ-parameters

In this paragraph some of the measured IAQ parameters are compared. The chapter comprises comparisons of:

- Sensory and chemical measurements
- Sensory and ventilation measurements
- Sensory and particulate matter
- Humidity and occupants' perception
- Thermal and acoustic measurements versus the occupants' perceptions

Comparisons within the questionnaire are given in paragraph 3.1. Comparisons of sensory measurements and the occupants' responses are given in paragraph 4.2. Ventilation and energy consumptions are analyzed in paragraphs 4.5 and 4.6.

All relations presented with a regression line are statistically significant at a 5% significance level.

4.7.1 Sensory and chemical measurements

It is interesting to determine whether the sensory measurements and the chemical measurements correlate, although in paragraph 4.3 it was shown that sensory and chemical pollution loads did not. In Figure 4.37 the mean perceived air quality (decipol) for the offices is given versus the mean TVOC ($\mu g/m^3$ toluene) concentration measured by Tenax-GC for the offices in the 56 buildings. The analysis showed no correlation between the mean perceived air quality and mean TVOC concentration. Also, the two IAQ-parameters did not correlate if the outdoor level was subtracted. This result is the same as the non-correlation between the total sensory and total chemical pollution loads, since it is the same ventilation rate that is multiplied by the concentration difference in the two mass balances (paragraph 4.3). That the two IAQ parameters did not correlate can partly be explained by the fact that not all organic compounds are odorous or irritating. Which TVOC were actually measured is also an unsolved question (paragraph 2.3.3).

In paragraph 3.2 it was shown that the perceived air quality in the offices was independent of the perceived air quality outdoor and in the ventilation supply air. However, the TVOC concentration in the office seemed to be dependent on the TVOC concentration outside, a relation which is illustrated in Figure 4.38. The relation is based on the mean values for each building.

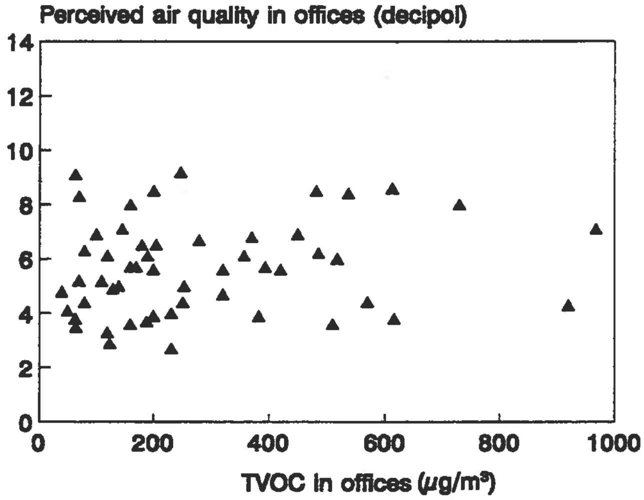


Figure 4.37 *The mean perceived air quality in investigated rooms per building versus the mean TVOC (Tenax-GC) concentration in the rooms per building.*

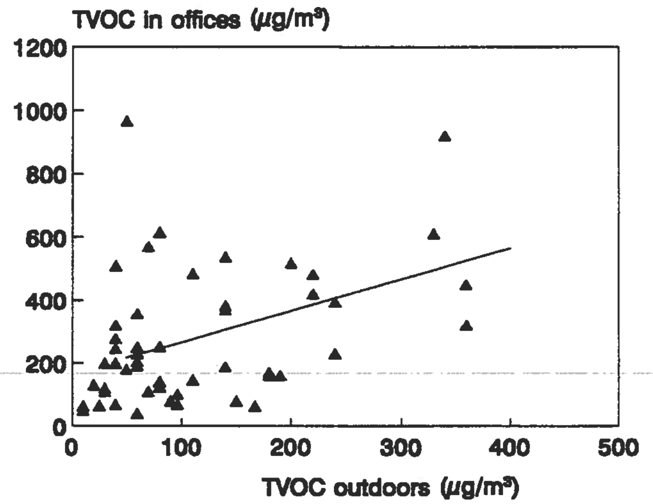


Figure 4.38 *Mean TVOC concentration in investigated rooms per building versus TVOC concentration outdoor per building.*

4.7.2 Sensory and ventilation measurements

One of the most important relations that was analyzed within this project is the relation between the perceived air quality and ventilation rates. Standards are based on the hypothesis that a higher ventilation rate results in better perceived air quality because of the dilution of pollutants. In this study was found that the perceived air quality was better in the buildings that had a high ventilation rate, a relation that is shown in Figure 4.39. The negative correlation between perceived air quality and airflow rate was statistically significant at a 5% level.

In the analysis of sensory versus ventilation measurements it is important to remember the limitations of this study. It is difficult to compare the 56 audited building, because not the same sources were present in the buildings as well as in the ventilation systems. A low airflow may be sufficient in one building and not in another building depending on the sources. In this comparison the quality of the supplied air was also not taken into consideration. If the outdoor air quality is poor, more air is needed to dilute than if the outdoor air is good. Furthermore, pollution sources present in the ventilation system make a comparison difficult or even not valid. In Figure 4.39 the mean perceived air quality for room air in a building is shown versus the mean outdoor airflow supplied to the investigated rooms for 52 buildings. To establish a dose-response relation between outdoor air supply and perceived air quality it is necessary to study the same source, however the relation shown in Figure 4.39 does point in the direction that a higher ventilation rate results in a better perceived air quality. Leaving the buildings with recirculation out of the analysis gave an even stronger correlation between outdoor air supply and perceived air quality.

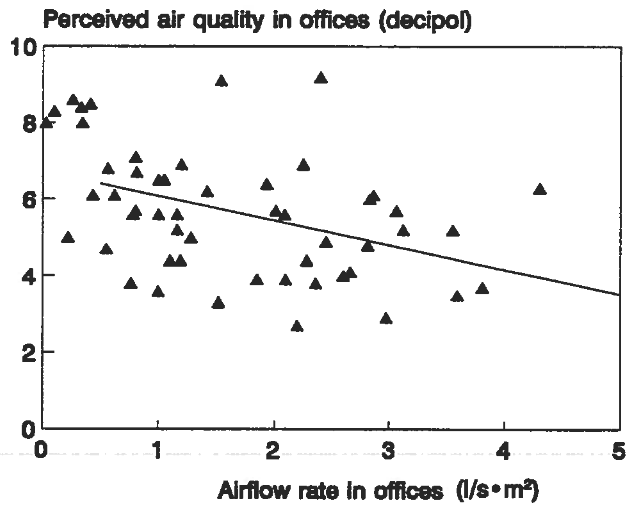


Figure 4.39 *Mean perceived air quality in investigated rooms per building versus the mean outdoor air supply for the investigated rooms per building.*

In paragraph 4.5 the ventilation performance was discussed. The problem with estimating the amount of outdoor airflow was addressed. It is well known that the CO_2 difference between indoor and outdoor can be used to estimate the outdoor air supply, hence the relation between CO_2 difference and perceived air quality in the offices was analyzed. A significant correlation between CO_2 difference and perceived air quality was found, a relation that is illustrated in Figure 4.40. As mentioned above this relation can not be seen as a dose-response reaction because different sources are being compared. A recent study by Knudsen (42) has shown that different materials have different dose-response relations and it is obvious that there were different materials in the audited buildings. Still the tendency of more outdoor air gives a better perceived air quality is present, as presented in Figures 4.39 and 4.40.

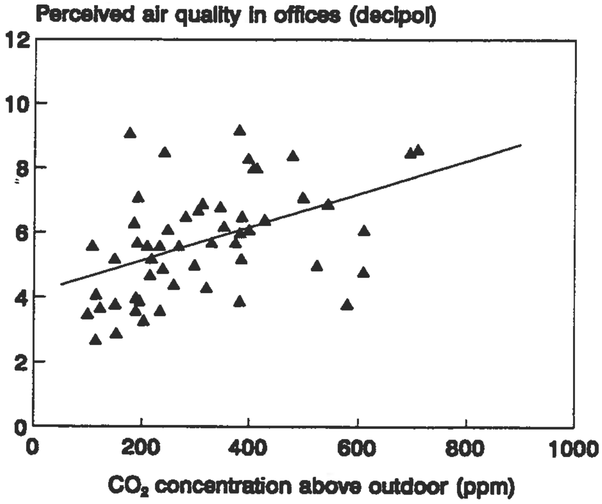


Figure 4.40 *Mean perceived air quality in investigated rooms per building versus CO_2 difference between indoor and outdoor per building.*

4.7.3 Sensory and particulate matter

Another IAQ parameter in the Audit Protocol was the respirable particulate matter concentration in the indoor air. The sensory panels perceived the annoyance of the indoor air, which includes particulate matter. However, in the audited building the concentration of particulate matter was very low, for most buildings below 100 $\mu g/m^3$, and the analysis did not show any correlation between the perceived air quality in the office and the measured particulate matter.

4.7.4 Humidity and occupants' perception

Several studies have shown that the occupants' perception of the dryness of the indoor air is more related to the indoor air pollution than the humidity of the air itself. In paragraph 3.1 it was shown that the air was perceived as being dry by the occupants. The dryness rating correlated to other perceptions of the indoor air quality and building related health symptoms. However, a statistical analysis showed that the dryness rating by the occupant also correlated with the measured relative humidity of the indoor air. Figure 4.41 shows the occupant dryness rating as a response of the measured humidity. The figure also shows that even if the relation is statistically significant, the dryness rating covered a very small range (2.0 to 3.5) while the relative humidity varied from 10% to 50%.

All buildings, except 3, had a relative humidity less than 50% and half of the rooms had a relative humidity less than 30% (Figure 4.42). However, some water vapour is added to the atmosphere of most buildings. This humidity is partly generated by occupants, but also in some cases, added by the air conditioning system. The distribution in Figure 4.43 shows two populations, which were very likely buildings without (low humidity) and with a humidification system. The first peak shows an average water vapour difference of 100 Pa, corresponding to 0.8 g/kg dry air added water, and the second peak is at 300 Pa,

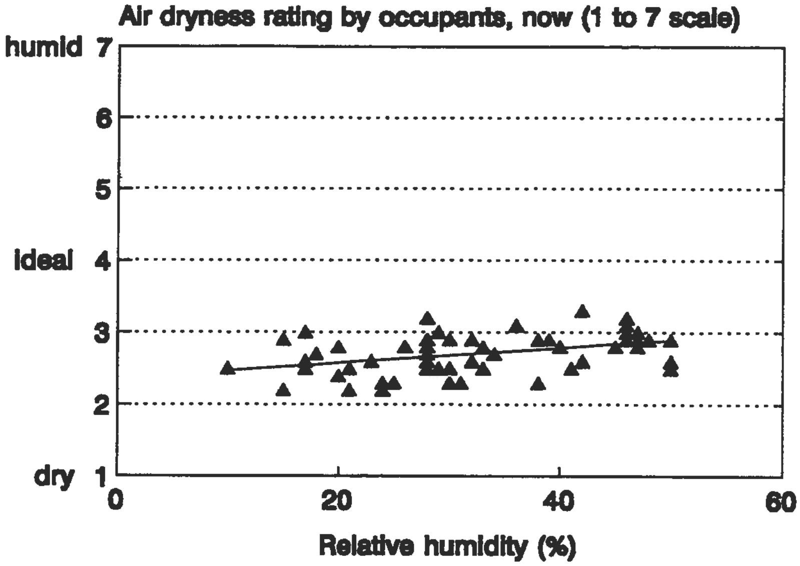


Figure 4.41 *Occupants' dryness rating as a function of the measured relative humidity.*

corresponding to 2 g/kg dry air added water. Note that one sitting occupant evaporates approximately 60 water g/hour. When ventilated with 10 l/s, this person adds 1.4 g water per kg dry air or circa 200 Pa water vapour pressure.

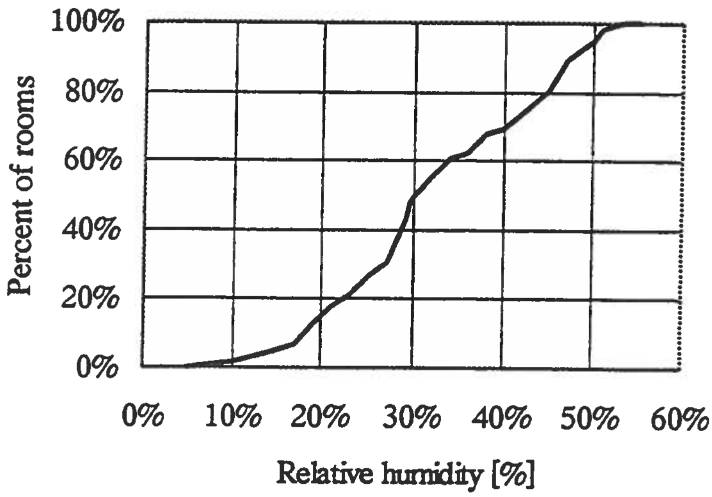


Figure 4.42 *Cumulated frequency distribution of relative humidity in indoor air.*

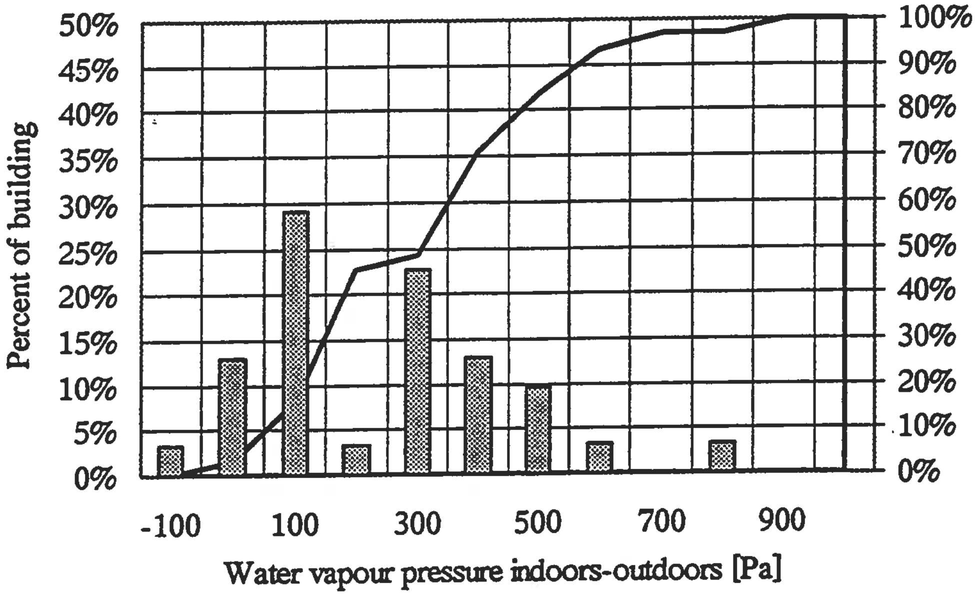


Figure 4.43 *Distributions of water vapour pressure difference between indoor and outdoor air in audited buildings.*

4.7.5 Thermal and acoustic measurements versus occupants' perceptions

The occupants' perception of the thermal and acoustic environment was generally rated at an acceptable level. The office temperatures measured in the 56 office buildings were also within an acceptable range, however, slightly on the warm side. As illustrated in Figure 4.44 the mean thermal comfort vote correlated with the measured room temperature.

The acoustic environment was generally rated acceptable. The occupants' rating of noise satisfaction was statistically significant correlated at a 5% level with the measured noise level. The correlation between occupants' noise satisfaction and noise level is given in Figure 4.45.

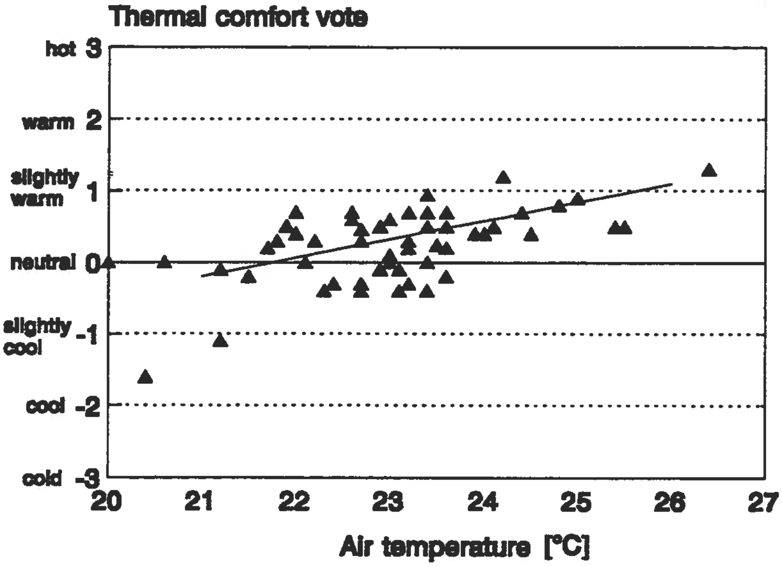


Figure 4.44 *Occupants' thermal comfort rating versus the measured room temperature.*

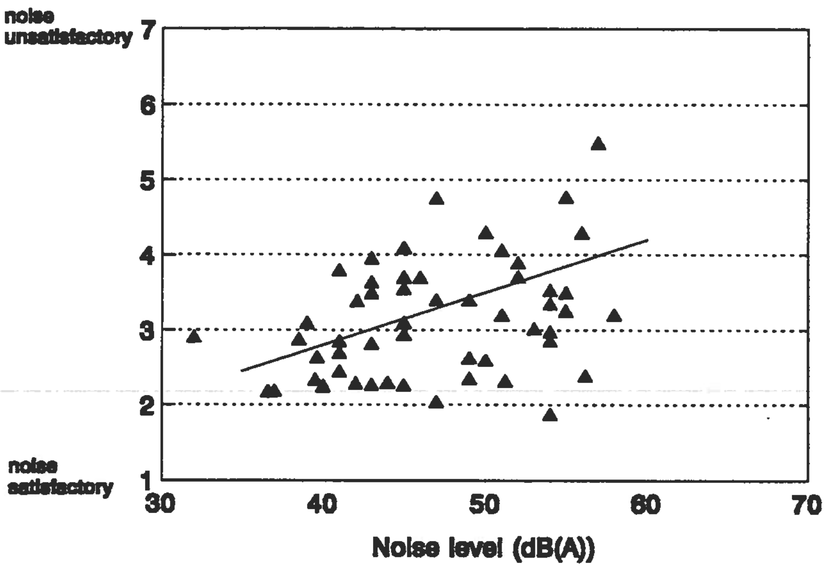


Figure 4.45 *Occupants noise satisfaction rating versus measured noise level.*

5. DISCUSSION IAQ-AUDIT PROCEDURE

This chapter discusses the procedures, methods and instruments used in the auditing of the 56 European buildings. The comments, adjustments and/or addings to the recommendations given in the manual (12) are a sum up and sometimes a compromise of all the participants involved.

5.1 General

Selection of buildings
Selection of buildings was difficult. Criteria such as representativity of National building stock with respect to age and type of construction, and good outdoor air quality were difficult to fulfil. The anonymity of occupants and the fear of the management of starting a riot caused by questionnaires, was another reason for selection difficulties.

Representativity of the audited buildings can particularly be challenged, as specific criteria were placed in their selection (more than 2 years in operation, size large enough to accommodate 150+ workers, etc..). Still, as no other region wide consistent auditing procedure has been used up to now, it must be considered that these buildings are just as good as a baseline as any other choice.

In selection of locations to be measured it was important to find locations representative for the buildings. However, the locations could not be too far apart physically regarding the sensory evaluations. In a building with a lot of floors only a few could therefore be investigated. Five locations may however not be enough to get representative data for a building with 100 or more offices.

Weather conditions
Locations outdoor air measurements should be well selected.

Information from the weather stations can give enough information on the outdoor conditions on the audit days, if this station is nearby. Buildings with computer-controlled ventilation often have their own weather station, which could of course be used, but attention should be given to the location of the sensors.

Procedure
Systematic observation of such conditions as room occupancy, fluctuations in nearby traffic, changing weather, etc.. may greatly facilitate critical evaluation of the collected data. It may be challenged, however, that using video-cameras will generally be welcome or even legally acceptable. The cost effectiveness of working-up such records may also be questioned, except perhaps in particular systems where operation specific sources or sinks are activated.

Measurement of one day per building is perhaps not sufficient to give a good indication of the pollution present. For financial reasons the audit procedure could only be executed for one day per building. Repetition could give more valid data.

The procedure described in the manual (12) was intended among others to assess information on existing office buildings for research purposes.

The manual was written for use in this project. For the moment the manual is planned to be used only as an catalogue for measurement procedures, not as a procedure to be used to investigate problem buildings. Questionnaire and checklist could be used as indicators for problems.

5.2 Checklist

The checklist applied to register characteristics of building, ventilation system and selected locations, was premade. The collected information was among others used for identification of pollution sources.

After the audit several data seemed to be missing in the checklist. Furthermore, a general comments was made that the checklist contains information that was not used for the interpretation in this project and that consequently be omitted.

Information on the power of the installed fans, lighting equipment and eventually other equipment, could be of use when evaluating the energy consumption of the building. Furthermore, the building surface area in relation to the volume, the heated floor area and conditioned volume, the insulation of the facade, floor and roof (U-values), the percentage and total solar energy transmittance (g-values) of glazing applied, internal heat load and orientation, could provide information when calculating the energy consumption.

The total floor area instead of area per floor, the total volume, the total supply airflow rate, the number of HVAC's present, policy of maintenance and the presence of a control system, could be included.

More details on the location investigated would be helpful, such as smoking or non-smoking activities of the occupants in the room, a subjective evaluation of the location, etc..

The technical staff sometimes gave wrong information, not on purpose, but because they did not have enough knowledge or were not accurate in reading. A personal inspection was therefore carried out by most participants.

The checklist was used only once before the audit. Also on the audit day itself, the checklist should be filled in, so at least two spot registrations are made.

A revised version of the checklist incorporating most of the above comments can be found in Appendix J.

5.3 Questionnaire

Comments and possible or recommended adjustments of the questionnaire used in this project are given. A revised version of the questionnaire was however not made. First, because this questionnaire was used for this study only, another study would probably require another kind of questionnaire, Second; because not on each item discussed, an agreement could be made on the recommendation for adjustments.

<u>General points</u>

Although a good response rate was generally obtained with the questionnaire, it was considered to be too long and, in parts, to require too much time (more then 10 minutes) and thought. It is suggested to shorten the questionnaire in the following ways.

- Take out one of the time periods (past month or now), which gave well-correlated results anyway (see paragraph 3.1). An alternative suggestion is to have two samples per building, one responding on the 'past month' part of the questionnaire and the other on the 'now' part of the questionnaire. No decision was made which of suggestions should be followed.
- Use a tabular form rather than a series of separate questions on the symptom data. Research has shown, however, that this gives more missing data and less variance within subjects and does not necessarily take less time, except for the time saved by data losses (43).
- Specific deletions as detailed further on.

It was noticed that the word "month" is ambiguous, since it could mean 20 or 25 working days, 28 or 31 days or 4 or 5 weeks. This is relatively easily dealt with by substituting the words "the past 4 weeks" for example. Symptoms of the past month should then maybe refer to as times per week instead of times per month.

It needs to be made clear throughout the questionnaire that the appropriate box is to be ticked and also to emphasize where only one box is to be ticked. There were several cases of people crossing through the inappropriate box and or ticking more than one box.

The development and use of the questionnaire can provide ideas about how to improve this questionnaire in particular and questionnaires in general. In particular the multiple translation of the questionnaire will be useful in further research and considerations of standardisation within Europe.

<u>Proposals for changes</u>

Cover page: The cover page should indicate how and when the questionnaire will be collected to avoid confusion on the part of the respondents. The statement about the time required to complete the questionnaire should be changed from 10 to perhaps 15 minutes unless the questionnaire itself is shortened. Some kind of stronger or verbal instruction is needed not conferring with colleagues about the questionnaire.

Time of day: It is suggested that the time of day be taken out since question A1 deals better with the amount of time the person has been in the office. However, the time of day gives additional information in two ways. First, it serves to confirm how close in time the questionnaire was completed to the sensory panel judgements, and second, it will permit the investigator to take account of the time of day the questionnaire was completed. Time of day has been shown in past studies to affect reporting of symptoms (44,45).

Location: The part of the questionnaire which asks about the occupant's location needs to be adapted to the way in which people in any particular building would describe their location, for example a room number, a floor number or a department. The best description will vary from building to building, as noted in the manual (12).

A2: There were some cases of more than one box being ticked for this question and the instruction to tick only one box therefore needs to be strengthened. For example it might say "you may feel that you do more than one type of work, but please indicate which is the biggest or most important part of your job".

A3 and A4: It has been suggested that the instruction "months not needed if more than 2 years" could be removed so that months data would be collected from everyone. One reason for suggesting this was that not having months for some people distorted the calculation of the average. This is important only if it is important to have a precise average. The other reason for the suggestion was that it complicated the instruction too much and it would be easier just to leave it out. Against this it has to be considered that if someone has been in a building for some time they will need to think too much how many months they had been there.
The recommendation is to leave this question as it is.

A5-A8: It needs to be clarified that the instruction "during the past month" refers to all four of these questions, in particular to question A8.

A8: The phrase "come to this building" was not universally understood to and needs to be changed to "work in this building".

A9: This question needs to be changed to include the respondent. It also needs to be clarified that the question refers to the whole room, even if it is a large open plan space.

A10-A12: These questions were found difficult by people in open plan offices; they might be some distance from a window and have no control over it. This could be overcome by expanding the questions in a way that has been done in the past. For example, a series of questions such as "how far is the nearest window?" and "do you have sight of a window?" could be asked. These questions would obviously cause the questionnaire to be longer and these factors are probably not sufficiently central to merit this. A clarification of the wording is therefore recommended. In one country the question was taken to refer only to openable windows and this also needs to be clarified.

A12: This may need to be changed to "Is a window ever open in your room?" to reflect the fact that someone else may open the window.

B1-B12: There were some illogical responses in this part of the questionnaire, with people saying that they did not report a symptom but then going on to say that it was better on days away from the office. It is hard to understand why this should happen but in any case such responses should be taken as meaning that the symptom was not reported.

B13-B14: Some cases of more than one box being ticked and of people not noticing that these questions should only be answered about building related symptoms. The instruction therefore needs to be strengthened.

C1: The term "thermal comfort" might be considered as jargon and perhaps the question needs to be re-phrased. The suggested wording is "How hot or cold did you normally feel in this office during the past month?".

C2: A number of comments were made about the use of a 10 point unnumbered scale. Some people thought that it should be a 7 point scale, the same as the other environmental ratings, and that it should perhaps go from -3 to +3 with 0 as just acceptable. Numbers would perhaps make the rating easier for the respondents and easier for the analysis since we could then be assured that every country had coded the boxes in the same direction.
One country also suggested that the scale should have wording on. Adding words, for example from awful to excellent, would make the scale unlike most of the others, it would take up more space on the questionnaire and it is doubtful that it would add substantially to the ease of completion or the validity of the questionnaire. Adding wording in this way also decreases the validity of the assumption interval level data. This would limit the analysis that could be carried out on the scale.
There was a feeling that the respondents would perhaps understand the scale as merely referring to overall indoor air quality, rather than to the acceptability of the air quality (if there is in fact a difference between these two concepts). It might therefore be better to phrase the question as a rating of air quality and thus make it more like the other ratings.
The adoption of any of these suggestions might depend partly on how important it is to be able to compare ratings on this scale with ratings already obtained on a line of acceptability. If this is not important than a 7-point horizontal sematic differential scale should be used, as for the other ratings, retaining the current end point labels. If the current scale is retained, then numbering the boxes would help.

Cl and C3: Some contradictory suggestions were made from different countries about how to modify these scales. One suggestion was to remove the bold from the optimum point, since this restrict the respondent's use of the scale. Another suggestion was to align the scales with the bold boxes one above each other and change them so that the optimum point was always 0. This would require some of the scales to be labelled 0-6 and others from -3 to +3.
It is perhaps unnecessary to emphasise the ideal point in three separate ways on one questionnaire (by using bold boxes, by using 0 for the optimum point and by aligning the optimum points). The use of bold boxes ought to be enough and even this is probably unnecessary. It is therefore recommended to leave these scales unchanged.

Another suggestion was to revert to a two-point scale (acceptable versus not acceptable) to simplify the questionnaire. There are two points to be made here. First, this would not necessarily be simpler for the respondents since they would have to convert a continuous range of feelings into a binary response. Second, the data recorded (especially in buildings with fewer people) would be less precise and less amenable to statistical analysis. This change is therefore not recommended.

There were again cases of more than one box being ticked on these scales, so the instruction to tick only one box needs to be emphasised.

One suggestion was to rate noise as annoyance rather than satisfaction, but this is unlikely to cause a significant change in the ratings. Satisfaction is a less emotive term, which will encourage use of a wider range on the scale. However, the evidence from field studies is that the wording used on noise questionnaires has very little effect on mean ratings from populations (46). No change in wording is recommended.

A box should be added at the bottom of this page for free comments on the environment.

D: There was again some illogical responding with people indicating they did not have a symptom, but then saying than it was worse than when they came to the office, or giving severity rating for the symptom.

E: In addition to the comments made on part C, the suggestion was made to change the question about overall satisfaction with light and with noise, to include the words light and noise in case people had forgotten that this is what the question is refereed to. This seems to be a sensible precaution for any investigators retaining this section in a separate questionnaire.

F1-F3: The query was made whether these scales include the effect of "window airing". The scales are certainly intended to include and control that people exert through the use of windows. If it needs to be clarified in any country, then this should of course be done. The suggestion was again made to use a scale from 0-6, but it was not stated why this should bring any advantage.

F4: The suggestion was made to use a scale from +3 to -3 with wording attached to the boxes, but the comments made at C2 would apply here also.

G2: It should be clarified whether this includes any eczema.

G4: This was unclear for some people and they did not interpret the arrows to indicate an "if" statement. The arrows therefore need to be replaced with explicit "if questions", for example "if yes, do you smoke in this room?".

Suggested additional questions

The number of VDU's (Visual Display Unit) in an office could be determined by the questionnaire, if this is not being covered by observations made by the researchers. Similarly the floor numbers and compass orientation could be included, if this is not otherwise indicated by the location statement.

One country suggested that the question on happiness at work, which was taken out in the design off the questionnaire, should be put back in. It is not clear what would be learned from this, except that people with fewer symptoms and a better view of the air quality are more likely to report happiness at work. The questionnaire would give no indication of whether happiness causes health or health causes happiness. Furthermore, the main reason that it was taken out was that it was felt that such questions might be unacceptable to the management of buildings, and therefore would make it more difficult to carry out the survey. It is not recommended to introduce this question.

It was pointed out that if the questions on thermal comfort are to be interpreted, questions on the clothing worn should also be included. This is of course correct if the individual comfort in relation to temperature is to be evaluated. The questions on thermal comfort can only be used to give an indication of whether there are such problems. No change is recommended.

Suggestions were made to add a question about itchy or red eyes to the symptom list. This would almost certainly change the reporting of dry eyes and watering eyes and would also lead to the danger of multiple reporting of the same symptom. For example the same symptom could be reported as both itchy eyes and dry eyes. The addition is not recommended.

It was thought that ergonomic complaints, such as back pain, should be included. These are of course legitimate questions about the state of health of people in buildings, but are not most relevant to an air quality study. The question about other symptoms ought to be adequate to cover these if they are important to individual people in the office.

There was a request of having more questions on lighting and noise. It is certainly true that adverse noise and lighting conditions can contribute to complaints in buildings and that is why there are questions to evaluate people's overall response to noise and lighting. However, it is not the purpose of this project to analyze in detail the reasons why people complain about noise and lighting.

Back-translation
The back-translations and commenting on that by BRE resulted in a list of errors, which were categorised in mistranslations, missing or added words, questions or instructions, small variations in expression, and difficulties in achieving a good translation. A detailed overview was given in paragraph 2.3.3.

Field procedure
It takes a long time to distribute and collect 200 questionnaires with 2 persons. It requires about 3-4 hours. More than 2 persons are required.

It is difficult to predict whether enough persons are present at the day of experiments. It is therefore advised to distribute 200 instead of 125 questionnaires, to reach at least 100 filled in questionnaires.

Analysis
There has been some discrepancy in the correction procedure applied to take account of gender and job type differences. At least one country has carried out a procedure different from that prescribed in the manual (12), using 'female clerical' as the baseline rather than 'male manager'. On reflection, the procedure used by this country is probably better than that in the manual, but it is too late to correct everybody's data. The initial analysis has shown that there is an approximately constant difference between the corrected and uncorrected BSI values, and little effect of job type overall; it was therefore decided that there is no point in pursuing analysis with corrected data at this stage.

The initial analysis has been done on the simplest possible basis of counting a symptom as occurring if it occurs at all. The calculation of PSI could take into account the frequency of symptoms (in case of monthly reports) and the severity of symptoms (in case of the 'now' reports). There are however some problems with applying weighting. The first is that, since not everybody completed the frequency and severity reports, there would be more missing data if the weighting were to be applied. In the particular case of the frequency of symptoms, this would need to be corrected for the number of days the person has spent in the office and this information is not completely reliable owing to misunderstandings in Section A of the questionnaire. The more detailed analysis should be pursued as a follow-up study.

The data in questions A1-A8 should at some point be used in the analysis, otherwise it was not necessary to collect such data: where possible, these factors should be used as correlates or confounding factors in the analysis.

Some analysis might be made using only the most sensitive occupants, if some way can be found of defining the most sensitive occupants, but it needs to be considered more widely among the participants whether this is a priority for the initial analysis. There are insufficient funds to conduct every possible analysis as part of the current contract and we should seek further funds for a more extensive analysis.

5.4 Sensory evaluation

General

Most countries involved executed this method for the first time. Anything done for the first time brings complications with it. If this method was to be used a second time, the equipment required is available and one knows now how to use it, the training will be a lot easier, etc.. Furthermore, any experiment which involves people takes more time. People can not be just treated as an instrument. Since at the moment no other instrument than the human nose is available to evaluate the perceived air quality, we had no other choice.

Another method is the use of an untrained panel. An untrained panel requires however at least 50 persons to reach the same accuracy as a trained panel of 12-15 persons (40). The field procedure would therefore be a lot more complicated.

Comparison of the performance of trained and untrained panels is not simple since the primary voting scales are different. Based on the deviations on the votes of an representative untrained panel (40), the exam-requirements of a trained panel (12) and based on the assumption of normal distribution, Table 5.1 presents the number of untrained panel members required to match a trained panel of 12 persons.

The required number of untrained panel members is calculated from the following equation:

$$\text{required no. of untrained} = (\text{expected std.dev./required std.err.})^2$$

Table 5.1 *Corresponding votes of perceived air quality (decipol) and acceptability together with required standard errors on votes and calculated required number of untrained panel members.*

Perceived air quality [decipol]	Approved std. error for panel of 12 trained persons	Acceptability	Required std. error	Expected st.dev.	Required no. of untrained persons
2	0.82	0.30	0.106	0.55	27
5	1.15	0.06	0.073	0.60	68
10	1.44	-0.14	0.051	0.55	116
15	1.70	-0.30	0.055	0.50	82
20	1.93	-0.45	0.063	0.45	51

If the air quality in the buildings to be considered is equally distributed from 0 to 8 decipol, an average of approximately 50 untrained panel members is required to match 12 trained panel members who have passed the two exams (12).

Electronic noses is a potential future substitute that also deserves some attention.

Reference gas

2-propanone is not typical of smells found in an office, and can therefore be a limiting factor in training people to assess building air. 2-propanone as a reference gas and a training method is not enough. Future panel training should preferably be based on a mix of pollution sources, f.e. pollution sources which can be encountered in the field, or a mix of gases. Alternative gases are currently being studied.

The 2-propanone gas can be generated in the decipolmeter by means of passive evaporation. By placing one or more 30-ml glass bottles filled with 10 ml 2-propanone and making different holes in the caps of these bottles, different 2-propanone concentrations can be established. The 2-propanone concentrations can be measured by a B&K multi-gas Monitor type 1302 calibrated with a 50 ppm 2-propanone gas.
Some countries did not follow these instructions. One country (UK) mounted the fan of the decipolmeter in the input side of the jar instead of in the output side (cone side), because they were afraid of the risk of explosion. Another country (D) used 100-ml bottles for the 2-propanone instead of 30 ml-bottles.

The steady-state concentration of 2-propanone in the top of the diffuser, depends on the level of the liquid in the small bottles (which is standardized at 10 ml), the location of the small bottles in the jar of the decipolmeter, the ambient temperature and the variation of this temperature (standardized at 22°C), and the size of the holes in the caps of the small bottles through which the 2-propanone diffuses.
The time it takes to reach a steady-state concentration depends on several factors, e.g. the time and temperature of 2-propanone before it is put in the small bottles, movement of bottles before they are placed in the jar, the transportation of the bottles and the time before the over-caps are removed from the bottles. The following strategy is therefore recommended. Fill the bottles at least one hour before the test with 2-propanone (that has been conditioned at 22°C the day before), place the bottles at the correct position in the jar and leave the over-caps off. It will then require at least 10 minutes before the test to reach a steady-state condition (with fan on, 6 Volt required).
Some countries complained about the sensitivity of the steady-state concentration to environmental conditions, such as temperature, and concluded that this required constant calibration. A training room in which these environmental conditions can be kept rather constant would however help to prevent this.

Training room

Setting up a training room according to the recommended criteria in the manual seemed to cause some difficulties. Not every country followed these criteria, some used normal offices, some empty rooms, and others used climate chambers. The background level of these training rooms could therefore vary from country to country, which makes the comparability of panels complicated.

In the training procedure it is assumed that the background level of the training room is below 1 decipol. The refreshment of the senses between evaluations is therefore assumed to be taken place automatically in the training room. For the countries with a background level higher than 1 decipol, the refreshment of the senses could have been missed.

Selection

The selection was based on the absolute total error of a person. The question was risen whether this selection should not be similar to exam 1, since one large mistake could mean not selected.

Panel members were selected regardless of whether they smoked. It was suggested to select the number of smokers in the panel equivalent to the percentage of smokers in the working environment, since one believes that smokers are evaluating the air different than non-smokers.

The question was raised whether the age criterion of 18-30 years was a valid criterion. In the UK, a 51-year old panel member was selected and appeared to be the second best, and remained to be one of the best throughout the training.

Training

The 20 decipol milestone was considered to be too high. In most buildings the perceived air quality was below 10 decipol, which indicates that the lower decipol values are of more importance. It was suggested to have an extra milestone below 10 decipol and to lower the highest milestone to for example 15 decipol.

The training was executed in groups. These groups varied from three to 8 persons. From earlier studies it was found that training in groups with more than four persons can influence the concentration of the panel members, since the waiting time between different evaluations will increase with more panel members (39). Less then three persons will shorten the waiting time too much, which influences the time necessary to refresh ones senses.

Performance

In this project the performance of a trained panel was described with exam 1 and exam 2 as given in the manual (12).

The training level can be determined by using the given votes compared to correct votes for the 2-propanone levels and by using the repeated votes and/or the standard deviation on the panel vote for the unknown sources. Some methods are available to calculate an index, which present the performance. The disadvantage of all these methods is the dependency on the chosen perceived air quality level and the number of unknown (2-propanone) sources.
A comparison of different calibration tests and panels can only be made if the chosen levels are comparable. So there is a strong need for a new method which is:

- independent of number of samples
- independent of chosen perceived air quality levels
- the result (value) has to be a relative or absolute error

With the introduction of the three new performance factors in paragraph 4.1, a new tool to calculate the performance of a panel, using the basics of exam 1 and exam 2, is available. All three performance factors can be described as a relative error since the voted error is related to the maximum allowed error.
The IPF (2-propanone) presents the performance of a single vote while the PPF (2-propanone) and DPF (other sources) presents the performance of a whole panel.
To create a performance method which is independent of the number of samples and the chosen perceived air quality level, the vote behaviour of a panel member or whole panel has to be included in the method. In the new approach the performance is related to the maximum allowed error (limits) so the vote behaviour has to be included in the limits. With the data from this project the error limits related to 2-propanone (exam 1) were corrected. The new IPF values determined with the corrected error limits seem to be independent of perceived air

quality level. The error limits related to other pollution sources (exam 2) have to be adjusted in the near future, using the audit panel data of this project and/or other 'new' data.

The DPF assumes that panel size lies around 12 to 15 persons. The standard deviation is the deviation on a single vote and not the deviation on the mean vote (standard error). In future calculations this should be included.

Exam 2 was based on the standard deviation of a panel evaluation of other sources than 2-propanone. This is an important parameter, since all instruments are selected on their ability to give a value with an as low as possible error. However, the question can be risen whether the DPF should at all be a measure of panel performance. For perceived air qualities other than 2-propanone it is common that panel members vary in their judgement. Some panel members find the smell of tobacco for example very annoying while others do not. For sources other than 2-propanone, the correct answer is not known and an evaluation of the vote is not yet possible as such.

An important criterion was not included, namely the reproducibility of a panel and/or panel member. Reproducibility can be defined as the standard deviation around the mean of two or more replicas of a source divided by the mean vote of that source. An additional performance factor for the reproducibility could be the Reproducibility Performance Factor defined as the standard deviation around the mean divided by the allowed standard deviation around the mean.

Although it was recommended in the manual (12), not all countries included a retraining and a calibration test at each day of the field experiments. The calibration tests are however important to check whether a certain panel member had a bad day (and to decide whether to exclude panel members or not). The form in which this calibration test was recommended can however be improved.

The quality control of panels between countries was minimized with exams 1 and 2 and the calibration test every day of the field testing. Differences between panels may however result from slightly different equipment, variation in the standard training room, cultural differences and expectations, training procedure, etc... A common sample to be tested by all panels involved could have given more ground for comparison.

<u>Field evaluation</u>
A refreshment room in the field is hard to accomplish. No room in an actual building has a background perceived air quality as low as the zero-decipol room (47). Furthermore, opening of windows is not always possible or will even disrupt the ventilation and airflow measurements. The selection of locations to be evaluated were therefore chosen to be as close to a refreshment place as possible, not always considering the fact whether these locations were representative of the building under study.

The assessment of air quality in a field situation was questioned. It was said that this evaluation will be influenced by for example visual impacts and noise. Suggested was therefore to obtain samples of building air to the laboratory and present them to the panel. Several problems will however have to be dealt with. First of all, the panel members require 1 l/s of sampled air over circa 1 minute per panel member, which results in at least 900 litre per location. How to collect and transport such an amount of air? Secondly, the air sampled has to be transported probably in some kind of bags. The transportation time will probably influence the quality of the air sampled through chemical reactions and sorption processes.

In the buildings studied, some countries asked the whole panel to enter a room and evaluate the perceived air quality, other countries divided their panel in groups of 1 or more persons. The pollution of twelve to fifteen panel members will however have an impact on the pollution level in that room. This will influence the perceived air quality evaluation as well as all other measurements taking place. It is therefore advised to reconsider this part of the procedure very carefully.

Several countries had their panels evaluate the perceived air quality at each selected location only once, while in the manual it was stated that this should have been done twice. Two evaluations is already very little and it was said that this might not even be enough to take into account for local or time variations.

Furthermore, evaluation of the outdoor air, supply air and adjacent places was not always done or was done incorrect. A proper selection of the outdoor air and supply air evaluation locations is required.

Some countries brought the milestones to the buildings studied. According to them it worked well, but some points have to be raised. First of all, the location in which these milestones were placed might have had a higher background level than 1 decipol. Secondly, these locations might have been exposed to changes in temperature; the steady state concentration of the milestones is influenced by that. Comparison of results between different buildings will therefore be difficult.

The perceived air quality was in none of the selected spaces below 2 decipol. This lack of low levels in the audited buildings can be related to the method used in two ways. The refreshment room selected for refreshing the panel senses was in most cases a location in the audited buildings. It was therefore almost certain that none of those locations reached a zero decipol level. The sensory panel could therefore not refresh their senses in a proper way. Furthermore, in the training method itself decipol levels below 2 decipol were not always possible to reach, since some participants used a training room which did not comply with the recommendations in the manual. In any case, levels below 2 decipol are hard to reach.

The reason for this can be given in two directions. Either, it is essential to improve methods for measuring low pollution levels (<2 decipol) or the pollution levels below 2 decipol are just not as critical as we think. The last reason indicates that the relation between the perceived air quality expressed in decipol with the percentage of dissatisfied visitors needs to be studied carefully, especially in the lower decipol levels.

5.5 General indoor air quality and climate

Equipment

The pumps frequently used introduced a noise level higher than the background level in the investigated spaces. The noise measurement could maybe be performed on another day than the audit day or switched of during the noise measurements.

Carbon monoxide may be an indicator of fresh cigarette smoke only if the concentration is higher than the detection limit of the instrument. This is not the case with generally used instruments to detect carbon monoxide and usual concentration levels in rooms were smoking occurs. A more accurate instrument should be selected to measure CO, for example with an detection limit of around 0.1 ppm. For evaluation of smoking it might however be advised to assess the number of smokers per investigated room through observation instead of measuring CO.

TVOC-concentrations measured by the Tenax-GC method cover a broad range from about 20 $\mu g/m^3$ to several mg/m^3. There was no indication that the composition is systematically different at high and low concentrations. While at low concentrations the determination of the TVOC-toluene index was still possible, qualitative identification from the mass spectrum was impaired.
The usefulness of a B&K multigas analyzer for TVOC-measurements is mainly limited by the variability of the sensitivities of the compounds present in the air.

Tenax-GC method

. Quantification by FID

It is known that the FID has a quite uniform sensitivity for hydrocarbons (expressed as FID signal per carbon-atom, respectively FID signal per mass concentration). VOC's containing heteratoms normally have a lower sensitivity. This can be explained from the fact, that in the FID the analyte is burnt in a hydrogen/air flame and it should not be surprising that already highly oxidised or under normal conditions not combustible substances as e.g. compounds with a high content of halogens are not very sensitive in the FID.
In conclusion, (T)VOC-concentrations from FID should be given as mass-concentrations ($\mu g/m^3$ or mg/m^3). And quantification by FID, unless calibrated for individual compounds, will underestimate the concentration of compounds containing oxygen and halogen atoms.

. Quantification by Mass Spectrometry (total ion chromatogram)

The total ion signal in mass spectrometry is more or less proportional to the number of analyte molecules (a detection system that "counts" molecules). Results therefore should be given in ppm-units, unless calibrated for individual compounds. The sensitivity of individual compounds is mainly influenced by the transmission characteristics (ion source, analyzer) of the model of mass spectrometer and can even be greatly influenced by the actual operating characteristics of the instrument. Typically, compounds with low sensitivity in FID will show up with higher intensity in the total ion chromatogram (e.g. halogenated compounds, siloxanes, etc..).
In conclusion, (T)VOC concentrations from total ion chromatogram should be given in ppm. And quantification by mass spectrometry, unless calibrated for individual compounds, may-depending on the composition of the sample - be influenced greatly by the type of instrument used and the actual operating conditions.

VOC data published in literature should be looked at and compared with other results very carefully. This is especially the case for TVOC-values for which it is of great importance to know the range of compounds covered by the sampling procedure (cutoff for low molecular hydrocarbons, small polar compounds). Literature data which are not accompanied by a suitable characterisation of the method are useless for comparison with other data.

For the assessment of VOC sources, an evaluation of the contribution of outdoor air and supply air should include identification of the involved compounds, if statements reaching beyond mere educated guesses are expected. This would also complement specific source testing methods like FLEC. If fungi are observed, they may be sources not only of extraneous compounds, but also of the more frequently observed VOCs.

Direct measurement by IR absorption using photo acoustical detection

In the multi-gas-monitor the classical method of infrared molecular absorption spectrometry is combined with photo acoustics as the principle for quantitative detection. Selectivity for the compounds under investigation is obtained by the use of the narrow band optical filters. The main interference in infrared absorption spectrometry in the vapour phase, i.e. from water vapour is suppressed by a special filter measuring the very strong absorption of water vapour only. As IR-spectra of organic compounds are rather complex (lending themselves as a technique for structural identification of molecules), the technique is most useful for the measurement of single or a few known compounds. As there is no separation, the measurement signals of this type of multigas-monitor will always be composed of the sum of responses from all the compounds present in the sample. To cope with this problem, the instrument can be operated in a cross-compensation mode, eliminating interferences computationally. While this method is working well in situations with a few known interferents, it may produce grossly erroneous results when unforeseen substances are present in the sample.

The instrument should therefore only then be operated in the cross-compensation mode, when the compounds present in the air are known and the instrument has been calibrated for cross compensation exactly with all these substances. This is clearly not the case when using this type of instrument for VVOC/VOC investigations of indoor air. Cross compensation therefore should not be used for this type of operation.

In contrast to the FID-detector used in gas chromatography, molecular spectroscopic methods yield concentrations in ppm-units. Whereas there is no objection to translate the concentration for the calibration compound (e.g. methane or toluene), it has to be kept in mind, that in the real measurement situation an unknown mix of compounds is present. The best to do in order to reach at least a rough estimate of the concentration is to assume uniform sensitivity per molecule (as done for the Tenax-method for toluene, but with lower chance that this assumption will hold). Converting the more correct ppm-concentration value to a mass concentration (mg/m^3) will - without any real need to do it - inflate the uncertainty of the result even more (see Figure 5.1).

Having brought up all these negative aspects of using a photo acoustical IR monitor for VVOC/VOC measurements it also has to be said that the short time response of this type of instruments may be of utmost interest and importance in identifying and locating sources of VOC-contamination in a building. Results from literature and also from this project show, that VOC-concentrations may vary within a short period of time. Moreover, being able to distinguish between stationary and rapidly changing concentrations in room air may be another clue for identifying the sources.

In conclusion: If a photo acoustical IR detector with suitable selectivity for VVOC/VOC is available, use it (without cross compensation) and interpret the resulting data very carefully.

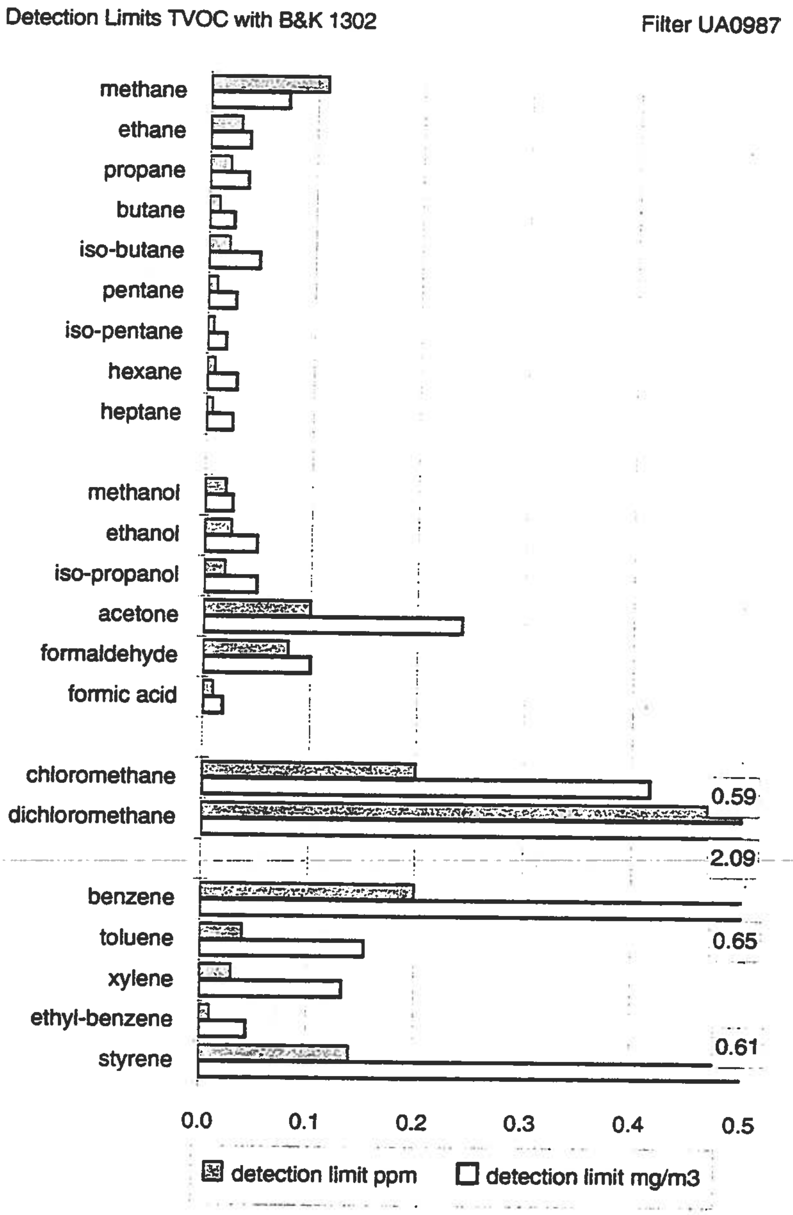


Figure 5.1 *Detection limits of TVOC with B&K 1302.*

<u>Comparison two methods</u>
Only methods sensitive to the same set of compounds can be expected to yield comparable results. But there is yet another critical point in comparing VOC-data. Concentration values can be given in two different types of unit: μg/m^3 or mg/m^3 (= mass of VOC - individual summed up - per unit of volume of air) and ppm (= number of VOC-molecules per number

of air-molecules). Some detectors are sensitive for mass (e.g. Flame Ionisation Detection (FID)), others "count" molecules leading therefore to molecular concentrations expressed in ppm units. A correct conversion between the two type of units is possible only if the concentration of every single compound present in the sample is known, a situation rarely found in practical VOC-analyses.

Field procedure

CO, CO_2, TVOC, temperature and relative humidity should whenever possible be measured continuously over at least 24 hours, to get more information on the variation in time as a result of number of persons, opening/closing doors/windows... In that way also the influence of the presence of researchers and panel members can be taken into account. Continuous recording of about a week around the Audit day could be useful to check whether the audit day is a special day or a standard day. CO_2, thermo-hydrograph or multigas semi-conductor sensors might be convenient for that purpose.

For accurate measurement including weak contributions, it seems necessary to register the outdoors CO_2 and CO concentration as well. At present, CO_2 has not been considered a priority outdoor air contaminant, except in long term averages as a greenhouse gas. Short term variations seem to be largely unexplored.

This project resulted in a huge amount of information on VOCs in the 56 investigated office buildings throughout Europe. The decision to add mass spectrometrical detection was worth doing, as it did not add too much to the primary analytical effort (sampling and GC-analysis). On the other hand it should be noted that only a small portion of the collected information has been retrieved. Considering the list of the most abundant compounds found in the 56 buildings, explanations for the occurrence of health symptoms could not be found. With respect to future IAQ Audit programmes it has to be evaluated very carefully if the effort of a (T)VOC analysis is relevant to sought results.

Other relevant results could be expected from analysis of SVOC and POM, but the methods are not yet established enough for routine type applications, as are group specific analysis on particularly obnoxious families like amines or sulphur compounds. A qualitative sensory indicator of the type of stimulus elicited (odour type, irritation site) may help to plan target-oriented measurements. However, the knowledge accumulated so far is not sufficient to presently elaborate such an indicator for the usually very dilute indoor settings.

5.6 Ventilation

Discussion of methods and equipment used

It may be noted that at least four of the project objectives made demands, sometimes conflicting, on the procedures used for ventilation measurements. These objectives were:

- To determine contaminant source strengths (sensory and chemical);
- To assess ventilation performance (measured compared to design ventilation rates);
- To enable comparison of IAQ-related parameters in different buildings;
- To develop a method (for Europe) to investigate IAQ in office buildings.

At the outset of the project, the greatest emphasis was placed on the first item. This was a demanding task which had a direct and significant impact on the ventilation measurement strategy chosen. The primary effect was to set a requirement to determine the mass balance of air exchanges in each measurement location within each test building. The implication of this, by necessity, was to cause resources to be focused on measurements at the local level of the rooms and, in general, not to carry out measurements at the level of the whole building or 'system'.

Typically, the approaches taken relied on tracer gas techniques to measure an overall ventilation rate for each test space, and a direct measurement of the supply rates from the ventilation system (where present) using an independent (more conventional) method. Smoke tubes were used in most cases to detect any airflow from adjacent spaces. In many cases, the magnitude of the inter-zone flows were estimated from measurements of the pressure drop and crack area, assuming an empirical 'crack flow' relationship. Alternatively, in some cases, flows from adjacent spaces were determined as part of the tracer gas measurements.

Infiltration was subsequently determined by subtracting the large system supply rate from the overall ventilation rate, taking account of any flows from adjacent spaces where appropriate. Where there was no ventilation supply system, i.e. in naturally ventilated buildings, the tracer gas measurement gave infiltration directly, after taking account of any flows from adjacent spaces.

- *Tracer gas measurements*

Tracer techniques employed included constant concentration, concentration 'decay', constant injection, and homogeneous emission (UK only). In general, the most reliable results were obtained in buildings with cellular offices, with doors closed and constant supply (and recirculation) rates. In some cases measurements were made easier by carrying them out at times when the ventilation system was switched off. In several buildings difficulties arose where:

- occupants required office doors to be open;
- tests were in large open plan rooms;
- air recirculated from elsewhere in the building;
- the air supply rate varied over time;
- flows occurred via multiple routes from adjacent spaces (e.g. via ceiling voids).

Uncertainties were reported in the range 5% to over 100%.

. *Ventilation system supply rates*

Methods used to measure ventilation supply rates included the 'pressure-compensating' flowmeter (TNO 'Flowfinder'), conventional low pressure-loss flowmeter, anemometry, velocity traverse and tracer gas dilution. Ventilation supply rates were generally reported to be amongst the most accurate. Difficulties were encountered in several cases where:

- air supply rates were variable over time;
- in large spaces with large numbers of supply inlets;
- supply inlets 'set back' in false ceilings or walls;
- supply rates were high.

Uncertainties were reported in the range 10 to 125%, typically 40%.

. *Infiltration*

Infiltration was generally found difficult to determine accurately since it involved the subtraction of two similar and large values (overall supply rate and ventilation supply rate). Sometimes only 'representative' measurements were taken in a few rooms, and assumed to apply to other rooms. Although apparently plausible in the absence of any alternative, this needs to be justified with care. In other cases infiltration was simply not determined. Where the system supplied an overpressure, infiltration was often assumed to be negligible. In theory this will be a correct assumption if leaks are small (so that two-way buoyancy air exchange does not occur); even so the pressure should be checked in all test rooms.

Uncertainties were reported in the range 40 to 200%, typically of the order of 100%.

. *Flows from adjacent spaces*

Test rooms were often chosen so that flows from adjacent spaces could be assumed to be negligible. In several cases significant air flows were detected, and were difficult to determine accurately within the time available for measurements. Problems arose where they were variable in time, particularly where doors were open to adjacent spaces. Measurement approaches used included:

- detection using smoke;
- measuring crack area and pressure drop;
- two-stage constant concentration with and without 'guard ring';
- simultaneous dual tracer gas technique (constant concentration).

Whilst the method measuring pressure drop and crack area was a good example of the ingenuity of the teams, it was generally not easy to apply in practice, and is not a proven technique. Overall, uncertainties were typically of the order of 100%.

. *Recirculation*

In many cases teams encountered systems in which air recirculated from other zones, or from a ceiling void as with induction systems. In principle, recirculation at the level of the whole building or 'system' level can be measured, and it was in some cases where supply rates and recirculation fraction were constant. However, these measurements were not specified as mandatory in the manual and were beyond the available resources in many cases. Consequently the outside air supply rate (as distinct from infiltration) was often not measured.

Recirculation rate was not required, in theory, to determine contaminant strengths in rooms. However, it was required to determine any contamination introduced by the ventilation system itself. In many of the case study buildings chosen, the recirculation rate would have been difficult, if at all possible, to measure in practice.
Examples of problems reported included:

- multiple induction systems, with outside air fractions of supply rate which varied according to temperature set-points;
- multiple air handling units supplying the same room;
- variable air volume (VAV) systems;
- recirculation of air from other zones outside the area of access for measurements;
- occupants preferring to keep internal doors open.

Summary and proposals for future studies

The experience of this study suggests that in many buildings the specific task of estimating contaminant source strengths was subject to an unacceptable accumulation of experimental uncertainties. It was always a possibility that difficulties would be encountered in applying tracer gas techniques in some of the buildings finally selected. This reflects the state of the art in the application of tracer gas techniques to large and complex office buildings and, in particular, that the application to determining contaminant source strengths was previously relatively untried.

A significant source of experimental uncertainty arose from the combined use of different instrumentation in measuring ventilation rates; eg flowmeter used to measure air supply rate, tracer gas analyzer used to determine overall ventilation rate and CO_2 meter (or several) used to indicate occupancy. Where possible these sources of error should be avoided.

However, satisfactory results were measured in cases where some degree of 'control' was possible. Examples were cellular offices, with doors closed and negligible 'leakage' paths to other rooms, constant air supply rate and recirculation fraction. We therefore suggest that controlled measurements in isolated, typical, rooms could be a viable way of estimating contaminant source strengths in buildings 'in use'. Furthermore, in general measurements were satisfactory for the purposes of assessing ventilation performance in terms of overall or outside air supply rates compared to design.

A more general assessment of the ventilation performance of a building, within the framework of assessing air quality, can be defined in terms of the following parameters:

- total supply rate of ventilation system;
- total extract rate of ventilation system;
- recirculation fraction of supply air;
- exfiltration and infiltration rates;

Measuring these would enable a comparison with other buildings and against design values, and correlation checks with questionnaire data. Such measurements can be adequately, and often most simply, measured for the whole building at the ventilation system as demonstrated, for example, by the Swiss (48) team and in the special investigations by the Belgian team (paragraph 3.8 and Appendix I). However, measurements of this type would generally take longer than the one day specified in this project.

In the case of naturally ventilated buildings, it is generally not practical or possible to carry out measurements for the whole building (49). In simple cases it was shown to be possible to carry out measurements in individual rooms, for example where air exchanges with adjacent spaces were observed to be negligible or solely directed outward from the test room.

It should be noted that measurements within this present study demonstrated that measured supply rates were frequently not as designed, and that building operators were often unaware of the existence of recirculation in the system, either because they were not familiar with the actual design or because it occurred by accidental cross-leakage. Recirculation rates can vary in time in unexpected ways, e.g. due to the operation of an economizer damper.

Metabolic carbon dioxide (CO_2) has been considered as a possible indicator of outside air ventilation rate, either overall or 'per person'. In principle, this also could enable a comparison with other buildings and against design values, and correlation checks with questionnaire data. CO_2 measurements were addressed in the special investigations carried out by the Belgian team, and were recently discussed by Persily (50). An advantage is the ease of measurement, since CO_2 is always present in occupied buildings. In the Audit procure it has been used as an indicator of the number of occupants present, where the ventilation rate is known from a separate measurement. In either case, certain minimum requirements must be met:

- steady-state conditions should be ascertained (a steady concentration is not a guarantee of steady-state, due to time lag);
- number of occupants and activity levels should remain constant and must be known;
- outdoor CO_2 concentration must be monitored since it is variable over time.

Persily lists other factors which can lead to an overestimate of the ventilation rate.
These concerns equally apply to the use of CO_2 to determine occupancy numbers. It is noted that in some cases an alternative for measuring ventilation rate may be to monitor CO_2 'decay' at the end of the day, for example, and determine the air change rate from the slope of the plot of the logarithm of concentration against time in the usual way.

An alternative approach has been proposed, using the 'passive' perfluorocarbon tracer (PFT) techniques (51,52) and homogeneous emission. This application was demonstrated by the UK team who applied the technique in parallel with the Audit Procedure. This approach can provide all of the required data, i.e. local 'effective' outside air ventilation rates, which can be compared against design supply rates and across buildings, and used to correlate against questionnaire data.

5.7 Energy consumption

The determination of the energy index requires the knowledge of yearly energy use (for any energy source) and of gross heated floor area. The latter can relatively easily be measured on plans, but the former may not be available in each building. If energy use is not recorded by the building management, information may be obtained from energy bills, which should always be available.

If a building is considered, make sure that the audited volume (the volume comprising the surveyed persons and the test locations) is the only one connected to the energy source counter. In other words, avoid to audit one building out of a series of connected to the same heating plant without a heat meter. If this is the case, take information on the whole set of buildings.

If only data from building drawings are used to estimate the floor area, errors may be introduced by taking into account areas, which are in fact not heated, or vice versa. The accuracy of the energy index is much better when the gross heated floor area (including walls) is collected.

In fact, the energy aspect was not treated with enough attention within this project. With some additional efforts, it would be possible to draw much more conclusions in relation with energy and ventilation.

From the experience gained during the audit, it can be concluded that in order to be able to manage and control energy consumption in office buildings, detailed information is needed on:

- electricity used for lighting and office appliances,
- electricity used for HVAC devices (pumps, fans, control systems, etc.),
- energy used for heating and for cooling, preferably in relation with internal and external temperatures and solar radiation.

This implies that appropriate meters should be installed, except in few recent buildings which are equipped.

As far as possible, data should be collected separately for heating and cooling processes, or for heating and cooling seasons. If possible, collect also separate data for air handling and other processes.

To make an assessment independent of the user, or to estimate the energy use with a standard user, a calculation of energy consumption under standard conditions may be performed according to a suitable standard, for example prEN 832 (53) or its future equivalent for office buildings. For that purpose, additional data is required, which are listed in the standard.

5.8 Pollution sources

The identification of pollution sources and of their relative importance have been made by use of the checklist, measurements of ventilation rate, CO, CO_2 TVOC, decipols and the calculation procedure given in the manual (12) and paragraph 4.3.

The use of these calculation procedures have resulted in unreliable results or results with large uncertainties up to 100% or more (Appendix J). It is not appropriate for the time being to present any new procedures as the knowledge, especially related to the first and second discussed reasons below, is scarce. There are four main reasons for the unreliable results.

Uncertainties in the calculated pollution loads

Large uncertainties in the calculated pollution loads, due to the calculation procedure, to uncertainties in the ventilation measurements, and uncertainties in measurement of specific compounds in the air.

In the calculation procedure terms like "Z- (A-B)· C" were used. A and B are usually perceived air quality or concentrations of TVOC and C corresponds to a ventilation rate. The variance δZ and the relative uncertainty $\delta Z^2/Z^2$ were calculated.

$$\delta Z^2/Z^2 = (\delta A^2 + \delta B^2)/(A-B)^2 + \delta C^2/C^2$$

The resulting formula shows, that the smaller (A-B) is, the bigger the relative uncertainty gets. In fact in many cases the difference between the measured concentrations was quite small. The error analysis showed large errors on the pollution loads up to 100% and more. These errors were also due to the errors of the ventilation measurements. Even using accurate ventilation measurement methods the errors for the rates were between 5 and 20%, most likely 20% and in some cases even higher.

Sorption effects

Adsorption, desorption and decomposition of components influence the concentrations in the air. The calculation procedures can not yet take this into consideration.

Several investigations have shown that sorption effects of material surfaces affect the indoor air quality (54, 55). One practical consequence is that adsorption and desorption may (temporarily) reduce or increase the effect of different pollution sources on the indoor air quality. A surface obviously being a source at the time of the measurement may previously have been acting as a sink. The two examples below are used to indicate how investigations aimed at establishing the relative importance of different sources can give misleading results.

Compounds originating from the supply air can be adsorbed on surfaces in the room. This may result in a reduced influence on the indoor air quality of pollutants supplied via the ventilation system.

Initially adsorbed substances originating from intermittent sources (e.g tobacco smoking) may subsequently be desorbed from the surfaces. This will be perceived as a higher than actual pollution load caused by material emissions. CO, used as the indicator of tobacco smoke, disappears very fast and does not ad- or desorb, while tobacco smoke does. CO is not a good indicator for tobacco smoke after the smoking has stopped (56).

Sensory evaluation dependency on pollution level

A recent study (42) has shown that the relation between perceived air quality and concentration of air pollutants may differ for different sources. The sensory emission rate can then consequently not be expressed by one value, but may vary with the pollution concentration, which depends on other sources and the ventilation rate. This finding indicates that it is not possible to obtain one universal measure for the sensory emission rate from the sources in this project, since only one measurement was made.

Conclusions on the importance of sources in the audited buildings is however still possible, since the direct measurements (in decipol) provided in most cases enough information and all measurements were performed under reasonable the same conditions. So relatively seen, these conclusions are defendable although, the exposure equipment used for assessing the supply air may have resulted in an overestimation of the perceived air quality of the supply air as a result of pollutants from the exposure equipment. Furthermore, temperature differences between supply air and room air might make direct comparison between the two perceived air qualities difficult.

Non steady state conditions

Conditions which were not in equilibrium due to changes in source emissions (occupants, smoking) especially in offices with small air changes per hour, may not be adequate for calculations based on steady state..

It can be concluded therefore that panel measurements for other purposes than describing the air quality in rooms (and not for calculation) should not for the moment be considered.

6. CONCLUSIONS/RECOMMENDATIONS

In this final chapter conclusions and recommendations based on this project are presented. Furthermore, challenges for the future with respect to general research on indoor air quality and energy performance of buildings is given.

6.1 Conclusions

Indoor air quality and energy consumption were assessed in 56 office buildings in nine different European countries during the heating season. A jointly agreed method of investigation comprising simultaneous measurement of indoor environment and occupant responses was used. The conclusions based on this project are divided into three parts:

(i) *General conclusions regarding indoor air quality and energy consumption*
(ii) *Conclusions regarding indoor air quality in the audited office buildings*
(iii) *Conclusions regarding energy consumption in the audited office buildings*

The figures presented below are average values for the audited buildings; however it should be noted that large differences between individual buildings were observed.

(i) General conclusions regarding indoor air quality and energy consumption

- No contradiction between low energy consumption and good indoor air quality was found. Hence, a potential exists for optimizing indoor air quality without consuming more energy. (Chapter 4.6)

- No correlation between energy consumption and outdoor airflow rate was found. This indicates that in general energy is used for other purposes than ventilation. (Chapter 4.6)

- No systematic regional differences were found in Europe concerning IAQ parameters, occupant responses or energy consumption. (Chapters 3.1, 3.2, 4.6)

(ii) Conclusions regarding indoor air quality in the audited office buildings

- The outdoor air change rate of the audited rooms averaged 2.5 h^{-1}. The average outdoor airflow rate was 1.9 $l/s.m^2$ or 25 l/s.person. The average TVOC concentration in $\mu g/m^3$ toluene was 337, the mean particulate matter concentration was 111 $\mu g/m^3$, the CO_2 concentration 700 ppm and the CO concentration below 1 ppm. These values meet the requirements in existing national standards and European guidelines. (Chapters 3.3, 3.5, 4.5)

- 27% of the occupants found the indoor air quality not acceptable at the time of the building audit and 32% found the indoor air quality not acceptable during the month preceding the audit. In all buildings the air was found to be dry by the occupants. In half of the buildings the air was perceived to be on the stuffy side. The indoor air was not perceived as strongly odorous by the occupants. (The average response rate of all occupants in the 56 audited buildings for the questionnaires was 79%). (Chapter 3.1)

- On the day of the building audit the three most prevalent building-related symptoms were dry skin (32%), blocked or stuffy nose (31%), and lethargy or tiredness (31%). The three most prevalent building-related symptoms for the month preceding the building audit were lethargy or tiredness (52%), headache (42%), and dry eyes (39%). (Chapter 3.1)

- The mean number of building-related symptoms on the day of the audit was approximately two out of a list of twelve symptoms, whereas the mean number of building-related symptoms for the month preceding the audit was approximately three out of the same list of twelve symptoms. (Chapter 3.1)

- The mean perceived air quality assessed by trained sensory panels in the selected spaces was approximately 6 decipol for office air, 4 decipol for supply air and 2 decipol for outdoor air. (Chapter 3.2)

- The most important pollution sources in the audited buildings were the materials and furnishing in the offices and the ventilation system in the buildings. The occupants were less significant pollution sources. The mean total sensory pollution load for the offices (including buildings materials, ventilation systems, occupants and previous and present smoking), was 0.7 olf/m^2. The occupants corresponded to 0.1 olf/m^2 and 0.3 olf/m^2 came from the ventilation systems (including in some cases previous smoking through recirculation). The total mean chemical pollution load for the offices (including buildings materials, offices, occupants, ventilation systems and previous and present smoking) was 0.3 µg TVOC/s·m^2. (Chapter 4.3)

- No relation was found between sensory and chemical pollution loads or perceived air quality and TVOC-levels. Some specific components (VOCs) have a high sensory effect, while others have not. Total volatile organic compounds might therefore not correlate with the sensory evaluations as is also the case for semi-volatile compounds or particulate matter and attached compounds, which were not characterized in this study. (Chapter 4.4, 4.7)

- Identified pollution sources comprised materials and furnishing in the office environment, ventilation system, occupants, tobacco smoking and outdoor pollution. The following contributors were suggested: flooring, glues, paints, wax, office machines, cleaning agents, filters, humidifiers, heat exchangers, ducts, present and previous tobacco smoking, consumer products, outdoor traffic and industrial pollution. (Chapter 4.4)

- The mean perceived air quality showed significant correlation with the measured ventilation rates, which implies that buildings with high ventilation rates had better perceived air quality than other buildings. (Chapter 4.7)

- The mean perceived air quality assessed by sensory panels giving the unadapted impression of the air quality did not show correlation with occupants' health and their acceptability of the air quality. For this the following should be considered: the perceived air quality is the initial impression of a guest visiting the building, whereas the occupants' perception is adapted to the environment. Differences in population make a comparison between buildings difficult. The perceived air quality was measured at five locations whereas occupant responses were related to the whole building. Furthermore, a relation between the perceived air quality and the building-related symptoms at the time of the audit was not necessarily expected, since most odorous pollutants are not necessarily a health risk and most individual measured and identified compounds were far below the health risk limits. Poor indoor air quality is not necessarily a hazard to the occupants' health. (Chapter 4.2)

- The measured operative temperatures (mean 22.5°C) and air velocities (mean 0.08 m/s) met in general recommendations in the thermal comfort standard (CEN 27730) and requirements in prENV 1752. In general the occupants felt slightly warmer than neutral. The operative temperature found neutral by the occupants was 21.8°C, which agrees accurately with the 22.0°C predicted by the PMV-model for winter conditions in offices. The average noise level was 47 dB(A). (Chapter 3.4)

- The measurements performed within this project showed that the mean outdoor air supply was 25 l/s.person, which in general meets the requirements in the CEN prENV 1752 pre-standard. However, the figures in the pre-standard assume that new buildings are designed using low-pollution materials and furnishing. (Chapter 4.5) *(iii) Conclusion regarding energy consumption in the audited office buildings*

- The mean energy consumption per gross heated floor was 1.100 MJ/m^2 per year. The yearly energy consumption per gross heated floor area varied by a factor 7 for the least energy consuming building to the most energy consuming building which shows a large theoretical economy potential as well as a great diversity of conditions for the different buildings within each country and for the different countries. (Chapter 3.7)

- One half of the energy was used on electricity, the other on fuel divided equally between district heating, heating oil and natural gas. (Chapter 3.7)

- Energy data were often difficult to obtain from the building management because the energy consumption was not known in details. This indicates that energy consumption is often of less importance to management and only represent a minor part of the running costs of the building. (Chapter 3.7)

- Energy consumption of the buildings audited in the North European countries was not higher than in the buildings audited in the other European countries, which seems to indicate that energy consumption has been adapted to national standards and outdoor conditions. (Chapter 4.6)

- Energy consumption varied strongly from building to building. In practice, it depends more on planning, construction, and management than on climate, building type or HVAC systems. It is hence possible to make low-energy buildings with different architectures and various HVAC systems. (Chapter 4.6)

- The air temperatures measured in the selected spaces of the audited buildings were in general in the upper range of the recommended values in the CEN 27730 (20-24°C). Lowering the air temperatures in the audited buildings could provide an energy saving potential. (Chapter 3.4)

6.2 Recommendations

In the following recommendations on how to optimize indoor air quality without consuming more energy in office buildings are presented. The recommendations are mainly based on the findings from this study. This chapter comprises recommendations given in order of priority on:

- energy and IAQ
- source control
- outdoor air
- individual control
- building design and maintenance
- methods and future audits

Energy and IAQ

One of the challenges for this study was to relate energy consumption and the indoor air quality, and to investigate the possibility of optimizing both parameters at the same time. The energy consumption varied substantially from building to building, with as much as a factor seven between the least energy-consuming building to the most energy-consuming building. Greek buildings consumed less energy than the rest of the European buildings probably because of a milder climate, whereas British buildings generally consumed more energy than other buildings, probably because of the non-restrictive British building standards.
The indoor air quality measured as perceived air quality, TVOC concentration and occupants' responses also varied significantly from building to building. No contradiction between energy consumption and IAQ was found, in fact some of the audited buildings showed both good indoor air quality and low energy consumption which demonstrates a significant potential for improved indoor air quality without consuming more energy. Good building design, including ventilation systems, and source control to reduce the strength of pollution sources and the decrement of heating/cooling loads are the key words. Energy consumption can be minimized in many ways and one is to reuse some of the energy in the exhaust air by means of heat exchangers. Heat exchangers are already installed in a large part of European buildings. However, it is important that the heat exchangers do not allow to transfer significant amounts of pollution from exhaust air to supply air. In some of the audited buildings a high degree of recirculation was observed. This can have an adverse effect on the indoor air quality when pollution sources are present in the ventilation system and the recirculated air.

Source control

The audited European office buildings in general showed rather poor indoor air quality, as perceived by the sensory panels, with some dissatisfaction among the occupants in spite of the high ventilation rates compared with existing national European (and North American) standards. One reason was that there were many substantial sources of indoor air pollution in the buildings. Existing and previous ventilation standards and guidelines have considered the occupants to be the only source of pollution in the indoor environment. However, this study clearly shows that this is not the case. This study quantifies that the occupants are a less dominant pollution source and that sources of pollution in the audited European office buildings comprised mostly building materials and components in the ventilation systems. Since the source of pollution mainly was the building rather than the occupants, documented

by low CO_2 concentrations, it is necessary to acknowledge the building including the ventilation system as a pollution source. To improve indoor air quality without consuming more energy, source control should be applied. Source control is the first priority instead of dilution of pollutants by ventilation or by cleaning the air. Source control must be applied to the materials, the systems and activities (e.g. smoking). By reducing pollution sources, e.g. by selection of low-polluting floor covering, indoor air quality may be maintained or even improved at lower ventilation rates. Manufacturers of building materials and furnishing should be encouraged to provide information on their products so engineers and architects more easily can select low-polluting materials. Designers of systems, manufacturers of components and maintenance professionals must be aware of the importance of systems as a potential source of pollution. A reduction or elimination of environmental tobacco smoke, for instance by regulation of the smoking policy in office buildings, can improve indoor air quality or allow lower ventilation rates.
As a generalization of the concept of source control to the energy aspects the strategic importance of an appropriate design that will take into account the natural energy means (passive technologies, daylighting) through the use of the architecture and the furnishing of the buildings, could be stressed. Therefore, there will result naturally a decrement of the demand for commercial energy forms which shall be seen as auxiliary or complementary energies.

Outdoor air

When ventilation procedures are discussed and ventilation rates compared, the quality of the outdoor air used for ventilation must be considered. This is particularly true when using "free cooling" (100% outdoor air in some periods of the day) strategies and when the building is located in polluted areas. Outside some of the audited European buildings the perceived air quality was found to be poor. In some cases even poorer than the perceived air quality indoors. In such cases increased ventilation with outdoor air would not help to improve the indoor air quality.
Furthermore, the TVOC concentration inside was affected by the outdoor air. It was shown that the TVOC concentration in the offices was directly correlated with the TVOC concentration of the outdoor air. The location of the air intakes is therefore also important. Moving the air intake from ground level to a higher level could improve the ventilation air substantially. Development for improved methods to clean outdoor air is recommended.

Individual control

To optimize the indoor environment both health and comfort of the building occupants must be considered. The objective is to satisfy as many occupants as possible. Large variations between the occupants' perceptions within the same building were registered. With sensitivity differing from person to person an obvious way to satisfy individual requirements is to establish individual control of environmental parameters. The control of the office environment was generally rated low by the occupants in the audited buildings. Especially the control of the office ventilation was rated low, in some cases equal to none. An easy alternative in some cases would be to allow the occupants to open the windows. In approximately half of the audited buildings the occupants could not, or were not allowed to, open the windows. Sometimes simply better communication between the occupants and the building operators

could improve the conditions. It is important to remember that the occupants in the audited European building suffered from building-related symptoms and perceived the indoor air as dry and stuffy, with 27% of the occupants being dissatisfied with the indoor air quality at the time of the building audit. Adverse perceptions and building related symptoms are expected to be improved by individual control.
Development of workstations with individual control especially in landscaped offices could be a possibility in the future.

Building design and maintenance

In the search for a better indoor environment it seems logical to look at the different parts of the process of building construction and maintenance. First requirements should be formulated to define a good indoor environment and then technical solutions should be selected to meet the requirements without spending (excessive) unnecessary energy. Once the building design is established, it is a question of using construction methods that ensure that the quality of the final product, the building and its systems, is in accordance with the design.
Finally, it is a question of maintenance of the function of the building. The prerequisites for successful maintenance and operation are set in the early phase of the system design. Both the sensory and the chemical measurements showed that the ventilation system is often a significant pollution source in itself. Especially the filters in the ventilation system were frequently suggested as a pollution source during the walk-through survey. The HVAC system including filters, ducts, humidifiers, heat-exchangers, induction units should be properly maintained and cleaned. One of the identified pollution sources in the European buildings was cleaning agents, so selection of proper materials for cleaning should also be considered. The office cleaning as a part of the building maintenance should improve, not deteriorate the indoor air quality. It is essential to instruct the building operators in how to consider the energy aspect as well as IAQ and human responses.

Methods and future audits

The present procedure with a one-day building audit was successfully carried out in all buildings by 9 teams, in 9 countries. The audit method, including equipment, is described in the Research Manual (12) and thoroughly discussed in chapter 5 of this report. In future building audits the method could be used and compared with the results from the present Europe-wide survey. Some improvements of the procedure could be adapted as suggested and recommended in chapter 5. The database with occupants' responses, measured IAQ-parameters and energy consumption is now available as a standard of reference.

6.3 Challenges for the future

6.3.1 Trends towards the future

People tend to spend most of their life indoors. The new patterns of life lead people to spend less time outdoors and to concentrate both for work and leisure in more or less closed spaces, i.e. buildings. This trend, which develops in parallel with the growing urbanization and the renovation of old town centres points out a challenge: how to make sure that those spaces are going to be safe regarding health and also to contribute to the productivity of the workers and the well-being of all occupants?
The audit reported concerned office buildings. However, besides the specifities of each building technology, there is a common problem that can be approached together.

There was a time that ventilation was considered to be a panacea. Ventilating those spaces abundantly, together with other environment controlling functions (heating, cooling, humidification, filtration, etc..) seemed easy to do while there seemed to be no causes for concern. The energy restrictions of the early 80s questioned the ventilation rates and made ventilation a parameter to play with when reduction of energy consumption was an objective. Measures to reduce energy consumption lead to the design of well-insulated and air tight building envelopes. As a consequence, these buildings often became less tolerant for errors in the operation of HVAC systems.

More recently, in spite of the relaxation of the World energy market, energy continues to be a central issue, mainly because of its major contribution to some of the most challenging global environmental problems. Taxes on CO_2 emissions and a ban on CFCs as refrigerants are just two examples of new type of problems energy use is faced with.

The question is not any more just to reduce the consumption of energy. Instead what matters is to increase the energy efficiency in the whole process starting from each primary energy form through all types of conversion and transportation until its final utilization. In those countries where the consumption is high, more efficiency will probably mean a reduction of the energy consumption; in those countries with still low levels of energy consumption, increasing the efficiency means to be able to have more energy services (in case of buildings: heating, cooling, lighting, etc..) with a lower increase of the energy consumption.

When referring to energy consumption, one must bear in mind the commercial energy forms. Passive heating or cooling strategies and daylighting might eventually not require anything more than a good design and the energy services (heating, cooling, lighting) provided by them do not enter into any current energy balance or national energy pie. These examples concerning passive strategies are typical for buildings. They may not apply extensively to every building, but shall not prevent to consider them as a background potential for each building design, either new or retrofitted.

Then, the challenge for the future is: how to design buildings which allow for good indoor environmental conditions and are at the same time energy efficient?

The key factors stay definitely in the design procedure: the identification of the building finalities, the negotiation of the expected/desired indoor environmental condition; the best integration of the skills and expertise in the design. In the design process not enough has been done regarding the methodology: the project is very often a more or less coordinated addition of several parts instead of a real integrated result.

But besides the methodology, there is also the need for more knowledge, more usable results and tools. Some experiences in the past of biased projects show clearly the lack of knowledge or the undermining of some issues to put focus on some aspects of the building. As examples one can refer, on the one hand, the sealed buildings of the late 60s, or the curtain walls before enough developed glazing systems were available and, on the other hand, the buildings with active solar panels and the associated aesthetic problems and also the largely passive buildings, with overheating consequences.

The same happens with the ventilation. The variation of ventilation rates through the years is an eloquent illustration. And yet the ventilation rates have been established only on the basis of the load due to occupants.

This project made its own contribution to the clarification of that issue. However, the debate is still open. There is still not enough knowledge available.

The European Database project (57) will bring an important contribution for that debate. Knowing the strength of different sources, the design of the building itself (its architecture and its furnishing) and of the building services, will become dependent on new design options: type of materials; strategies of environmental control; technical systems themselves and controlling devices, in order to reach the so called clean buildings.

In summary, one could say that the challenge above must be approached from the source control strategy: first of all reduce by all means the needs for commercial energy before planning for the best (cleaner and more efficient) controlling systems.

Such a strategy will be addressed in the next sections.

6.3.2 Reduction of pollution sources

The Audit project has shown that there are many possible sources of air pollution that may affect the indoor air quality. It is not only a question of emissions of volatile organic compounds from building materials. Other examples of important sources are furnishing, ventilation systems, consumer products and outdoor sources. Measures aiming at the reduction of the pollution load in buildings should involve all of these potential sources.

From an energy point of view, it is evident that additional ventilation for removing these pollutants is not a rational strategy. The long term approach is to achieve low emitting materials and clean ventilation systems in such a way that the ventilation needs are only determined by the pollution levels emitted by occupants.

In the European Database project the main objective is to develop a database containing emission data of individual building materials, entire HVAC systems and entire buildings quantified in chemical and sensory terms (57). This database should furthermore include an evaluation of the resulting levels of indoor air pollution based on a model for prediction of indoor air quality in real spaces and on existing toxicology knowledge. A by-coming objective is the development of measuring methods and models for emission from indoor air pollution sources, depending on age of the source, air pollution concentration, air velocity, temperature and humidity.

Building materials

It is important to continue the efforts to favour the development of low emitting materials. There is a need to improve and spread the techniques for emission testing of products before they are introduced on the market.

Furthermore, the refinement of a method to identify the major pollution sources among surface materials in an existing office building, without excessive disturbtion of normal work and without destroying parts of the building, is necessary. So far, it seems possible to get a more detailed identification by the use of the FLEC (Field and Laboratory Emission Cell) (33). However, more research is required on the temporal variation of the measured VOC concentrations and the influence of typical variations in temperature, humidity, ventilation rate and other environmental parameters.

Adsorption, desorption and decomposition of pollutants influence the concentrations in the air. The calculation procedures available can not yet take this into consideration. So also knowledge on sorption effects are a challenge for the future.

Ventilation systems

Ventilation systems as major sources of pollution require a careful evaluation of the role of each component. This work started up under the European Database project but it deserves a special study on the components themselves, such as humidifiers and filters.

A specific problem with components is their cleanability and maintenance during the lifetime of the building. The cleaning of the incoming outdoor air is a key issue. Specific emphasis is needed on how to clean air and which specific requirements with regard to human requirements and component performance should be set.

Maintenance is a problem of great actuality, not only regarding systems but also regarding the buildings themselves (retrofitting). With all the uncertainties regarding the design of HVAC systems and the matching of what has been designed with what is installed and is in operation, there is certainly a need to approach the maintenance issue in depth.

6.3.3 Control of indoor environment

To be able to control the indoor environment many standards and guidelines are available. Some of them are ready to be used and even work out fine, others need improvement.

Standards for ventilation

The most recent proposal for ventilation standards is the prENV 1752 (36), now under public enquiry within CEN. The prENV 1752 provides a strong incentive to design for low-polluting buildings. The proposed requirements are based on maximum allowed percentage of dissatisfied by first olfactory impression of the indoor air quality. From the present study, made on "normal" (not sick) office buildings, it appears that in nearly all buildings the ventilation rates are large enough to maintain bioeffluents below the proposed limits. A majority of the audited rooms comply with ventilation rates required for single office rooms. With this respect, prENV 1752 is slightly ahead of today's usual ventilation rates.

However, when requirements on perceived indoor air quality are considered this is not the case. The audited buildings were surely not clean, in that sense that the main pollution source was the building itself in most cases. However, the majority of the occupants were satisfied with the indoor air quality, and in most of the locations, requirements given in prENV 1752 can not be satisfied without outdoor air cleaning. The challenge for the future is to propose a standard for existing buildings, which should be based on some more prenormative research.

It would furthermore be an essential challenge for the future to develop a model which can predict the air quality in a space even before the building is constructed. Such a model could be a similar tool as well-known existing models for predicting the thermal and acoustical environment during the design process. This tool would be proper basis for future standards on indoor air quality and ventilation requirements.

Standards for air filters and air cleaning devices

In this study it was pointed out again that air filters can be a major source of pollution. The performance of air cleaning devices that remove particles is currently prescribed by their efficiency, airflow resistance and dust-holding capacity. In field applications the pressure drop (airflow resistance) over a filter is usually the determining factor of how long a filter will be used. No standard procedure has been developed to test gaseous contaminant filters for general ventilation applications.

Some laboratory studies have indicated that loaded filters that remove particles can pollute the passing air instead of cleaning it, in terms of an increase in perceived air quality (58).

The challenge of the future is to propose guidelines that include the perceived air quality evaluation of filters. Furthermore, knowledge on the prevention of this polluting effect should be extended. From the prevention point of view one could consider using filters that remove not only particles but also gaseous pollutants, but of course the first prevention is always source control.

Standards for emission

WG10 of the European concerted action, Emissions of building materials is currently working on an overall evaluation procedure for the effects on health and comfort caused by emissions of materials.

The challenge for the future is to label building materials with regard to the emitted pollutants, so architects and building owners are able to select the building materials with lowest polluting effect.

6.3.4 Better building design

Failure to create acceptable indoor environments may have the origin in failure in the design of buildings. It may be a question of failure to apply the available knowledge and techniques. Another reason may be that the available knowledge is not detailed enough or that the existing techniques are not good enough.

The design process shall clearly ask from the architecture the effort to do as much as it can, to prevent the demand of commercial forms of energy. This can not be seen as a restriction to the creativity of the architect but as one more constraint among many others which architecture has to face. And this is not because of energy but by environmental reasons, the same type of reasons that lead architecture to care about the urban and indoor space (or environment).

In the past 20 twenty years, The European Commission has done an effort unique in the World towards preparing, making available and promoting the application of tools as developed as possible to properly take passive and natural energy means into the design process. Efforts on daylighting, passive design and testing tools and facilities and new technologies and materials make of the basket of results obtained under DGXII sponsored research in this field an outstanding push towards the design approach that one can anticipate for the future.

There is still an urgent need for improved knowledge on natural ventilation evaluation and the role of the thermal mass, in particular when coupled with ventilation.

All that, for what regards mainly the role of the exogenous influences in the indoor environment. There is now a need to clarify the role of the auxiliary systems. What type of systems (displacement, induction) are used, heating and cooling air for thermal purposes or using air only for hygiene purposes, and furthermore to adopt other strategies for heating/cooling?

What is finally the role of smart controlling devices? What is their role on the priority to the use of the background (natural and passive) energies and on the control of the quality of the indoor environment and of the energy performance?
It is a question of priorities, whether a building should be equipped with an error tolerant system with a low level of complexity, or if a system with more technical refinements should be selected. Before a technically complex systems is selected, a thorough analysis should always clearly show the advantages of this selection compared to a more basic system.

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TABLE OF SYMBOLS AND ABBREVIATIONS

B =	building materials	
BSI =	Building Symptom Index	
BSI ff=	(f) based on the frequency scale	(f) with the full list of symptoms
BSI fs=	(f) based on the frequency scale	(s) with a short list of symptoms
BSI sf=	(s) based on the severity scale	(f) with the full list of symptoms
BSI ss=	(s) based on the severity scale	(s) with a short list of symptoms
C =	consumer products	
Ca =	perceived air quality in adjacent space (decipol)	
CCOa =	measured CO-concentration in adjacent space (ppm)	
CCOo =	measured CO-concentration in outdoor air (ppm)	
CCOr =	measured CO-concentration in space (ppm)	
CCOv =	measured CO-concentration in supply air (ppm)	
CCO2a =	measured CO_2-concentration in adjacent space (ppm)	
CCO2o =	measured CO_2-concentration in outdoor air (ppm)	
CCO2r =	measured CO_2-concentration in space (ppm)	
CCO2v =	measured CO_2-concentration in supply air (ppm)	
CO =	Carbon monoxide	
CO_2 =	Carbon dioxide	
Cpo =	perceived air quality outdoors (decipol)	
Cpr =	perceived air quality in space (decipol)	
Cpv =	perceived air quality of supply air (decipol)	
CTVOCa =	TVOC-concentration in adjacent space ($\mu g/m^3$)	
CTVOCo =	TVOC-concentration in outdoor air ($\mu g/m^3$)	
CTVOCr =	TVOC-concentration in space ($\mu g/m^3$)	
CTVOCv =	TVOC-concentration in supply air ($\mu g/m^3$)	
dp =	pressure difference (Pa)	
DPF =	Panel Performance Factor	
E =	equipment	
F =	furnishing	
FID =	Flame Ionisation Detector	
FLEC =	Field and Laboratory Emission Cell	
Gc =	chemical pollution load in space ($\mu g/s$)	
GC =	Gas Chromatography	
Gs =	sensory pollution load in selected space (olf)	
Gsm =	sensory pollution load caused by other sources in space (olf)	
Gsp =	sensory pollution load caused by occupants (olf)	
Gss =	sensory pollution load caused by smoking (olf)	
Gsv =	sensory pollution load caused by ventilation system (olf)	
Gt =	total sensory pollution load in selected space (olf)	
HVAC =	Heating, Ventilating and Air Conditioning	
IAQ =	Indoor Air Quality	
IPF =	Individual Performance Factor	
IR =	Infra Red	
Leq =	equivalent sound level (dB(A))	
MS =	Mass Spectrometry	
N_2O =	Nitrogen Oxide	

nc	=	number of cigarettes per hour
O	=	outdoor sources
PAQ	=	Perceived Air Quality
PCO	=	production of CO per cigarette (ml/cigarette)
PCO2	=	production of CO_2 per person (l/h.person)
PCO2p	=	production of CO_2 per olf (l/h.olf)
PD	=	Percentage Dissatisfied
PPF	=	Panel Performance Factor
PFT	=	Passive Fluorocarbon Tracer
Qar	=	flow rate from adjacent room (l/s)
Qo	=	total outdoor air supply (l/s)
Qor	=	infiltration flow rate (l/s)
Qvo	=	outdoor airflow rate per person (l/s.person)
Qvr	=	mechanical supply flow rate (l/s)
R	=	degree of recirculation (fraction)
RH	=	Relative Humidity (%)
SBS	=	Sick Building Syndrome
SF_6	=	SulphurhexaFluoride
SVOC	=	Semi Volatile Organic Compound
T	=	tobacco smoke
tair	=	air temperature (°C)
Vair	=	air velocity (m/s)
top	=	operative temperature (°C)
VAV	=	Variable Air Volume
VDU	=	Visual Display Unit
VOC	=	Volatile Organic Compound
TVOC	=	Total Volatile Organic Compounds
VVOC	=	Very Volatile Organic Compound

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EC - IAQ - 1.2	Cooperation Agreement	TNO
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EC - IAQ - 1.4	Selection (December 1992)	EA
EC - IAQ - 1.5	Description of Building	SBI
EC - IAQ - 1.6	Comments to Research Manual	SBI
EC - IAQ - 1.7	Questionnaire (Qpaper 1.5)	BRE
EC - IAQ - 1.8	Indoor Climate	Univ.Athens
EC - IAQ - 1.9	Chemical Measurements	TNO
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EC - IAQ - 4.2	National and international data analysis (April 1994)	TNO
EC - IAQ - 4.3	Example national report (April 1994)	TNO
EC - IAQ - 4.4	Detailed ventilation studies: first results (April 1994)	WTCB
EC - IAQ - 4.5	Summary of meeting in Athens (May 1994)	TNO
EC - IAQ - 4.6	National report of the Netherlands (August 1994)	TNO
EC - IAQ - 4.7	National report of Denmark (November 1994)	TUD
EC - IAQ - 4.8	National report of Greece (November 1994)	Uni.Athens
EC - IAQ - 4.9	National report of Switzerland (December 1994)	EPFL
EC - IAQ - 4.10	National report of Norway (October 1994)	Byggforsk
EC - IAQ - 4.11	National report of Finland (November 1994)	VTT
EC - IAQ - 4.12	National report of United Kingdom (February1995)	BRE
EC - IAQ - 4.13	National report of France (February 1995)	CSTB
EC - IAQ - 4.14	National report of Germany (November 1994)	Un.Berlin
EC - IAQ - 4.15	Detailed report sources (January 1995)	SBI
EC - IAQ - 4.15	Detail report ventilation (March 1995)	WTCB

Phase 5:

EC - IAQ - 5.1	EC-Audit paper presented in Budapest	TNO
EC - IAQ - 5.2	Minutes of meetings in Budapest (August'94)	TNO

EC - IAQ - 5.3	Minutes of meeting in Delft (November 1994)	TNO
EC - IAQ - 5.4	Draft final report (October 1994)	TNO
EC - IAQ - 5.5	Paper presented in Lyon (November 1994)	TNO
EC - IAQ - 5.6	DREAM Database (December 1994)	EPFL
EC - IAQ - 5.7	Second draft final report (January 1995)	TNO
EC - IAQ - 5.8	Third draft final report (February 1995)	TNO

APPENDICES

APPENDIX A SELECTED BUILDINGS

The Netherlands

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	16-11-93	suburb	traffic	8,500	5	200	yes	4	-
B	1-2-94	downtown	traffic	10,000	11	450	yes/no	29	-
C	3-2-94	downtown	traffic	10,000	11	450	yes/no	27	-
D	8-2-94	suburb	.	7,500	5	180	yes	5	-
E	10-2-94	suburb	.	5,600	5	150	yes	26	-
F	22-2-94	downtown	railway station	35,000	5	1050	yes	8	-

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	mixing	linear air diffusors	2	0-67%	radiator	-	mineral wool	enamel paint	felt carpet
B	mixing	induction units	2	-	air	evaporation	soft board	dispersion paint	felt carpet
C	mixing	induction units	1	-	air	spray	soft board	dispersion paint	felt carpet
D	displacement	floor supply units, climated facade	2	0-50%	air	steam	plaster board	PVC	felt carpet
E	mixing	induction units	1	-	air	steam	mineral fiber	PVC	felt carpet
F	displacement	floor supply units, climated facade	22	0-100%	air	spray	concrete	enamel paint	felt carpet

Denmark

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	15-3-94	downtown		9,380	7	375	yes	24	3
B	16-3-94	suburb		7,680	4	400	yes	3	.
C	17-3-94	country		19,800	1	520	yes	10	.
D	22-3-94	suburb		4,104	3	126	yes	8	.
E	23-3-94	country		4,440	3	209	yes	5	.
F	24-3-94	country		5,000	2	200	yes	8	.

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	natural	.	.	.		.	mineral wool	enamel paint	linoleum
B	mixing	CAV		no			mineral wool	dispersion paint	nap carpet
C	mixing	dual ducts		no			mineral wool	dispersion paint	nap carpet
D	natural	.	.	.		.	mineral wool	dispersion paint	felt carpet
E	mixing	CAV		no			soft board	dispersion paint	linoleum
F	mixing	VAV		yes			mineral wool	dispersion paint	nap carpet

United Kingdom

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	24-2-94	downtown	traffic	4,000	5	280	no	6	.
B	2-3-94	downtown	traffic	12,100	21	1000	no	9	.
C	9-3-94	downtown	traffic	8,000	6	800	no	4	.
D	15-3-94	downtown	traffic	6,000	4	400	no	22	.
E	22-3-94	downtown	traffic	55,000	13	2000	no	19	.
F	29-3-94	suburb	.	1,200	2	160	no	5	.

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	mixing	balanced VAV		80%	air	steam	acoustic tiles	emulsion paint	nap carpet
B	mixing	mechanical supply only		80%	air	.	mineral wool	vinyl wallpaper	nap carpet
C	mixing	induction units		75%	air	steam	mineral fibre	emulsion paint	nap carpet
D	natural	.	.	.	radiator	.	mineral fibre	vinyl	carpet
E	mixing	perforated plate diffusors		90%	air	steam	perforated plastic coated metal	wood panel	carpet
F	mixing	VAV		max. 90%	air	steam	painted metal	emulsion paint	carpet

Greece

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	8-3-94	suburb	moderate busy road	7,495	4	250	yes	5	no
B	10-3-94	rural	none	9,540	3	380	yes	3	no
C	11-3-94	rural	none	9,190	3	300	yes	2	no
D	28-3-94	downtown	busy road	2,410	6	120	yes	4	no
E	29-3-94	suburb	parking garage	2,492	1	120	yes	21	no
F	31-3-94	downtown	busy road	4,170	7	140	yes	30	no

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	displacement	supply only	1	yes	air	spray	mineral fibres	plaster board	PVC tiles
B	mixing	balanced system with dual ducts	2	yes	air	no	mineral fibres	plaster board or chipboard	carpet
C	mixing	balanced system with dual ducts	2	yes	air	no	mineral fibres	plaster board or chipboard	carpet
D	mixing	balanced system with dual ducts	1	yes	water	no	mineral fibres	plaster board	ceramic tiles
E	mixing	balanced system with dual ducts	1	yes	air	no	aluminium	plaster board	carpet
F	natural	.	0	.	water	no	plaster board	plaster board	ceramic tiles

France

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	24-2-94	suburb	.	3,000	5	125	yes	7	.
B	1-3-94	downtown	traffic	8,950	10	450	yes	10	.
C	22-3-94	downtown	.	3,500	5	140	yes	45	31
D	31-3-94	suburb	.	3,380	4	270	yes	9	.
E	19-4-94	downtown	traffic	42,000	35	2000	yes	5	.
F	5-5-94	suburb	traffic, parking	9,600	10	670	yes	9	.

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	mixing	balanced	1	no	electric	.	acoustic tiles	enamel paint	carpet
B	mixing	balanced with fan coil units	1	75%	air	steam	perforated plates	wall paper	carpet
C	natural	.	.	.	radiator	.	concrete	wall paper	linoleum/ carpet
D	mixing	exhaust	.	no	radiator	.		wall paper	carpet
E	mixing	balanced	9	no	air	spray	perforated metal	metal	carpet
F	mixing	balanced	2	60%	radiator	.	perforated plates	enamel paint	carpet

Switzerland

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	9-12-93	downtown	traffic	7,406	14	240	yes/no	22	.
B	25-1-94	downtown	traffic	21,275	6	750	yes	14	.
C	26-1-94	downtown	traffic	38,440	5	1200	no	4	.
D	1-2-94	country	traffic	12,000	5	223	yes	3	.
E	2-2-94	country	traffic	9,067	7	200	yes/no	20	.
F	26-1-94	downtown	traffic	34,980	6	800	yes/no	36	.
G	26-1-94	downtown	traffic	42,000	9	800	yes/no	18	.
H	1-3-94	downtown	traffic	11,309	8	240	yes/no	21	.

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	mixing	dual ducts	1	20%	water	.	acoustic tiles	dispersion paint	felt carpet
B	mixing	dual ducts	5	33%	water	spray	acoustic tiles	enamel paint/ textile	felt carpet
C	mixing	VAV	4	>0%	air	spray	acoustic tiles	dispersion paint	felt carpet
D	displacement	balanced 50%	2	no	water	spray	concrete	dispersion paint	nap carpet
E	mixing	induction units	2	14%	water	steam	acoustic tiles	dispersion paint	nap carpet
F	mixing	balanced	3	<75%	air	spray	acoustic tiles	enamel paint	felt carpet
G	displacement	supply	3	no	air	spray	acoustic tiles	enamel paint	felt carpet
H	mixing	induction unit	2	no	air	spray	acoustic tiles	enamel paint	felt carpet

Finland

Building	Date of investigation	Situation	External pollution[1]	Total floor area [m²]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	8-2-94	suburb	traffic	4,000	3	120	no	23	14
B	9-2-94	industrial	printing press	23,000	4	850	yes	3	.
C	10-2-94	downtown	traffic, harbour	1,500	6	170	yes	96	3
D	15-2-94	downtown	bus station, traffic	4,900	6	100	no	5	.
E	16-2-94	downtown	harbour, traffic	16,000	11	110	yes	23	.
F	17-2-94	downtown	harbour, traffic	9,300	4	230	no	7	.

1: all buildings had power plant as external pollution

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	mixing	Uno-diffusors	1	no	radiator	.	mineral wool	dispersion paint	linoleum
B	mixing	radial air diffusors	>1	no	radiator	.	sparse steel	dispersion paint	linoleum
C	mixing	linear air diffusors	1	30-80%	radiator	.	concrete, plaster board	dispersion paint	linoleum
D	mixing	linear air diffusors	>1	no	radiator	.	concrete, plas. board, min. wool	dispersion paint	linoleum
E	mixing	induction units	>1	no	air	.	perforated plates	dispersion paint	linoleum
F	mixing	linear air diffusors	>1	no	radiator	.	mineral wool	dispersion paint	linoleum

Norway

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	26-1-94	suburbs	traffic	1,800	3	130	yes/no	8	.
B	9-2-94	industrial area	traffic	7,848	10	350	yes/no	30	14
C	2-3-94	industrial area	traffic	4,060	6	198	yes/no	27	.
D	9-3-94	downtown	traffic	4,180	7	175	yes/no	60	4
E	16-3-94	downtown	traffic	10,312	8	255	yes/no	30	6
F	23-3-94	suburbs	.	3,500	4	320	yes/no	24	.

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	mixing	diffusors	2	.	electric	.	acoustic tiles	dispersion paint	felt carpet
B	mixing	induction units	5	.	air	.	perforated metal plates	dispersion paint	vinyl (PVC)
C	mixing	diffusors	3	0-50%	electric	spray	metal tiles	textiles	felt carpet
D	mixing	diffusors	2	.	water	.	acoustic tiles	dispersion paint	linoleum
E	mixing	induction units	2	.	air	.	acoustic tiles	wall paper	felt carpet
F	mixing	diffusors	8	.	electric	.	concrete	wall paper	linoleum

Germany

Building	Date of investigation	Situation	External pollution	Total floor area [m^2]	Number of floors	Number of occupants	smoking allowed	Age of building [years]	Renovation [years]
A	3-2-94	downtown	traffic	17,146	19	1250	yes	39	.
B	8-2-94	industrial	.	4,000	4	200	yes	17	2
C	9-2-94	downtown	traffic	10,563	13	700	yes	25	2
D	23-2-94	downtown	traffic	44,000	6-10	2500	yes	4	.
E	1-3-94	downtown	traffic	47,718	19	1200	yes	18	.
F	8-3-94	country	.	68,500	3-4	2000	yes	11	.

Building	Ventilation						Surface Materials		
							Ceiling	Walls	Floor
	principle	type	no. AHU	recirculation	heating system	humidification			
A	natural	.	.	.	water	.	concrete	dispersion paint	PVC
B	mixing	CAV	1	no	air	spray	concrete	dispersion paint	felt carpet
C	displacement	IU	1	no	air	spray	concrete	dispersion paint	felt carpet
D	mixing	CAV	4	no	air	.	concrete	dispersion paint	nap carpet
E	mixing	IU	1	no	air	spray	concrete	dispersion paint	linoleum
F	mixing	VAV	6	no	air	spray	concrete	dispersion paint	nap carpet

APPENDIX B QUESTIONNAIRE RESULTS

***Table B.1** Response rate and number of filled-in questionnaires in for the 56 European IAQ Audit buildings.*

	Buildings								
Country	A	B	C	D	E	F	G	H	Mean
Response rate [%]									
NL	73%	85%	84%	74%	62%	86%			77%
DK	77%	76%	78%	68%	92%	85%			79%
UK	81%	66%	67%	71%	83%	77%			74%
GR	71%	88%	67%	65%	68%	54%			69%
F	78%	92%	93%	83%	76%	87%			85%
CH	96%	94%	90%	85%	94%	82%	78%	97%	90%
FIN	85%	78%	75%	95%	86%	76%			83%
N	82%	74%	67%	77%	60%	68%			71%
D	67%	90%	87%	73%	76%	84%			80%
All buildings									79%
Filled-in									
NL	139	149	156	134	104	145			138
DK	164	129	118	79	92	85			111
UK	149	180	168	151	150	108			151
GR	100	110	94	78	81	70			89
F	62	112	97	137	110	132			108
CH	77	141	108	119	94	115	102	126	110
FIN	92	97	75	89	71	145			95
N	106	251	136	115	143	155			151
D	84	113	109	91	95	105			100
All buildings									117

Table B.2 Sex distribution in the 56 European Audit buildings.

		A	B	C	D	E	F	G	H	Mean
NL	Male [%]	60%	70%	75%	62%	84%	83%			72%
	Female [%]	40%	30%	25%	38%	16%	17%			28%
DK	Male [%]	50%	38%	27%	29%	54%	54%			42%
	Female [%]	50%	62%	73%	71%	46%	46%			58%
UK	Male [%]	39%	45%	39%	44%	37%	27%			38%
	Female [%]	61%	55%	61%	56%	63%	73%			62%
GR	Male [%]	45%	39%	53%	42%	52%	60%			49%
	Female [%]	55%	61%	47%	58%	48%	40%			51%
F	Male [%]	35%	46%	43%	38%	39%	22%			37%
	Female [%]	65%	54%	57%	62%	61%	78%			63%
CH	Male [%]	21%	40%	54%	43%	53%	35%	53%	51%	44%
	Female [%]	79%	60%	46%	57%	47%	65%	47%	49%	56%
FIN	Male [%]	63%	59%	21%	13%	23%	53%			39%
	Female [%]	37%	41%	79%	87%	77%	47%			61%
N	Male [%]	42%	52%	78%	61%	44%	78%			59%
	Female [%]	58%	48%	22%	39%	56%	22%			41%
D	Male [%]	46%	45%	33%	51%	52%	38%			44%
	Female [%]	54%	55%	67%	49%	48%	62%			56%
All buildings							Male [%]			47%
							Female [%]			53%

***Table B.3** Mean age for the occupants in the 56 European IAQ Audit buildings.*

	Building								
Mean age	A	B	C	D	E	F	G	H	Mean
NL	39	41	40	39	39	39			40
DK	38	37	38	40	37	35			38
UK	38	29	40	38	34	31			35
GR	40	29	31	35	40	34			35
F	36	44	43	40	41	39			41
CH	44	38	36	39	40	43	42	39	40
FIN	39	41	43	43	46	39			42
N	43	42	39	40	45	39			41
D	45	40	42	40	42	38			41
All buildings									39

Table B.4 Number of smokers in the 56 European IAQ Audit buildings.

	Building								Mean
Smokers	A	B	C	D	E	F	G	H	
NL	26%	35%	31%	25%	17%	25%			27%
DK	43%	39%	41%	23%	31%	45%			37%
UK	26%	37%	21%	10%	16%	20%			22%
GR	33%	40%	56%	66%	44%	47%			48%
F	34%	32%	33%	27%	32%	36%			32%
CH	16%	42%	41%	31%	19%	20%	21%	36%	28%
FIN	22%	18%	27%	29%	31%	23%			25%
N	26%	21%	28%	25%	32%	36%			28%
D	37%	38%	32%	42%	14%	32%			33%
All buildings									31%

Table B.5 Allergic history for the occupants in the 56 European IAQ Audit buildings.

	Buildings								Mean
Asthma [%]	A	B	C	D	E	F	G	H	
NL	17%	16%	14%	11%	9%	8%			13%
DK	8%	6%	7%	11%	8%	3%			7%
UK	13%	10%	13%	11%	7%	10%			11%
GR	15%	5%	6%	0%	8%	8%			7%
F	16%	9%	12%	10%	17%	7%			12%
CH	10%	6%	10%	14%	10%	10%	7%	12%	10%
FIN	10%	17%	27%	18%	27%	11%			18%
N	5%	6%	8%	7%	12%	8%			8%
D	13%	4%	7%	4%	6%	5%			7%
All buildings									10%
Eczema [%]									
NL	27%	21%	25%	19%	21%	22%			23%
DK	37%	38%	32%	43%	33%	30%			36%
UK	22%	18%	24%	17%	21%	21%			21%
GR	13%	3%	9%	10%	9%	3%			8%
F	18%	21%	19%	20%	29%	19%			21%
CH	24%	29%	28%	21%	26%	13%	17%	19%	22%
FIN	51%	44%	62%	55%	42%	54%			51%
N	30%	35%	26%	22%	28%	29%			29%
D	32%	22%	30%	30%	23%	33%			28%
All buildings									27%
Hay fever [%]									
NL	32%	17%	22%	10%	26%	16%			21%
DK	35%	28%	25%	27%	24%	17%			26%
UK	37%	32%	31%	30%	28%	24%			30%
GR	26%	29%	21%	20%	28%	28%			25%
F	20%	33%	28%	38%	31%	34%			31%
CH	19%	27%	29%	28%	27%	22%	19%	22%	24%
FIN	35%	25%	29%	23%	36%	32%			30%
N	17%	22%	19%	24%	21%	22%			21%
D	23%	17%	30%	13%	16%	27%			17%
All buildings									25%

Table B.6 Work function for the occupants in the 56 European IAQ Audit buildings.

Country		A	B	C	D	E	F	G	H	Mean
NL	Managerial work [%]	22	15	28	24	17	6			19
	Specialist skill [%]	16	29	36	31	63	32			34
	Clerical [%]	49	46	28	37	18	55			39
	Other [%]	13	10	8	8	3	7			8
DK	Managerial work [%]	11	3	5	3	9	6			6
	Specialist skill [%]	18	5	10	39	16	25			19
	Clerical [%]	65	70	79	55	61	51			64
	Other [%]	6	21	5	4	14	18			11
UK	Managerial work [%]	9	14	16	14	12	11			13
	Specialist skill [%]	13	2	20	32	12	6			14
	Clerical [%]	75	76	57	51	66	78			67
	Other [%]	3	8	7	3	9	5			6
GR	Managerial work [%]	4	6	6	13	11	4			7
	Specialist skill [%]	20	82	51	47	44	62			51
	Clerical [%]	71	11	43	33	44	34			39
	Other [%]	4	1	0	7	0	0			3
F	Managerial work [%]	8	11	5	4	19	2			8
	Specialist skill [%]	34	32	34	19	27	31			29
	Clerical [%]	51	51	47	72	45	61			55
	Other [%]	7	5	13	5	10	6			8
CH	Managerial work [%]	50	16	13	41	33	12	16	18	25
	Specialist skill [%]	10	18	1	26	18	45	31	3	19
	Clerical [%]	29	49	72	23	44	30	49	72	46
	Other [%]	11	17	13	10	5	12	5	7	10
FIN	Managerial work [%]	4	8	5	8	10	4			7
	Specialist skill [%]	58	56	22	36	7	47			38
	Clerical [%]	24	30	64	42	59	34			42
	Other [%]	13	5	9	14	24	15			13
N	Managerial work [%]	20	12	11	19	13	19			16
	Specialist skill [%]	41	47	37	48	32	24			38
	Clerical [%]	29	33	43	26	40	40			35
	Other [%]	10	8	9	8	15	17			11
D	Managerial work [%]	16	18	27	16	34	1			19
	Specialist skill [%]	42	39	38	13	21	73			38
	Clerical [%]	33	34	27	22	41	15			29
	Other [%]	9	9	8	49	3	10			15
All buildings								Managerial [%]		13
								Specialist [%]		31
								Clerical [%]		46
								Other [%]		9

Table B.7 *Indoor air acceptability rating for the occupants in the 56 European IAQ Audit buildings. The acceptability scale range from 'clearly not acceptable' (-5) indoor air to 'clearly acceptable' (+5) indoor air.*

	Buildings								
Country	A	B	C	D	E	F	G	H	Mean
Past month									
NL	2.1	-0.5	-1.4	0.1	2.0	1.5			0.6
DK	0.3	0.0	0.8	0.1	0.7	0.1			0.3
UK	0.8	0.9	0.3	0.0	-0.1	1.4			0.6
GR	0.3	-0.2	-0.2	2.7	-0.4	0.0			0.4
F	2.5	1.2	2.4	3.1	1.0	1.1			1.9
CH	1.6	0.5	0.1	3.2	0.7	1.9	2.3	1.3	1.6
FIN	1.2	2.6	2.0	1.3	0.0	1.1			1.3
N	2.5	-1.0	-1.1	1.8	1.4	-0.9			0.5
D	1.4	1.3	1.7	1.2	1.7	-0.3			1.2
All buildings									0.9
Here and now									Mean
NL	2.3	0.0	-1.0	0.3	2.3	1.5			0.9
DK	0.3	0.2	1.0	0.6	0.8	0.4			0.6
UK	0.0	0.1	-0.1	-0.4	-0.4	0.3			-0.1
GR	1.2	0.2	0.2	1.8	-1.4	0.8			0.5
F	2.7	1.5	2.3	3.4	0.6	1.4			2.0
CH	2.1	1.2	0.9	3.4	1.4	2.5	2.6	1.7	2.0
FIN	1.1	2.6	2.0	1.7	0.7	1.7			1.6
N	2.1	-0.3	-0.5	1.8	2.0	-0.3			0.8
D	2.7	1.8	2.3	1.6	2.3	0.3			1.8
All buildings									1.1

Table B.8 Air dryness rating on a scale from 1 to 7 for the occupants in the 56 European IAQ Audit buildings. 1 corresponds to 'dry air', 4 is the ideal point and 7 is 'humid' indoor air.

	Buildings								
Country	A	B	C	D	E	F	G	H	Mean
Past month									
NL	2.8	2.1	2.0	2.3	2.9	2.7			2.5
DK	2.3	2.1	2.3	1.8	2.3	2.5			2.2
UK	2.6	3.2	2.6	2.7	2.6	2.8			2.7
GR	1.7	2.0	2.5	3.8	2.5	2.9			2.5
F	2.8	2.4	3.0	3.1	2.7	2.5			2.8
CH	2.5	2.6	2.5	3.2	2.1	2.7	2.6	2.6	2.6
FIN	2.6	2.8	2.7	2.3	1.9	2.4			2.4
N	2.6	2.0	2.1	2.8	2.5	2.1			2.4
D	2.5	2.7	2.6	2.2	2.4	2.4			2.5
All buildings									2.5
Here and now									Mean
NL	2.8	2.5	2.3	2.5	3.0	2.9			2.7
DK	2.5	2.3	2.6	2.2	2.6	2.9			2.5
UK	2.8	3.2	3.0	2.9	2.9	2.9			3.0
GR	2.3	2.3	2.7	2.6	2.6	2.9			2.5
F	3.1	2.8	3.3	3.2	2.9	2.5			3.0
CH	2.7	2.9	2.9	3.1	2.5	2.8	2.8	2.6	2.8
FIN	2.7	2.9	2.5	2.4	2.2	2.5			2.5
N	2.8	2.2	2.5	3.0	2.6	2.3			2.6
D	2.8	2.9	2.8	2.5	3.0	2.5			2.7
All buildings									2.7

Table B.9 *Air stuffiness rating on a scale from 1 to 7 for the occupants in the 56 European IAQ Audit buildings. 1 corresponds to 'fresh' indoor air and 7 to 'stuffy' air.*

	Buildings								
Country	A	B	C	D	E	F	G	H	Mean
Past month									
NL	3.2	4.6	5.2	4.7	3.5	3.7			4.2
DK	4.6	4.9	4.6	4.9	4.2	4.8			4.7
UK	5.3	5.3	4.8	5.2	5.2	5.5			5.2
GR	4.2	4.9	4.9	3.2	4.9	4.6			4.4
F	4.3	4.5	3.8	3.3	3.2	5.0			4.0
CH	3.4	4.7	5.0	2.9	4.7	3.4	3.4	3.9	3.9
FIN	4.1	3.1	3.9	4.1	5.0	4.0			4.0
N	3.3	5.1	5.0	3.7	4.0	5.2			4.4
D	3.5	3.9	3.6	4.1	3.5	5.1			4.0
All buildings									4.3
Here and now									Mean
NL	3.1	4.3	5.1	4.3	3.2	3.2			3.9
DK	4.3	4.5	4.3	4.2	4.1	4.1			4.3
UK	4.5	4.4	3.8	4.3	4.2	4.6			4.3
GR	4.8	4.7	4.6	2.9	4.6	4.5			4.4
F	3.9	3.8	3.8	2.8	3.6	4.8			3.8
CH	2.8	4.0	4.0	2.6	4.0	2.9	3.1	3.3	3.3
FIN	3.3	2.8	3.6	3.5	4.5	3.7			3.6
N	3.2	4.5	4.6	3.4	3.4	4.6			4.0
D	2.8	3.3	3.2	3.2	3.0	4.6			3.3
All buildings									3.9

Table B.10 *Air odour rating on a scale from 1 to 7 for the occupants in the 56 European Audit buildings. 1 corresponds to 'odourless' indoor air and 7 corresponds to 'smelly' air.*

	Buildings								
Country	A	B	C	D	E	F	G	H	Mean
Past month									
NL	2.4	3.6	3.7	3.5	2.5	2.7			3.1
DK	3.1	3.3	2.7	2.9	2.8	2.3			2.9
UK	2.9	2.9	2.6	2.7	2.5	4.0			2.9
GR	3.3	4.5	4.1	2.2	3.9	4.8			3.8
F	3.8	3.5	3.5	2.7	3.2	3.0			3.3
CH	2.6	3.6	4.2	2.5	3.3	3.0	2.7	2.9	3.1
FIN	3.0	2.5	2.9	3.3	3.4	3.0			3.0
N	2.0	2.7	2.9	2.2	2.0	2.9			2.4
D	2.7	2.6	2.0	2.5	2.3	3.4			2.6
All buildings									3.0
Here and now									Mean
NL	2.1	3.7	3.4	3.0	2.3	2.3			2.8
DK	2.9	3.1	2.7	2.6	2.6	2.3			2.7
UK	2.3	2.5	2.3	2.4	2.1	2.7			2.4
GR	3.9	4.1	4.1	2.0	3.5	4.6			3.7
F	4.0	3.7	4.0	2.2	2.9	2.9			3.3
CH	2.0	2.9	3.4	2.0	2.8	2.1	1.8	2.5	2.4
FIN	2.6	2.1	2.7	2.8	3.0	2.9			2.7
N	1.9	2.2	2.4	2.0	1.7	2.5			2.1
D	2.4	2.3	1.8	2.3	2.0	3.1			2.3
All buildings									2.7

Table B.11 Thermal comfort rating on a -3 to +3 point scale given by the occupants in the 56 European IAQ Audit buildings. -3 is 'too cold', 3 is 'hot' and 0 is 'neutral' thermal environment.

	Building								
Past month	A	B	C	D	E	F	G	H	Mean
NL	0.3	0.1	0.6	0.4	0.7	-0.1			0.3
DK	0.5	0.4	0.5	0.5	0.8	1.0			0.6
UK	-0.3	0.1	-0.2	0.5	0.7	0.0			0.1
GR	1.4	1.2	1.1	0.9	0.2	-0.6			0.7
F	0.5	0.4	0.5	1.0	-1.1	1.5			0.5
CH	-0.4	0.2	0.1	0.1	-0.2	0.0	0.5	0.3	0.1
FIN	-1.2	-0.5	0.2	-0.5	0.7	-0.8			-0.4
N	-0.2	-0.2	0.2	0.2	0.0	0.4			0.1
D	0.1	-0.2	-0.1	0.0	-0.2	0.4			0.0
All buildings									0.2
Here and now									Mean
NL	0.3	0.2	0.7	0.6	0.4	-0.1			0.4
DK	0.7	0.4	0.9	0.5	0.5	0.5			0.6
UK	-0.4	0.7	-0.3	0.5	0.5	0.3			0.2
GR	1.2	0.7	0.7	0.8	0.0	-0.4			0.5
F	0.6	0.2	0.5	0.7	-1.6	1.3			0.3
CH	-0.4	0.1	-0.4	0.0	-0.2	0.0	0.2	-0.1	-0.1
FIN	-1.1	-0.3	0.4	-0.3	0.9	0.4			0.0
N	0.3	0.1	0.5	0.4	0.2	0.4			0.3
D	-0.1	-0.2	0.0	0.0	-0.1	0.3			0.0
All buildings									0.2

Table B.12 *Light satisfaction on a scale from 1 to 7 given by the occupants in the 56 European IAQ Audit buildings. 1 corresponds to 'light satisfactory overall' 7 corresponds to 'light unsatisfactory overall'.*

	Building								
Past month	A	B	C	D	E	F	G	H	Mean
NL	2.7	2.5	2.2	2.8	2.4	1.9			2.4
DK	2.4	2.7	2.5	2.5	2.4	2.5			2.5
UK	2.8	3.2	3.1	3.0	2.9	3.5			3.1
GR	2.2	3.1	3.0	2.4	3.6	4.3			3.1
F	3.1	3.4	2.6	2.7	3.3	2.6			2.6
CH	2.1	3.3	2.7	2.2	2.8	2.4	2.8	3.2	2.7
FIN	2.1	2.5	2.1	2.4	2.9	2.1			2.4
N	1.7	2.1	1.9	1.9	1.5	2.0			1.9
D	2.1	2.4	2.0	2.8	2.0	2.8			2.4
All buildings									2.6
Here and now									Mean
NL	2.2	2.2	2.0	2.5	2.2	1.8			2.2
DK	2.7	2.8	2.4	2.6	2.5	2.7			2.6
UK	2.6	3.3	3.1	3.1	3.0	3.2			3.1
GR	3.2	3.0	3.3	2.2	3.3	4.0			3.2
F	3.0	3.3	2.6	2.4	3.1	2.5			2.8
CH	2.0	2.7	2.4	1.8	2.4	2.3	2.4	3.0	2.4
FIN	2.1	2.3	1.8	2.2	2.4	2.0			2.1
N	1.7	1.9	2.0	1.8	1.5	2.2			1.9
D	1.9	1.9	1.7	2.6	1.6	2.6			2.1
All buildings									2.5

Table B.13 *Noise satisfaction on a scale from 1 to 7 given by the occupants in the 56 European Audit buildings. 1 corresponds to 'noise satisfactory overall' 7 corresponds to 'noise unsatisfactory overall'.*

	Building								
Past month	A	B	C	D	E	F	G	H	Mean
NL	2.4	3.4	4.4	3.3	3.8	2.7			3.3
DK	3.5	4.0	3.9	2.6	3.5	4.1			3.6
UK	4.0	3.3	4.0	3.6	2.5	2.6			3.3
GR	2.8	4.5	4.2	3.3	3.0	5.6			3.9
F	3.1	3.7	4.2	2.5	3.2	5.4			3.7
CH	3.1	3.9	2.4	2.2	2.5	2.8	2.7	2.7	2.8
FIN	2.9	2.9	2.3	2.7	3.5	2.3			2.8
N	2.5	4.2	3.8	2.5	2.2	3.4			3.1
D	2.0	2.1	2.2	2.5	2.4	4.9			2.7
All buildings									3.2
Here and now									Mean
NL	1.3	3.4	4.3	3.4	3.7	2.6			3.1
DK	3.2	3.5	3.8	2.7	3.7	3.9			3.5
UK	3.7	3.2	3.5	3.3	2.9	3.0			3.3
GR	4.3	4.1	3.7	3.0	3.4	5.5			4.0
F	2.9	4.0	3.6	2.4	3.5	4.8			3.5
CH	3.1	3.6	2.3	2.0	2.6	2.9	2.8	2.9	2.8
FIN	2.9	2.3	2.2	2.6	3.4	2.2			2.6
N	2.3	4.1	3.5	2.5	2.3	3.1			3.0
D	1.9	2.4	2.3	2.9	2.3	4.8			2.8
All buildings									3.2

Table B.14 *Control of ventilation and cleanliness of office reported by the occupants in the 56 Audit buildings, both rates are on scales from 1 to 7. For ventilation 1 corresponds to 'none control' and 7 corresponds to 'full control'. For cleanliness 1 is 'unsatisfactory cleanliness' and 7 is 'satisfactory cleanliness'.*

	Building								
Control on ventilation	A	B	C	D	E	F	G	H	Mean
NL	3.6	1.2	1.2	1.5	2.9	1.8			2.0
DK	2.9	2.6	1.5	4.1	2.4	1.2			2.3
UK	1.1	1.8	1.2	4.1	1.2	1.2			1.8
GR	3.9	2.5	2.1	4.8	1.7	1.4			2.7
F	2.0	4.7	3.2	3.3	2.1	1.7			2.8
CH	1.1	1.4	1.4	4.6	1.8	1.9	2.3	1.4	2.0
FIN	1.4	2.1	3.4	2.4	2.8	2.0			2.4
N	2.4	1.7	2.0	2.3	2.2	2.9			2.3
D	4.6	4.5	2.3	4.4	1.8	2.9			3.4
All buildings									2.4
Cleanliness of office									Mean
NL	4.8	4.5	4.7	5.1	4.7	4.8			4.8
DK	2.9	3.9	4.5	5.6	4.6	4.3			4.3
UK	5.2	4.2	4.3	5.0	4.9	5.5			4.9
GR	3.8	5.3	4.9	6.0	4.4	2.9			4.6
F	4.6	3.6	3.7	4.9	4.3	3.4			4.1
CH	6.4	4.6	5.4	5.8	5.3	4.9	4.4	4.4	5.1
FIN	4.4	4.6	4.8	3.7	3.3	3.3			4.0
N	3.6	3.4	3.9	3.1	3.0	4.0			3.5
D	3.5	5.4	4.3	5.2	4.8	4.4			4.6
All buildings									4.4

Table B.15 Building-related symptoms, The Netherlands.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	32%	38%	42%	41%	24%	31%	35%
• watering eyes	8%	13%	10%	12%	6%	9%	10%
• blocked/stuffy nose	13%	34%	35%	34%	15%	17%	25%
• runny nose	7%	12%	17%	15%	9%	8%	11%
• dry/irritated throat	22%	37%	41%	34%	14%	26%	29%
• chest tightness	6%	20%	22%	10%	7%	8%	12%
• flu-like symptoms	14%	22%	27%	23%	12%	12%	18%
• dry skin	16%	19%	21%	20%	8%	12%	16%
• rash/irritated skin	4%	6%	8%	10%	4%	3%	6%
• headache	18%	38%	47%	32%	26%	35%	33%
• lethargy or tiredness	21%	46%	48%	46%	30%	28%	37%
• other symptoms	5%	13%	14%	16%	5%	10%	11%
Symptoms <u>here and now</u>							
• dry eyes	23%	32%	34%	34%	14%	25%	27%
• watering eyes	4%	5%	2%	7%	1%	1%	3%
• blocked/stuffy nose	16%	29%	31%	37%	19%	23%	26%
• runny nose	4%	10%	8%	10%	5%	3%	7%
• dry/irritated throat	19%	36%	35%	31%	17%	26%	27%
• chest tightness	3%	13%	15%	7%	5%	3%	8%
• flu-like symptoms	4%	11%	13%	11%	10%	14%	11%
• dry skin	21%	24%	22%	21%	21%	17%	21%
• rash/irritated skin	7%	14%	14%	8%	8%	6%	10%
• headache	9%	19%	28%	22%	9%	16%	17%
• lethargy or tiredness	12%	26%	32%	25%	20%	15%	22%
• other symptoms	5%	9%	12%	10%	5%	9%	8%

Table B.16 Building-related symptoms, Denmark.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	38%	51%	32%	46%	50%	35%	42%
• watering eyes	13%	11%	10%	16%	10%	12%	12%
• blocked/stuffy nose	20%	27%	17%	30%	20%	24%	23%
• runny nose	14%	14%	15%	16%	11%	9%	13%
• dry/irritated throat	31%	29%	28%	28%	34%	31%	30%
• chest tightness	3%	6%	4%	7%	3%	9%	5%
• flu-like symptoms	13%	20%	15%	10%	9%	19%	14%
• dry skin	25%	31%	19%	22%	18%	22%	23%
• rash/irritated skin	8%	8%	1%	4%	1%	5%	5%
• headache	42%	53%	38%	36%	36%	49%	42%
• lethargy or tiredness	36%	48%	34%	43%	45%	45%	42%
• other symptoms	5%	12%	8%	13%	7%	19%	11%
Symptoms <u>here and now</u>							
• dry eyes	30%	38%	33%	31%	32%	31%	33%
• watering eyes	4%	1%	2%	7%	1%	2%	3%
• blocked/stuffy nose	22%	29%	28%	33%	23%	24%	27%
• runny nose	9%	7%	12%	8%	8%	8%	9%
• dry/irritated throat	28%	28%	30%	27%	32%	28%	29%
• chest tightness	3%	2%	1%	4%	1%	4%	3%
• flu-like symptoms	3%	10%	4%	7%	8%	8%	7%
• dry skin	38%	43%	38%	50%	33%	34%	39%
• rash/irritated skin	11%	14%	8%	7%	11%	10%	10%
• headache	25%	24%	22%	19%	25%	26%	24%
• lethargy or tiredness	27%	33%	25%	28%	23%	35%	29%
• other symptoms	2%	10%	9%	14%	7%	14%	9%

Table B.17 Building-related symptoms, United Kingdom.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	46%	45%	36%	35%	50%	57%	45%
• watering eyes	22%	30%	13%	16%	21%	30%	22%
• blocked/stuffy nose	53%	49%	41%	43%	60%	56%	50%
• runny nose	33%	25%	20%	25%	29%	29%	27%
• dry/irritated throat	45%	44%	38%	37%	41%	48%	42%
• chest tightness	22%	15%	14%	11%	11%	10%	14%
• flu-like symptoms	29%	37%	29%	29%	30%	34%	31%
• dry skin	34%	25%	19%	11%	26%	31%	24%
• rash/irritated skin	16%	16%	7%	5%	16%	21%	14%
• headache	59%	57%	47%	46%	65%	74%	58%
• lethargy or tiredness	66%	60%	48%	54%	70%	70%	61%
• other symptoms	17%	16%	15%	9%	14%	21%	15%
Symptoms <u>here and now</u>							
• dry eyes	27%	33%	22%	22%	25%	35%	27%
• watering eyes	5%	8%	5%	4%	5%	8%	6%
• blocked/stuffy nose	35%	35%	31%	30%	41%	42%	36%
• runny nose	14%	12%	9%	14%	10%	13%	12%
• dry/irritated throat	30%	27%	26%	23%	33%	38%	30%
• chest tightness	12%	7%	7%	4%	3%	4%	6%
• flu-like symptoms	8%	13%	9%	8%	9%	7%	9%
• dry skin	43%	28%	24%	20%	34%	31%	30%
• rash/irritated skin	19%	10%	9%	9%	13%	13%	12%
• headache	24%	30%	25%	23%	31%	27%	27%
• lethargy or tiredness	41%	49%	34%	33%	40%	49%	41%
• other symptoms	12%	7%	17%	5%	10%	8%	10%

Table B.18 Building-related symptoms, Greece.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	74%	80%	53%	11%	31%	35%	47%
• watering eyes	40%	36%	17%	0%	10%	23%	21%
• blocked/stuffy nose	36%	50%	38%	6%	35%	19%	31%
• runny nose	30%	24%	17%	4%	10%	16%	17%
• dry/irritated throat	52%	55%	45%	0%	23%	38%	36%
• chest tightness	44%	36%	40%	11%	24%	23%	30%
• flu-like symptoms	38%	42%	38%	14%	32%	35%	33%
• dry skin	52%	38%	26%	6%	23%	14%	27%
• rash/irritated skin	32%	22%	17%	0%	4%	7%	14%
• headache	62%	71%	64%	27%	62%	41%	55%
• lethargy or tiredness	64%	86%	60%	47%	60%	50%	61%
• other symptoms	0%	30%	6%	0%	0%	0%	6%
Symptoms <u>here and now</u>							
• dry eyes	44%	49%	28%	14%	8%	20%	27%
• watering eyes	14%	9%	0%	0%	4%	12%	7%
• blocked/stuffy nose	28%	40%	26%	7%	19%	8%	21%
• runny nose	14%	14%	6%	11%	12%	0%	10%
• dry/irritated throat	40%	39%	32%	7%	19%	23%	27%
• chest tightness	32%	25%	30%	7%	19%	8%	20%
• flu-like symptoms	20%	14%	19%	14%	8%	8%	14%
• dry skin	39%	29%	17%	0%	27%	14%	21%
• rash/irritated skin	15%	17%	6%	0%	8%	8%	9%
• headache	38%	29%	23%	7%	19%	22%	23%
• lethargy or tiredness	42%	35%	53%	7%	15%	32%	31%
• other symptoms	18%	1%	6%	7%	0%	1%	6%

Table B.19 Building-related symptoms, France.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	22%	46%	26%	19%	40%	28%	30%
• watering eyes	33%	31%	29%	23%	30%	32%	30%
• blocked/stuffy nose	41%	48%	41%	35%	44%	36%	41%
• runny nose	16%	37%	32%	32%	39%	37%	32%
• dry/irritated throat	46%	57%	46%	35%	54%	44%	47%
• chest tightness	12%	34%	22%	10%	40%	37%	26%
• flu-like symptoms	46%	54%	32%	20%	49%	25%	38%
• dry skin	30%	41%	22%	16%	40%	27%	29%
• rash/irritated skin	26%	26%	14%	13%	24%	26%	22%
• headache	57%	56%	52%	46%	54%	61%	54%
• lethargy or tiredness	53%	65%	72%	57%	65%	63%	63%
• other symptoms	13%	13%	19%	6%	23%	15%	15%
Symptoms <u>here and now</u>							
• dry eyes	18%	36%	20%	11%	31%	16%	22%
• watering eyes	18%	22%	12%	10%	18%	17%	16%
• blocked/stuffy nose	23%	33%	32%	20%	35%	22%	28%
• runny nose	13%	25%	14%	15%	20%	21%	18%
• dry/irritated throat	25%	44%	29%	19%	43%	23%	31%
• chest tightness	8%	29%	18%	7%	28%	26%	19%
• flu-like symptoms	15%	23%	14%	10%	23%	7%	15%
• dry skin	24%	35%	24%	15%	36%	18%	25%
• rash/irritated skin	17%	22%	9%	9%	16%	18%	15%
• headache	23%	27%	20%	15%	30%	25%	23%
• lethargy or tiredness	28%	28%	35%	27%	39%	31%	31%
• other symptoms	8%	11%	7%	2%	13%	6%	8%

Table B.20 Building-related symptoms, Switzerland.

	A	B	C	D	E	F	G	H	Mean
Symptoms <u>past month</u>									
• dry eyes	45%	62%	60%	25%	54%	34%	39%	34%	44%
• watering eyes	14%	24%	30%	12%	21%	20%	20%	15%	19%
• blocked/stuffy nose	40%	51%	52%	15%	44%	23%	38%	45%	39%
• runny nose	12%	21%	33%	6%	19%	17%	14%	28%	19%
• dry/irritated throat	48%	53%	60%	14%	47%	26%	37%	52%	42%
• chest tightness	13%	25%	27%	3%	9%	15%	12%	25%	16%
• flu-like symptoms	30%	40%	49%	4%	29%	11%	22%	31%	27%
• dry skin	23%	31%	37%	12%	34%	23%	25%	25%	26%
• rash/irritated skin	4%	13%	14%	0%	11%	6%	7%	9%	8%
• headache	32%	49%	53%	24%	43%	27%	37%	48%	39%
• lethargy or tiredness	29%	66%	70%	32%	47%	40%	48%	59%	49%
• other symptoms	7%	25%	25%	6%	12%	15%	9%	12%	14%
Symptoms <u>here and now</u>									
• dry eyes	23%	31%	34%	11%	30%	24%	32%	36%	28%
• watering eyes	3%	5%	12%	5%	6%	4%	9%	10%	7%
• blocked/stuffy nose	41%	45%	46%	15%	37%	30%	36%	39%	36%
• runny nose	9%	7%	17%	9%	14%	16%	12%	16%	13%
• dry/irritated throat	45%	43%	38%	11%	35%	34%	33%	41%	35%
• chest tightness	9%	14%	15%	2%	9%	8%	10%	17%	11%
• flu-like symptoms	16%	32%	32%	8%	18%	11%	13%	22%	19%
• dry skin	32%	34%	35%	23%	51%	33%	32%	29%	34%
• rash/irritated skin	6%	14%	14%	8%	9%	10%	8%	16%	11%
• headache	9%	21%	17%	8%	10%	12%	15%	27%	15%
• lethargy or tiredness	15%	35%	41%	22%	26%	18%	22%	36%	27%
• other symptoms	5%	10%	8%	3%	7%	12%	10%	16%	9%

Table B.21 Building-related symptoms, Finland.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	22%	24%	22%	30%	39%	30%	28%
• watering eyes	20%	14%	13%	13%	30%	16%	18%
• blocked/stuffy nose	24%	33%	19%	27%	38%	29%	28%
• runny nose	19%	17%	10%	11%	24%	15%	16%
• dry/irritated throat	22%	22%	15%	25%	37%	24%	24%
• chest tightness	4%	3%	8%	7%	16%	10%	8%
• flu-like symptoms	16%	11%	12%	15%	23%	18%	16%
• dry skin	19%	13%	20%	24%	33%	21%	22%
• rash/irritated skin	10%	8%	11%	8%	18%	11%	11%
• headache	22%	14%	16%	23%	24%	25%	21%
• lethargy or tiredness	39%	34%	41%	44%	50%	39%	41%
• other symptoms	17%	13%	10%	12%	13%	11%	13%
Symptoms <u>here and now</u>							
• dry eyes	21%	23%	25%	34%	34%	23%	27%
• watering eyes	10%	10%	4%	9%	12%	10%	9%
• blocked/stuffy nose	36%	32%	31%	40%	34%	47%	37%
• runny nose	20%	10%	7%	16%	15%	13%	14%
• dry/irritated throat	20%	22%	33%	34%	42%	28%	30%
• chest tightness	5%	3%	10%	8%	9%	9%	7%
• flu-like symptoms	19%	12%	11%	24%	22%	18%	18%
• dry skin	50%	44%	49%	56%	57%	47%	51%
• rash/irritated skin	17%	12%	20%	24%	19%	20%	19%
• headache	8%	9%	15%	9%	18%	17%	13%
• lethargy or tiredness	17%	25%	31%	23%	46%	28%	28%
• other symptoms	15%	8%	3%	7%	13%	4%	8%

Table B.22 Building-related symptoms, Norway.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	27%	46%	47%	37%	34%	46%	40%
• watering eyes	9%	10%	11%	7%	11%	13%	10%
• blocked/stuffy nose	15%	33%	28%	17%	26%	33%	25%
• runny nose	8%	14%	10%	7%	9%	13%	10%
• dry/irritated throat	18%	39%	41%	21%	29%	39%	31%
• chest tightness	2%	8%	12%	4%	9%	11%	8%
• flu-like symptoms	13%	21%	19%	4%	8%	16%	14%
• dry skin	28%	40%	36%	19%	35%	38%	33%
• rash/irritated skin	7%	10%	10%	6%	7%	15%	9%
• headache	29%	39%	48%	35%	27%	48%	38%
• lethargy or tiredness	38%	65%	70%	55%	57%	70%	59%
• other symptoms	7%	16%	11%	10%	6%	13%	11%
Symptoms <u>here and now</u>							
• dry eyes	17%	35%	33%	18%	22%	34%	27%
• watering eyes	6%	7%	4%	4%	4%	6%	5%
• blocked/stuffy nose	23%	35%	35%	23%	23%	33%	29%
• runny nose	8%	11%	12%	10%	4%	9%	9%
• dry/irritated throat	20%	40%	36%	29%	30%	29%	31%
• chest tightness	3%	7%	13%	8%	8%	4%	7%
• flu-like symptoms	9%	13%	11%	7%	7%	12%	10%
• dry skin	38%	50%	37%	33%	44%	34%	39%
• rash/irritated skin	7%	17%	12%	13%	13%	9%	12%
• headache	13%	21%	25%	13%	12%	20%	17%
• lethargy or tiredness	39%	53%	60%	45%	36%	52%	48%
• other symptoms	10%	13%	11%	10%	10%	6%	10%

Table B.23 Building-related symptoms, Germany.

	A	B	C	D	E	F	Mean
Symptoms <u>past month</u>							
• dry eyes	19%	46%	29%	49%	38%	59%	40%
• watering eyes	10%	11%	12%	18%	14%	22%	15%
• blocked/stuffy nose	20%	41%	29%	45%	32%	59%	38%
• runny nose	10%	15%	14%	24%	21%	24%	18%
• dry/irritated throat	22%	43%	39%	41%	44%	59%	41%
• chest tightness	5%	12%	7%	14%	16%	17%	12%
• flu-like symptoms	10%	31%	23%	44%	32%	48%	31%
• dry skin	11%	35%	16%	40%	38%	27%	28%
• rash/irritated skin	4%	18%	10%	17%	10%	14%	12%
• headache	30%	37%	26%	40%	33%	51%	36%
• lethargy or tiredness	45%	49%	47%	59%	49%	63%	52%
• other symptoms	7%	6%	8%	12%	15%	15%	11%
Symptoms <u>here and now</u>							
• dry eyes	10%	22%	13%	26%	22%	27%	20%
• watering eyes	5%	1%	3%	1%	4%	5%	3%
• blocked/stuffy nose	30%	33%	28%	39%	40%	58%	38%
• runny nose	6%	9%	11%	8%	11%	15%	10%
• dry/irritated throat	17%	6%	25%	30%	24%	41%	24%
• chest tightness	4%	5%	8%	7%	6%	12%	7%
• flu-like symptoms	19%	23%	20%	28%	30%	32%	25%
• dry skin	25%	32%	17%	43%	38%	21%	29%
• rash/irritated skin	8%	10%	8%	5%	10%	13%	9%
• headache	13%	13%	6%	15%	14%	17%	13%
• lethargy or tiredness	22%	13%	19%	29%	23%	37%	24%
• other symptoms	1%	5%	4%	7%	6%	7%	5%

Table B.24 BSI' last month for the 56 European IAQ Audit buildings.

Country	A	B	C	D	E	F	G	H	Mean
BSIff (full)									
NL	1.7	3.0	3.6	2.8	1.6	2.0			5.5
DK	2.6	3.2	2.3	3.0	2.5	2.8			2.7
UK	4.4	4.9	3.5	3.2	4.3	4.7			4.2
GR	5.2	5.3	4.2	1.3	3.1	3.0			3.7
F	2.2	3.6	2.0	1.4	3.1	2.6			2.5
CH	2.1	4.2	4.4	1.4	3.5	2.3	2.8	3.4	3.0
FIN	1.9	1.5	1.7	2.2	3.3	1.9			2.1
N	2.0	3.3	3.2	2.1	2.3	3.4			2.7
D	1.7	3.2	2.5	3.7	3.0	4.5			3.1
All buildings									3.3
BSIfs (short)									Mean
NL	1.3	2.3	2.6	2.2	1.2	1.6			1.9
DK	2.0	2.4	1.7	2.2	2.0	2.0			2.1
UK	3.2	3.4	2.6	2.3	3.1	3.4			3.0
GR	3.4	3.8	2.9	1.0	2.3	2.0			2.6
F	1.6	2.2	1.3	0.9	2.0	1.7			1.6
CH	1.6	3.0	3.1	1.2	2.6	1.7	2.1	2.4	2.2
FIN	1.3	1.1	1.2	1.7	2.2	1.4			1.5
N	1.6	2.8	2.9	2.0	2.1	2.8			2.4
D	1.4	2.4	1.9	2.6	2.2	3.1			2.3
All buildings									2.2

Table B.25 BSI' here and now for the 56 European IAQ Audit buildings.

Country	A	B	C	D	E	F	G	H	Mean
BSIsf (full)									
NL	1.2	2.2	2.4	2.1	1.3	1.5			1.8
DK	1.9	2.3	2.0	2.3	2.0	2.1			2.1
UK	2.7	3.1	2.3	1.9	2.4	2.7			2.5
GR	3.3	3.0	2.4	0.8	1.6	1.6			2.1
F	1.8	2.8	2.2	1.5	2.6	1.9			2.1
CH	1.7	2.8	2.8	1.0	2.4	1.7	2.0	2.2	2.1
FIN	1.9	1.6	2.1	2.7	3.0	1.9			2.2
N	1.7	2.8	2.5	1.8	1.9	2.2			2.2
D	1.6	1.8	1.5	2.2	2.1	2.5			2.0
All buildings									2.1
BSIss (short)									Mean
NL	1.0	1.7	1.9	1.8	1.0	1.2			1.4
DK	1.6	1.9	1.7	1.8	1.6	1.7			1.7
UK	2.1	2.5	1.8	1.5	2.0	2.2			2.0
GR	2.3	2.2	1.8	0.4	1.1	1.2			1.5
F	1.3	1.7	1.5	1.0	1.8	1.2			1.4
CH	1.3	2.1	1.9	0.7	1.9	1.3	1.6	1.6	1.6
FIN	1.3	1.2	1.6	1.9	2.3	1.3			1.6
N	1.5	2.3	2.2	1.6	1.6	2.0			1.9
D	1.2	1.4	1.0	1.5	1.5	1.8			1.5
All buildings									1.6

APPENDIX C SENSORY MEASUREMENTS

Table C.1 Mean perceived air quality in the selected offices, the supply air and the outdoor air (in decipol).

Perceived air quality [decipol]	Buildings								Mean
Offices	A	B	C	D	E	F	G	H	[decipol]
NL	5.0	3.7	3.9	3.5	3.8	2.9			3.8
DK	8.5	5.2	5.2	6.5	4.9	3.3			5.6
UK	5.6	6.8	5.6	8.0	4.4	5.6			6.0
GR	8.5	7.1	9.2	6.0	7.1	8.6			7.8
F	6.5	3.8	8.4	6.2	6.7	6.1			6.3
CH	8.0	6.1	4.7	6.9	5.7	6.4	6.1	4.3	6.0
FL	5.2	4.1	5.0	4.8	4.4	4.4			4.7
N	5.6	4.0	3.6	3.9	2.7	3.6			3.9
D	8.3	6.9	9.1	5.7	5.7	6.3			7.0
All buildings									**5.7**
Supply air									
NL	2.6	2.7	3.2	2.5	2.0	2.2			2.5
DK		5.6	7.6	-	7.4	7.2			7.0
UK	3.8	4.4	2.4	-	2.9	3.6			3.4
GR	4.9	-	-	4.1	2.1	-			3.7
F	2.0	2.8	-	-	3.7	3.4			3.0
CH	2.7	3.6	3.4	4.1	3.0	3.3	2.3	3.0	3.2
FL	4.4	3.7	3.5	3.2	2.8	2.3			3.3
N	1.9	2.9	2.4	2.3	2.1	4.0			2.6
D	-	4.2	4.3	2.4	1.5	9.8			4.4
All buildings									**3.7**
Outdoor air									
NL	0.9	1.9	1.9	0.7	0.9	0.6			1.2
DK	2.0	0.4	0.2	0.4	0.2	1.1			0.7
UK	7.3	2.1	1.7	2.7	3.5	2.7			3.3
GR	1.2	1.0	0.7	3.4	0.9	3.2			1.7
F	7.8	2.5	1.6	1.0	2.0	5.3			3.4
CH	4.3	2.1	1.8	1.4	1.4	0.5	0.9	1.1	1.7
FL	2.1	1.3	2.1	1.7	3.4	2.1			2.1
N	1.3	1.6	2.0	1.5	1.7	1.6			1.6
D	1.3	2.1	1.6	2.6	1.9	0.8			1.7
All buildings									**1.9**

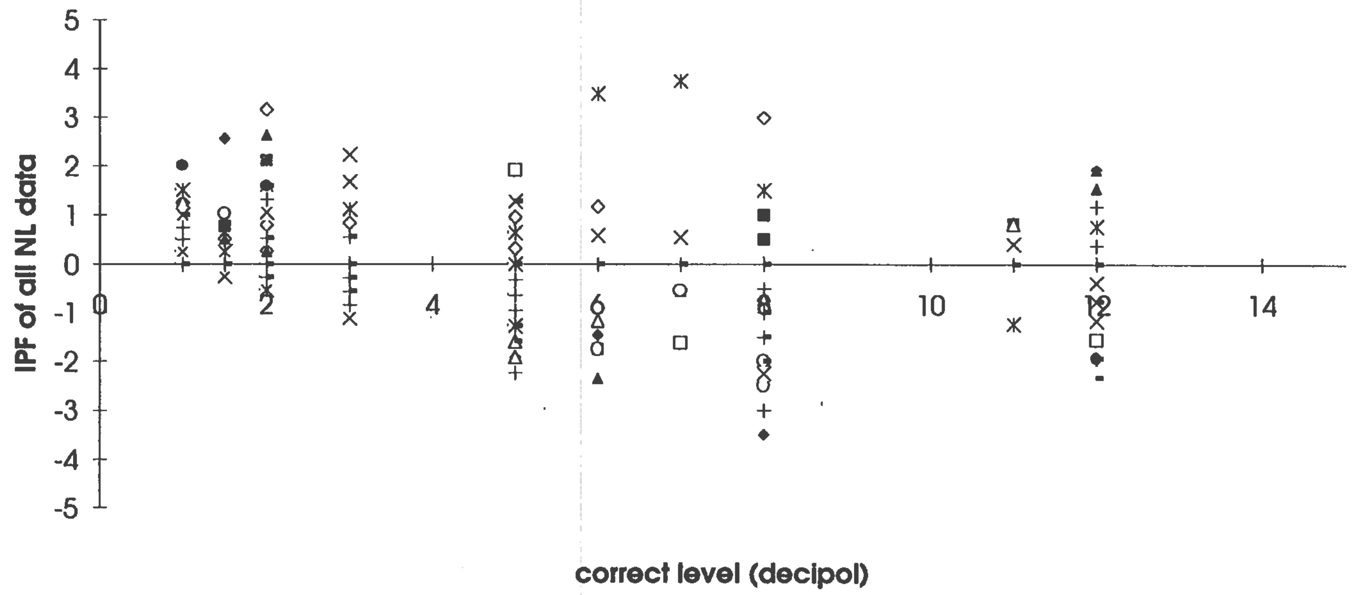
EC - IAQ Audit project 1994

NETHERLANDS (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	0.25	-0.06	-0.06	-0.09	-0.14	0.07	0.00
STDEV	0.51	0.33	0.37	0.32	0.45	0.35	0.39

	Voted
| IPF | < 1	67%
1 < | IPF | < 2	27%
| IPF | > 2	6%



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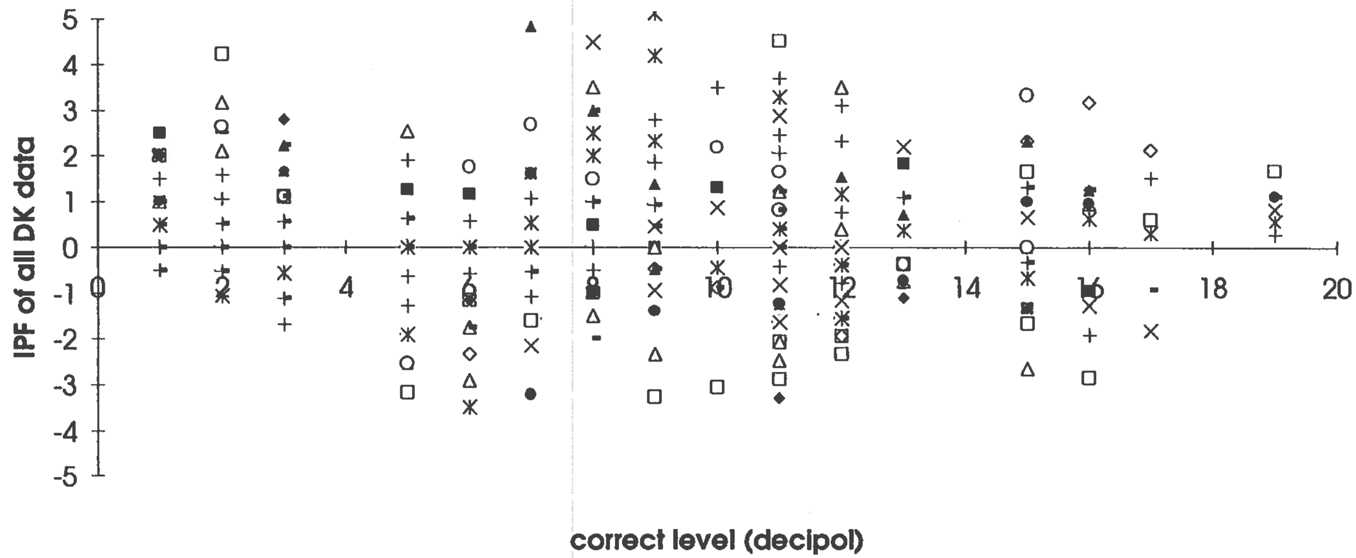
DENMARK (corrected limits 0-5 decipol))

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	0.22	0.16	0.09	-0.08	0.32	0.36	0.18
STDEV	0.38	0.29	0.39	0.44	0.54	0.63	0.44

	Voted
|IPF| < 1	57%
1 < |IPF| < 2	30%
|IPF| > 2	13%



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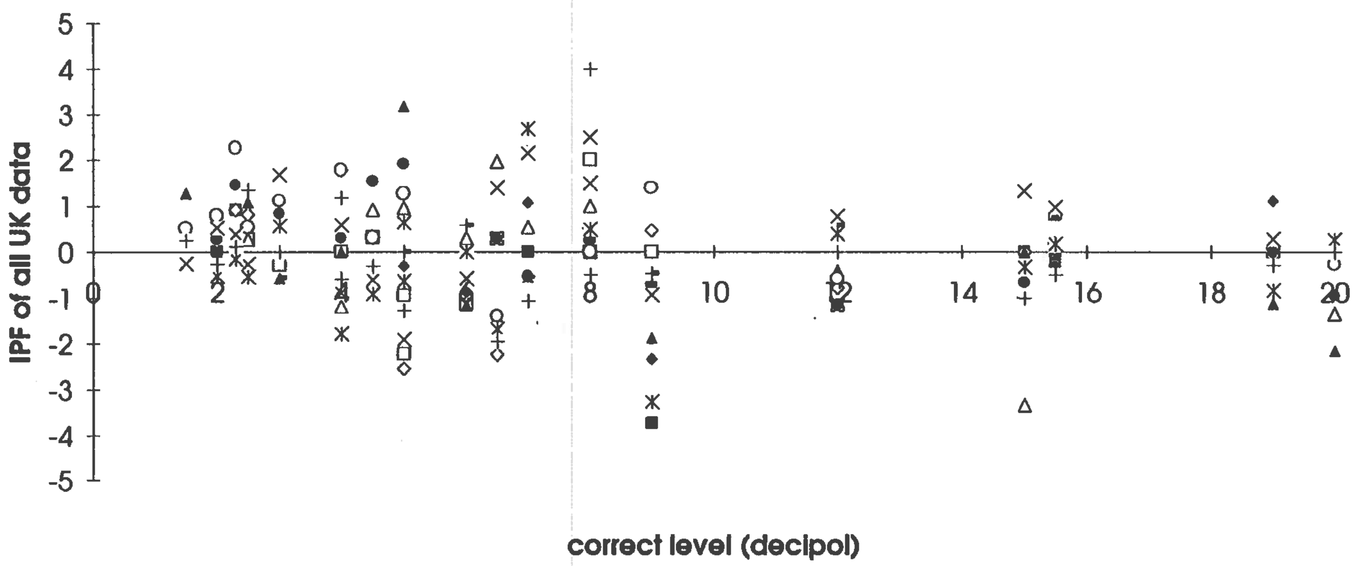
UNITED KINGDOM (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	-0.20		0.04	0.15			0.00
STDEV	0.52		0.26	0.38			0.39

	Voted
| IPF | < 1	72%
1 < | IPF | < 2	21%
| IPF | > 2	7%



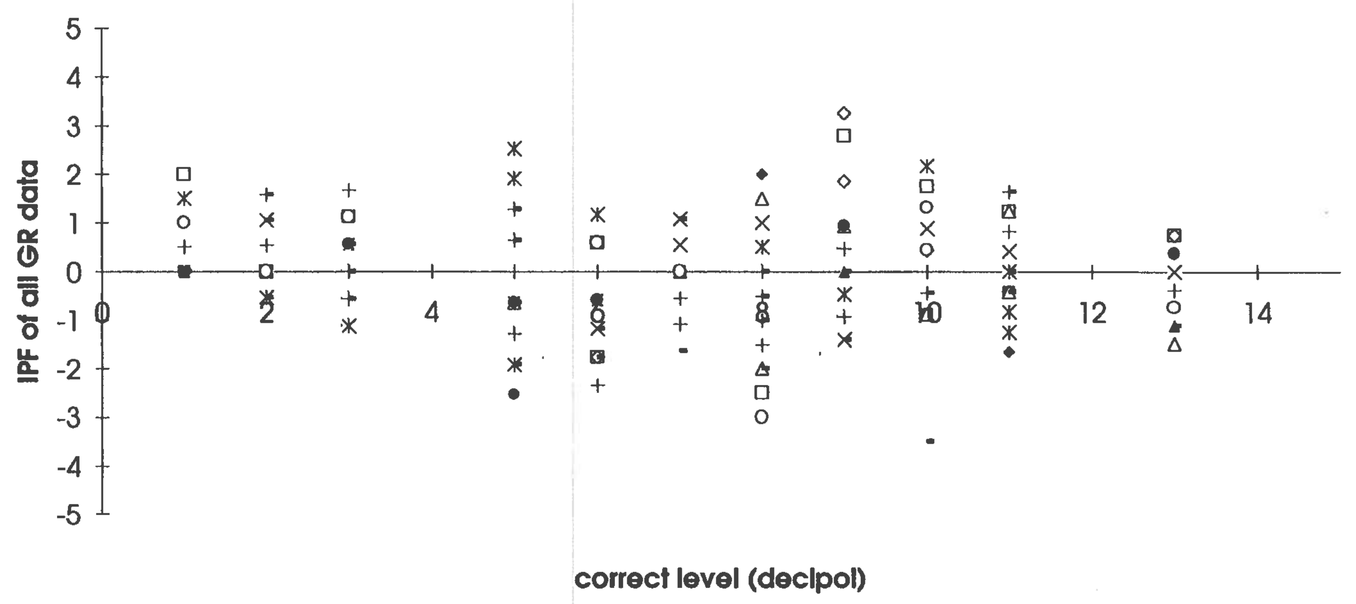
EC - IAQ Audit project 1994

GREECE (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	0.04	0.20	-0.09	-0.13	0.06	0.12	0.03
STDEV	0.47	0.40	0.38	0.29	0.39	0.20	0.36

	Voted
|IPF| < 1	60%
1 < |IPF| < 2	33%
|IPF| > 2	8%



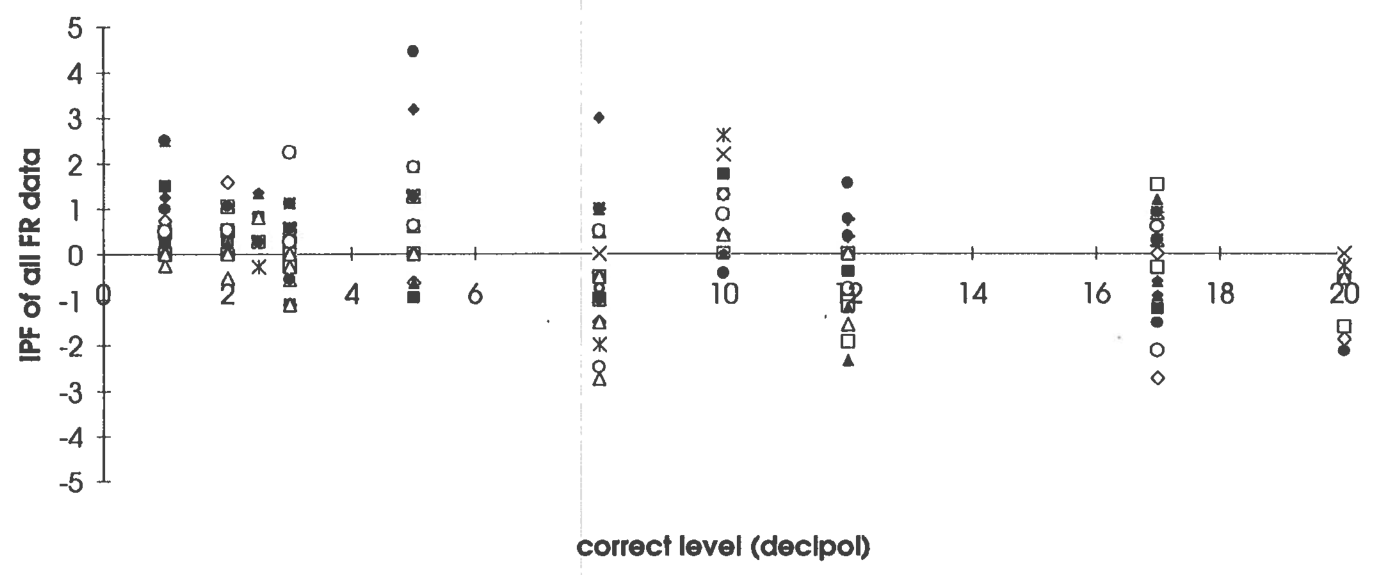
EC - IAQ Audit project 1994

FRANCE (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	-0.37	-0.22	0.01	0.63	0.08	0.34	0.08
STDEV	0.41	0.40	0.38	0.75	0.28	0.12	0.39

	Voted
|IPF| < 1	72%
1 < |IPF| < 2	21%
|IPF| > 2	7%



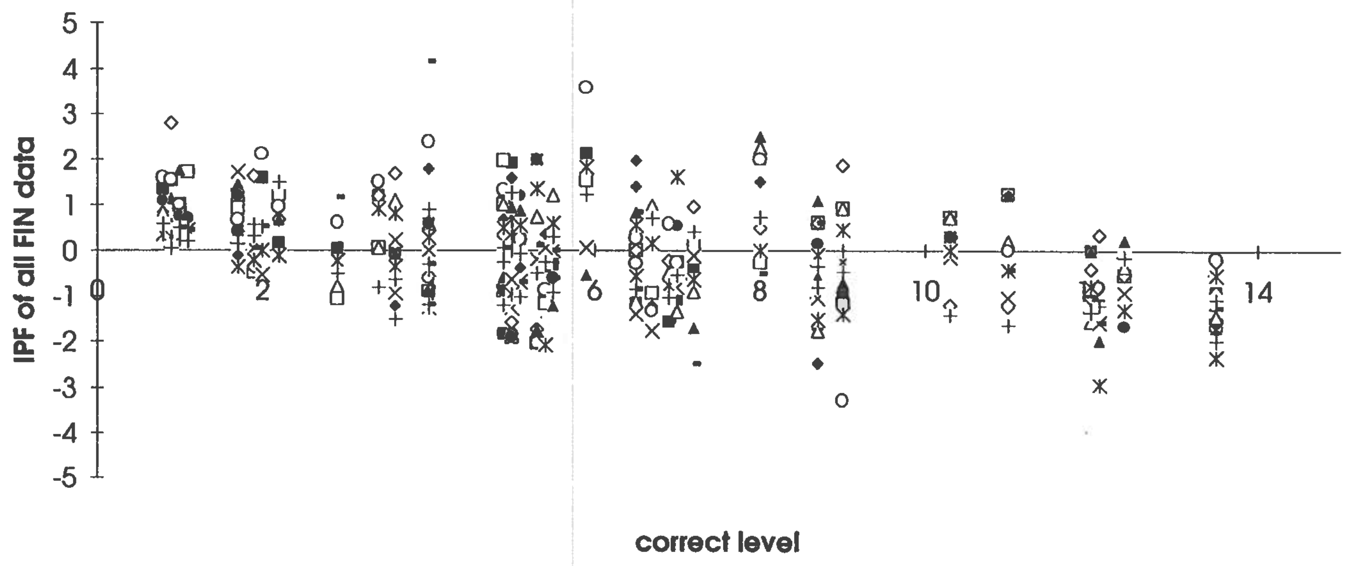
EC - IAQ Audit project 1994

FINLAND (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	0.26	-0.21	-0.32	0.16	0.00	-0.21	-0.05
STDEV	0.35	0.18	0.40	0.42	0.30	0.28	0.32

	Voted
|IPF| < 1	69%
1 < |IPF| < 2	28%
|IPF| > 2	3%



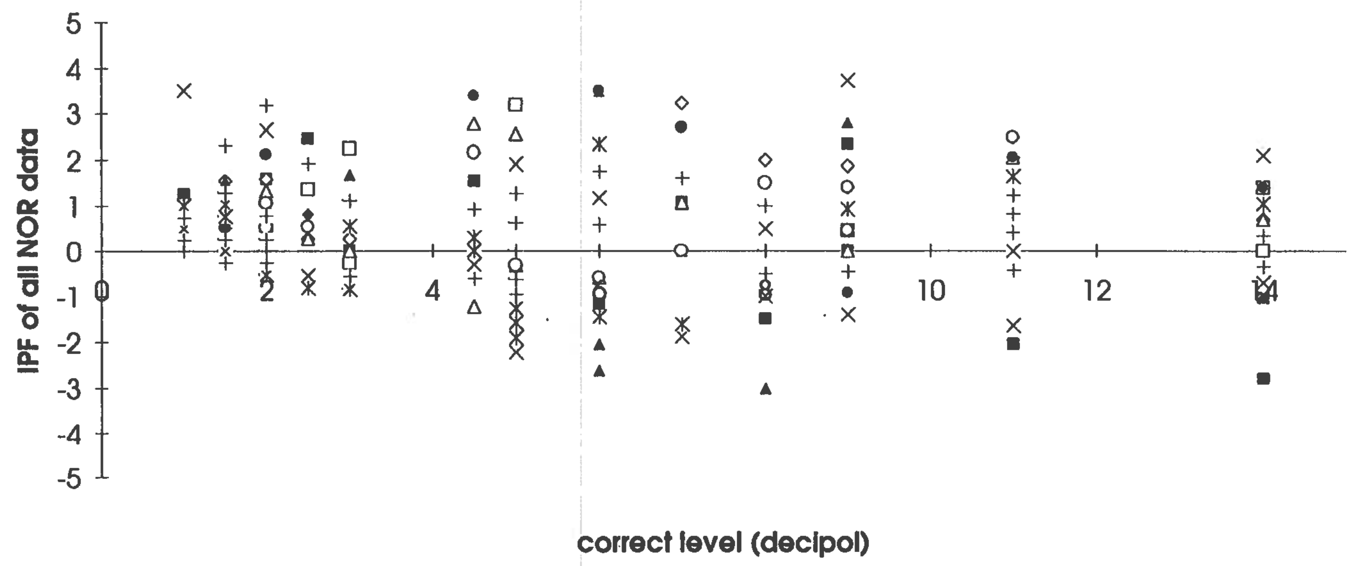
EC - IAQ Audit project 1994

NORWAY (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Build F	Overall
MEAN	0.44	0.49	0.44	0.38	-0.06	0.25	0.32
STDEV	0.25	0.44	0.27	0.59	0.22	0.45	0.37

	Voted
| IPF | < 1	69%
1 < | IPF | < 2	24%
| IPF | > 2	8%



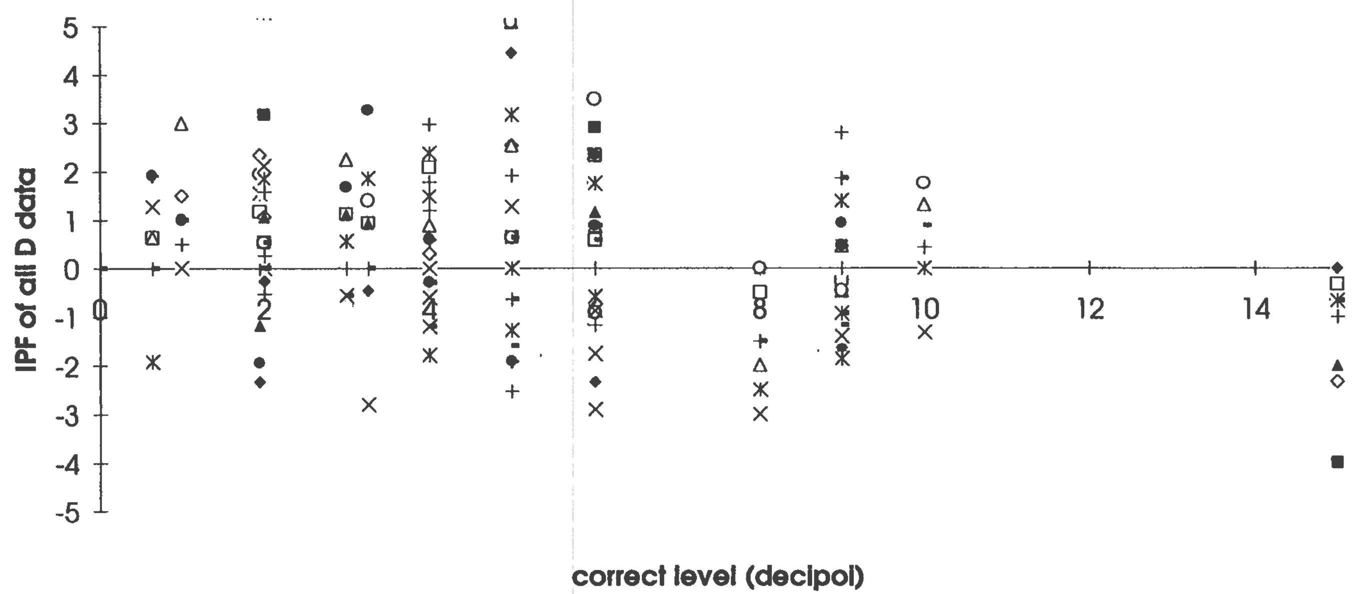
EC - IAQ Audit project 1994

GERMANY (corrected limits 0 - 5 decipol)

PANEL PERFORMANCE FACTOR

	Build A	Build B	Build C	Build D	Build E	Overall
MEAN	0.43	0.20	0.70	0.92	0.26	0.50
STDEV	0.70	0.83	0.57	0.45	0.43	0.60

	Voted
|IPF| < 1	61%
1 < |IPF| < 2	26%
|IPF| > 2	13%



APPENDIX D GENERAL INDOOR AIR QUALITY MEASUREMENTS

The Netherlands

Table D.1 *Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2 [ppm]		CO [ppm]	TVOC		Particulate matter [µg/m³]
	Continuous	Spot		[ppm] Methane	[µg/m³] Toluene	
A - offices	666	934	0.4	2.6	252	83
- supply air	467	540	0.2	2.2	240	
- outside air	.	410	0.2	1.9	80	
- adjacent	.	770	0.2	2.4	315	
B - offices	481	533	0.6	2.4	188	44
- supply air	397	392	0.5	2.1	50	
- outside air	.	411	0.5	1.8	140	
- adjacent	.	551	0.5	4.9	920	
C - offices	805	805	0.6	3.4	382	70
- supply air	388	406	0.5	2.5	80	
- outside air	.	423	0.5	1.8	140	
- adjacent	.	769	0.5	3.5	475	
D - offices	446	489	0.3	2.0	65	50
- supply air	.	405	0.3	1.9	25	
- outside air	.	389	0.3	1.3	25	
- adjacent	.	.	.	.	.	
E - offices	446	536	0.3	1.9	64	35
- supply air	.	385	0.3	1.7	30	
- outside air	.	386	0.3	1.4	10	
- adjacent	.	458	0.3	1.9	110	
F - offices	594	636	0.9	2.4	124	151
- supply air	379	496	0.9	2.3	100	
- outside air	.	484	0.9	1.7	80	
- adjacent	.	616	0.9	2.2	120	

Tabel D.2 The 15 most abundant identified VOC's per building and concentration in μg/m³ (toluene equivalent).

Compounds	Concentration of compound per building [μg/m³]					
	A	B	C	D	E	F
L-limonene	20	5	286	.	.	12
toluene	16	16	24	8	8	19
n-heptane	20	18	14	.	2	.
2-methyl-hexane/benzene	18	6	11	3	.	12
acetone	10	5	10	3	4	13
acetic acid	.	5	9	2	4	4
benzaldehyde	.	6	8	3	4	4
m-xylene	7	9	9	3	.	10
2-methyl 1,3-butadiene	9	.	11	3	.	11
C3-benzene	.	.	9	2	2	4
benzene	.	15	.	.	.	.
methyl-cyclohexane	12	12	6	.	.	.
cyclo-hexane	12	9	.	.	3	.
dimethyl-cyclopentan	6	5	.	.	.	.
n-hexane	.	.	6	.	.	5
o-xylene	.	.	.	2	.	4
p-xylene	.	.	.	.	.	4
nonane/o-xylene	11	.	.	.	.	.
nonane/styrene	.	.	6	.	3	.
nonanal	.	.	.	3	4	.
butane	.	.	.	.	.	3
decanal	.	.	.	2	3	.
2-methylpentane	.	.	.	.	.	4
ethanal	.	.	.	24	.	.
tetrachloorethylene	.	.	.	2	.	.
decane C10H22	.	.	6	.	3	.
undecane C11H24	.	.	.	.	3	.
aliphatic C7H16	14	13	7	.	.	.
aliphatic C9H20	8	5	.	.	.	.
acetic acid but.est.	.	.	.	.	2	.
acetic acid eth.est.	.	.	.	.	2	.
terpene component	.	.	.	2	2	.

Denmark

***Table D.3** Average values of CO, CO_2 and TVOC measurements.*

Building	CO_2 [ppm] continuous	CO_2 [ppm] spot	CO [ppm] continuous	CO [ppm] spot	TVOC [mg/m³] toluene (B&K) continuous	TVOC [mg/m³] toluene (B&K) spot	TVOC (tenax) [µg/m³]	Particulate matter [µg/m³]
A - offices	1222	1078	0.6	0.8	7.4	7.3	200	110
- outside air	-	382	-	0.7	-	3.9	30	
B - offices	735	767	0.8	0.6	6.5	5.4	110	160
- supply air	-	-	-	-	-	-	40	
- outside air	-	382	-	0.5	-	4.6	30	
C - offices	521	599	0.4	0.4	4.8	4.5	70	64
- supply air	-	-	-	-	-	-	40	
- outside air	-	382	-	0.4	-	4.6	40	
D - offices	624	772	0.9	0.7	5.7	5.7	180	47
- outside air	-	386	-	0.6	-	4.1	50	
E - offices	563	613	0.5	0.5	6.8	6.2	130	65
- supply air	-	-	-	-	-	-	40	
- outside air	-	375	-	0.4	-	4.6	20	
F - offices	571	589	0.4	0.3	6.6	6.6	120	80
- supply air	-	500	-	0.3	-	-	60	
- outside air	-	386	-	0.2	-	5.8	30	

***Tabel D.4** The 15 most abundant identified VOC's per building and concentration in µg/m³ (toluene equivalent).*

Compounds	Concentration of compound per building [µg/m³]					
	A	B	C	D	E	F
L-limonene	3	7	1	3	4	4
toluene	7	13	4	14	6	16
n-heptane				4		
acetone	3	14	5	5	5	5
benzaldehyde	5	3	2	3	4	3
2-methyl 1,3 butadiene		18	2			3
benzene	3	5	1	8		5
methyl-cyclohexane	5					
n-hexane				4	3	
m-xylene	4	7	1	12	4	6
o-xylene			1	5		2
p-xylene				3		
nonanal	4	4	6	4	4	4
decanal			4			2
2-methyl-pentane		3				
ethanol		5				
decane C10H22					6	
undecane C11H24	2	3		3	4	
acetic acid ?						5
pentadecane C15H32				3		
branched aliphatic				4		
2,4-dimethylhexane	4	3	2		3	3
1-butanol	4	4			5	3
trimethyl-benzene	3	3	2	4	4	3
C5-alcohol	3				9	
3-methyl-pentane		10				
phtalate compound			3			
allphatic C	2		2			2

United Kingdom

***Table D.5** Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2 [ppm]		CO [ppm]	TVOC	Particulate matter [μg/m³]
	Continuous	Spot		[μg/m³] Toluene	
A - offices	584	588	0.66	200	28
- supply air	.	.	.	120	.
- outside air	.	320	.	170	60
- adjacent	.	.	.	.	85
B - offices	773	464	0	370	20
- supply air	.	368	.	238	.
- outside air	.	.	0	140	20
- adjacent	.	.	.	.	.
C - offices	740	473	0.5	420	32
- supply air	.	.	.	376	.
- outside air	.	320	.	220	30
- adjacent	.	.	.	.	.
D - offices	984	656	0	732	22
- supply air	.	.	.	.	.
- outside air	.	.	.	.	.
- adjacent	.	683	.	760	20
E - offices	639	498	3.24	574	10
- supply air	.	.	.	750	10
- outside air	.	340	3.24	70	0
- adjacent	.	504	3.25	506	10
F - offices	462	416	0	320	8
- supply air	.	391	.	160	.
- outside air	.	.	.	40	.
- adjacent	.	.	.	373	.

Tabel D.6 *The 15 most abundant identified VOC's per building and concentration in $\mu g/m^3$ (toluene equivalent).*

Compounds	**Concentration of compound per building [$\mu g/m^3$]**					
	A	**B**	**C**	**D**	**E**	**F**
toluene	19	12	34	146	49	154
l-limonene	23	12	95	.	14	9
n-hexane	.	5	7	102	26	44
1,1,1-trichloroethan	68	13	7	26	15	.
acetone	13	18	16	57	.	7
2-methyl-pentane	5	.	7	67	.	16
m-xylene	9	5	15	43	.	.
benzene	.	5	19	39	.	14
n-heptane	.	.	8	29	14	32
C3-benzene	5	4	7	.	14	.
aliphatic C7H16	.	.	7	20	16?	18
3-methyl pentane	.	.	7	49	.	17
methyl cyclohexane	.	.	7	23	.	25
methyl cyclopentane	.	.	.	45	.	17
undecane C11H24	.	.	.	.	65	6
2-methyl butane	4	.	.	51	.	.
o-xylene	.	.	.	22	.	.
terpene compound	6	.	7	.	11	.
benzaldehyde	6	5	.	.	.	.
ethanol	5	5	.	.	.	.
acetic acid ethyl ester	.	31	.	.	.	.
(CF2)n	.	.	29	.	.	.
2-methyl propanoic acid	24	.	.	.	.	.
decan C10H22	.	.	.	.	21	.
dodecanoic acid	.	.	.	.	21	.
butane	.	.	.	21	.	.
phtalate compound	.	.	.	.	.	16
benzoic acid?	.	.	.	.	15	.
alicyclic	.	.	.	.	11	.
cyclo hexane	.	.	.	.	.	10
1-ethoxy-2-propanol	8	9	.	.	.	.
acetic acid?	.	.	.	.	.	.
tetradecane C14H30	.	5	.	.	.	.
2-methyl-1,3-butadiene	.	4	.	.	.	.

Greece

***Table D.7** Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2[ppm]	CO [ppm]	TVOC	Particulate matter [μg/m³]
	Spot	spot	[μg/m³] Toluene	
A - offices	620	<2	482	550
- supply air	593	<1	80	
- outside air	380	<2	220	
- adjacent	335	<1	260	
B - offices	858	<1	968	148
- supply air	.		.	
- outside air	360		50	
- adjacent	784		754	
C - offices	750	<1	246	59
- supply air	.		.	
- outside air	370		40	
- adjacent	653		240	
D - offices	752	<1	518	177
- supply air	460		260	
- outside air	370		200	
- adjacent	440		770	
E - offices	541	<1	146	160
- supply air	580		70	
- outside air	350		110	
- adjacent	626		369	
F - offices	1280	2.2	612	100
- supply air	.	.	.	
- outside air	570	2	330	
- adjacent	911	3	538	

***Tabel D.8** The most abundant identified VOC's per building and concentration in µg/m³ (toluene equivalent).*

Compounds	Concentration of compound per building [µg/m³]					
	A	B	C	D	E	F
toluene	46	31	17	84	12	94
m-xylene	23	187	4	43	5	59
benzene	22	.	5	34	7	56
n-hexane	16	.	6	17	6	29
2-methyl-pentane	13	.	3	24	3	45
1,1,1-trichlorethane	11	.	15	.	.	.
acetone	11	24	16	46	9	53
C3-benzene	11	65	.	21	3	29
2-meth-1,3-butadiene	10	.	12	13	5	27
n-heptane	10	.	.	.	4	16
p-xylene	9	57	.	12	.	18
octane	8	.	.	.	.	.
3-methyl-pentane	8	.	.	13	.	26
2-butoxy-ethanol	.	.	6	.	.	.
2-methyl-butane	.	.	3	14	.	37
alpha-pinene	.	134	.	.	.	.
aliphatic C?	.	.	5	.	.	.
benzaldehyde	.	.	.	.	2	.
butoxyethoxyethylacetate	.	.	.	.	6	.
C2C13F3 (freon..)	.	.	.	.	.	16
C3-benzene	.	44	.	14	.	19
C9H20	.	32	.	.	.	.
decane C10H22	.	107	.	.	.	.
L-limonene	.	26	.	.	.	.
dodecanoic acid	.	.	.	21	21	.
naphthalene	.	.	5	11	3	.
nonanal	.	.	4	.	.	.
nonane	.	78	.	.	.	.
o-xylene	.	30	.	16	3	28
terpene compound	.	22	.	.	.	.

France

***Table D.9** Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2 [ppm]	CO [ppm]	TVOC	Particulate matter [µg/m³]
	Spot	spot	[µg/m³] Toluene	
A - offices	611	1	204	.
- supply air	428	1	150	
- outside air	330	1	60	
- adjacent	602	1	.	
B - offices	904	10	616	57
- supply air	816	9	618	
- outside air	325	7	80	
- adjacent	597	11	790	
C - offices	826	0	537	128
- supply air	.	.	.	
- outside air	347	1	140	
- adjacent	507	0	510	
D - offices	752	0.5	486	.
- supply air	.	.	.	
- outside air	400	0	110	
- adjacent	575	0	355	
E - offices	634	0	278	54
- supply air	390	0	95	
- outside air	330	0	40	
- adjacent	532	0	334	
F - offices	940	0	357	64
- supply air	564	0	360	
- outside air	330	0	60	
- adjacent	780	0	390	

Tabel D.10 *The 15 most abundant identified VOC's per building and concentration in μg/m³ (toluene equivalent).*

Compounds	**Concentration of compound per building [μg/m³]**					
	A	**B**	**C**	**D**	**E**	**F**
2-methyl-pentane	.	26	11	9	.	7
n-hexane	.	30	.	.	.	.
C7H16	.	.	.	6	.	.
methyl-cyclohexane	.	.	.	5	.	6
n-heptane	.	.	10	15	.	7
C-?? alcane	4	.	.	.	.	.
C9H20 alcane?	.	.	24	.	.	.
decane C10H22	4	.	10	.	.	.
undecane C11H24	.	.	13	.	.	.
tetradecane C14H30	4	.	.	.	.	.
toluene	19	132	81	25	21	17
m-xylene	20	63	24	10	.	12
o-xylene	11	24	10	.	.	6
p-xylene	6	28	.	.	.	.
trimethyl-benzene	4	18	12	.	.	8
2-me-hexane/benzene?	7	41	22	13	.	10
ethanol	.	15	.	48	110	10
1-butanol	.	.	.	10	.	.
acetone	17	32	15	9	36	10
cyclohexanone	.	.	.	.	21	.
l-limolene	89	.	.	.	.	11
alpha-pinene	.	16	.	.	.	.
1,1,1-trichlorethane	10	56	10	.	14	14
dichlorobenzene	.	18	14	.	.	.
acetic acid	7	.	11	5	11	.
dodecanoic acid	.	.	.	6	.	.
benzaldehyde	4	.	.	.	11	10
decanal	.	.	.	5	.	.
phtalate compound	.	.	.	16	.	.
siloxanes	.	.	.	16	16-62	.

Switzerland

Table D.11 *Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2 [ppm]		CO [ppm]	TVOC	Particulate matter [μg/m³]
	Continuous	Spot		[μg/m³] Toluene	
A - offices	775	833	<1	160	300
- supply air		895		200	
- outside air		420	<1		
- adjacent		800		580	300
B - offices	723	622		190	250
- supply air		440		160	
- outside air		375	<1	60	<100
- adjacent		620			
C - offices	642	564	<1	320	<100
- supply air		360	<1	310	<100
- outside air		350	<1	360	<100
- adjacent		500	<1	390	<100
D - offices	781	904	<1	450	<100
- supply air		400		170	
- outside air		360		360	
- adjacent		900		320	
E - offices	703	689	1	160	<100
- supply air		360		170	
- outside air		360	0	190	
- adjacent		530		220	
F - offices	652	828	<1	1820	240
- supply air		700	<1	580	
- outside air		400	<1	420	
- adjacent		890	<1	1980	280
G - offices	703	799		120	260
- supply air		650		70	
- outside air		400	<1	30	
- adjacent		700		110	300
H - offices	711	712	<1	920	<100
- supply air		380		820	
- outside air		392		340	
- adjacent		700		390	<100

Tabel D.12 *The most abundant identified VOC's in audited buildings and concentration in µg/m³ (toluene equivalent).*

Compounds	Number of buildings where detected	Average concentration of compound [µg/m³]
toluene	8	27
acetone	8	25
aiphatic C7H16	8	16
m-xylene	8	15
dichloromethane	8	11
n-heptane	8	26
C5H2O8 ester	8	10
2-methyl-pentane	8	9
trimethyl-benzene	8	6
aliphatic C7H16	8	23
methyl-cyclohexane	8	17
l-limolene	8	13
o-xylene	8	5
benzaldehyde	8	5
p-xylene	8	5
1-butanol	8	17
ethanol	8	4
undecane C11H24	8	4
dodecane C12H26	8	2
2-methyl-1,3-butadiene	7	3
3-methyl-pentane	7	6
dimethyl-cyclopentane	7	6
decane C10H22	7	4
1,1,1-trichloroethane	6	3
dimethyl-cyclopentan	5	6
methyl-cyclopentane	4	11
acetic acid ehtyl ester	4	3
n-hexane	1	201

Finland

***Table D.13** Average values of CO_2, CO and TVOC measurements.*

Building	CO_2 [ppm]	CO [ppm]	TVOC [mg/m³] Methane	TVOC [mg/m³] Toluene	Particulate matter [μg/m³]
A - offices	728	0.6	0.93	0.11	58
- supply air	478	0.5	0.79	0.05	
- outside air	491	1.6	1.11	0.07	
- adjacent	.	.	.	0.03	
B - offices	640	0.5	1.05	0.05	< 20
- supply air	472	0.4	0.90	0.07	
- outside air	467	1.2	0.79	0.01	
- adjacent	621	1.4	0.91	0.10	
C - offices	759	1.4	7.28	0.14	58
- supply air	787	1.1	10.86	0.19	
- outside air	462	0.5	0.84	0.08	
- adjacent	707	1.1	7.14	0.08	
D - offices	742	0.6	1.17	0.04	48
- supply air	463	0.4	0.74	0.04	
- outside air	472	0.3	0.75	0.06	
- adjacent	761	0.8	1.26	0.02	
E - offices	795	0.7	1.35	0.08	65
- supply air	484	0.5	0.96	0.08	
- outside air	.	.	.	0.09	
- adjacent	.	0.7	1.76	0.12	
F - offices	759	0.9	2.02	0.29	55
- supply air	526	0.6	0.88	0.06	
- outside air	.	.	.	0.06	
- adjacent	749	0.9	2.02	0.03	

Tabel D.14 *The identified VOC's per building and concentration in μg/m³ (toluene equivalent).*

Compounds	Concentration of compound per building [μg/m³]					
	A	B	C	D	E	F
acetone	1	.	.	1	1	3
acetic acid methylester	5	.	3	.	.	.
hexane	2	1	2	1	5	6
methylpropanoic acid methylester	3	.	.	.	.	.
toluene	2	14	5	5	7	10
xylene	3	19	4	2	2	9
C10H16 (cyclic)	1	5	.	.	2	.
C10H22 (branched)	5	.	15	2	.	28
benzene	.	4	.	1	2	3
methylhexane	.	1	1	1	2	2
methylcylohexane	.	2	1	.	1	.
hexanal	.	2	.	.	.	.
octane	.	2	.	1	.	1
ethenylbenzene	.	2	.	.	.	1
trimethylhexane	.	1	.	.	.	.
nonane	.	3	.	.	.	1
C9H18	.	1	.	.	.	.
heptanol	.	4	.	.	.	.
a-pinene	.	3	.	.	.	.
propylbenzene	.	2	.	.	.	.
ethylmethylbenzene	.	4	.	.	.	.
C3-subst. benzene	.	4	.	.	.	.
methylundecane	.	3	.	.	.	.
trimethylbenzene	.	9	.	.	.	2
methylethylbenzene	.	2	.	.	.	14
C16H34	.	2	.	.	.	.
tetradecane	.	2	1	.	.	.
2-propyl furane	.	.	1	.	.	4
tetradecanoic acid 1-methylester	.	.	2	.	1	.
dochloromethane	.	.	.	1	2	2
methylpentane	.	.	.	1	1	.
hexanol	.	.	.	1	2	.
ethylbenzene	.	.	.	1	.	3
limolene	.	.	.	2	.	.
trichloroethane	.	.	.	.	2	2
heptane	.	.	.	.	2	.
tetrachloroethene	.	.	.	.	1	.
methylpropene	.	.	.	.	1	.
dodecane	.	.	.	.	2	.
1-butanol	.	.	.	.	.	2
C9H12	.	.	.	.	.	4

Norway

Table D.15 *Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2 [ppm]		CO [ppm]	TVOC		Particulate matter [µg/m³]
	Continuous	Spot		[mg/m³]	[µg/m³] Toluene	
A - offices	505	661	1.9	3.99	1840	19
- supply air	.	449	2.1	3.79	210	
- outside air	.	452	1.5	3.54	370	
- adjacent	.	587	2.4	4.26	850	23
B - offices	588	641	1.7	3.60	230	23
- supply air	.	453	1.8	3.28	220	
- outside air	.	453	1.8	3.10	240	
- adjacent	.	618	1.8	3.24	300	30
C - offices	622	623	0.8	3.68	160	24
- supply air	.	485	0.7	4.29	90	
- outside air	.	435	0.7	6.00	180	
- adjacent	.	673	.	.	250	40
D - offices	740	625	1.1	4.73	200	9
- supply air	.	426	0.8	2.96	50	
- outside air	.	430	1.0	3.89	40	
- adjacent	.	540	1.1	3.82	430	18
E - offices	616	543	1.2	4.89	230	16
- supply air	.	434	1.1	5.03	140	
- outside air	.	428	1.0	3.30	60	
- adjacent	.	535	1.2	4.60	250	30
F - offices	679	676	1.7	4.40	510	29
- supply air	.	441	1.6	3.70	180	
- outside air	.	443	1.7	3.94	40	
- adjacent	.	678	1.7	.	230	44

Tabel D.16 *The most abundant identified VOC's per building and concentration in µg/m³ (toluene equivalent).*

Compounds	**Concentration of compound per building [µg/m³]**					
	A	**B**	**C**	**D**	**E**	**F**
2-methyl-pentane	192	18	10	7	6	14
3-methyl-pentane	242	24	12	8	7	16
acetone			3	7	7	
aliphatic C7H16	171	19	8	7	6	50
benzene	109	20	7	10	8	
cyclo-hexane	118	12	5	5		25
dimethyl-cyclopentane	54		5			14
L-limonene		8				365
m-xylene	23	14	5	9	7	
methyl-cyclohexane	235	24	10	10	8	42
methyl-cyclopentane	337	29	15	10	9	24
n-heptane	314	28	12	11	11	89
n-hexane	708	62	36	20	19	45
toluene	158	95	32	51	20	18

Germany

Table D.17 *Average values of CO, CO_2, TVOC and particulate matter measurements.*

Building	CO_2 [ppm]		CO [ppm]	TVOC		Particulate matter [μg/m³]²
	Continuous	Spot		[ppm] methane	[μg/m³] Toluene	
A - offices	748	747	0.39	3.3	70	91
- supply air	.	350	0.25		.	
- outside air	.	350	0.25		96	
B - offices	680	662	1.28	4.7	101	38
- supply air	.	350	0.9		64	
- outside air	.	350	0.9		96	
C - offices	590	587	0.78	4.4	64	33
- supply air	.	412	0.5		127	
- outside air	.	412	0.5		167	
D - offices	1050	886	1.15	5.2	393	92
- supply air	.	412	0.9		630	
- outside air	.	512	0.9		240	
E - offices	628	600	0.59	4.6	170	57
- supply air	.	410	0.4		210	
- outside air	.	410	0.4		180	
F - offices	562	564	0.11	3.8	80	56
- supply air	.	380	0.15		110	
- outside air	.	380	0.15		150	

Tabel D.18 *The 15 most abundant identified VOC's per building and concentration in $\mu g/m^3$ (toluene equivalent).*

Compounds	Concentration of compound per building [µg/m³]					
	A	B	C	D	E	F
acetone	8	4	26	44	18	16
toluene	2	13	6	28	13	10
benzene	2	2	2	7	7	1
tetrachlorethylene	2	1	2	4	.	1
benzaldehyde	2	2	1	.	4	2
2-methyl-pentane	1	3	3	.	5	1
acetic acid?	.	3	4	6	5	2
terpene-compound	2	2	2	5	.	.
ethanol	16	4	12	7	.	.
m-xylene	.	2	.	10	10	2
C3-benzene	.	1	.	.	8	1
p-xylene	.	.	.	4	3	1
butane	22	.	.	.	3	.
acetic acid	3	4	.	.	.	.
1-butanol	3	.	.	.	.	1
l-limolene	2	.	.	25	.	.
n-heptane	2	.	2	.	.	.
3-methyl-pentane	.	2	3	.	.	.
o-xylene	.	.	.	4	3	.
2-methyl butane	.	1	.	.	5	.
nonane/styrene	.	1	.	.	.	2
aliphatic cpd	.	.	4	.	.	.
methyl-cyclohexane	.	.	3	.	.	.
octane	.	.	2	.	.	.
dichloro methane	.	.	1	.	.	.
alpha-pinene	.	.	.	5	.	.
undecane C11H24	.	.	.	4	.	.
decane C10H22	.	.	.	3	.	.
acetic acid b.est?	.	.	.	.	3	.
2-meth-1,3 butandiene	.	.	.	.	.	1

APPENDIX E GENERAL INDOOR CLIMATE MEASUREMENTS

Table E.1 *Average values of thermal and noise measurements in The Netherlands.*

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	22.7	22.2	0.10	26	44
	- supply air	19.8			28	
	- outside air	4.4			53	
B	- offices: 1.1 m	21.7	21.8	0.11	33	47
	- supply air	19.3			38	
	- outside air	11.6			56	
C	- offices: 1.1 m	22.0	22.1	0.07	38	50
	- supply air	20.4			32	
	- outside air	7.2			60	
D	- offices: 1.1 m	23.0	23.4	0.14	29	49
	- supply air	19.3			36	
	- outside air	10.5			57	
E	- offices: 1.1 m	22.9	23.1	0.10	29	46
	- supply air	16.6			41	
	- outside air	6.5			47	
F	- offices: 1.1 m	21.2	21.4	0.10	28	50
	- supply air	21.6			31	
	- outside air	-0.5			71	

Table E.2 *Average values of thermal and noise spot measurements in Denmark.*

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	23.6	23.4	0.08	29	51
	- outside air				48	
B	- offices: 1.1 m	23.3	23.0	0.08	26	43
	- supply air	24.5			25	
	- outside air	3.3			84	
C	- offices: 1.1 m	23.8	23.5	0.06	23	41
	- supply air	25.0				
	- outside air	5.1			58	
D	- offices: 1.1 m	23.6	23.5	0.01	24	41
	- outside air	3.8			73	
E	- offices: 1.1 m	24.0	23.7	0.08	32	45
	- supply air	25.4				
	- outside air	8.7			93	
F	- offices: 1.1 m	24.1	23.8	0.11	38	52
	- supply air	25.5			39	
	- outside air	6.9			71	

Table E.3 *Average values of thermal and noise measurements in United Kingdom.*

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	23.4	23.4	0.16	28	52
	- supply air	.			.	
	- outside air	11.0			90	
B	- offices: 1.1 m	23.4	24.0	0.10	28	58
	- supply air	.			.	
	- outside air	8.3			64	
C	- offices: 1.1 m	22.4	22.8	0.08	47	54
	- supply air	.			.	
	- outside air	10.0			87	67
D	- offices: 1.1 m	21.9	21.7	0.11	38	55
	- supply air	.			.	
	- outside air	8.8			75	
E	- offices: 1.1 m	22.8	23.8	0.13	46	54
	- supply air	.			.	
	- outside air	12.8			78	
F	- offices: 1.1 m	23.2	23.1	0.10	30	54
	- supply air	.			.	
	- outside air	11.5			51	67

***Table E.4** Average values of thermal and noise measurements in Greece.*

Building	location	tair [°C]	tmrt [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	24.2	24.1	0.11	30	56
	- supply air	39.4			16	
	- outside air	20.7			35	65
B	- offices: 1.1 m	23.4	23.4	0.06	31	51
	- supply air	.			.	
	- outside air	15.0			30	75
C	- offices: 1.1 m	22.6	23.5	0	28	54
	- supply air	.			.	
	- outside air	12.5			35	60
D	- offices: 1.1 m	24.8	24.7	0.13	50	53
	- supply air	25.7			46	
	- outside air	13.0			68	68
E	- offices: 1.1 m	23.4	22.9	0.09	28	54
	- supply air	28.6			19	
	- outside air	12.2			45	65
F	- offices: 1.1 m	22.7	21.6	0.06	32	57
	- supply air	.			.	
	- outside air	15.0			28	70

***Table E.5** Average values of thermal and noise measurements in France.*

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	22.6	21.1	0.03	46	32
	- supply air	20.0			44	
	- outside air	9.1			80	49
B	- offices: 1.1 m	23.6	22.3	0.07	45	43
	- supply air	25.9			38	
	- outside air	9.4			66	68
C	- offices: 1.1 m	23.4	21.0	0.05	42	43
	- supply air	.			.	
	- outside air	10.2			50	54
D	- offices: 1.1 m	24.4	22.8	0.09	46	49
	- supply air	.			.	
	- outside air	14.2			32	75
E	- offices: 1.1 m	20.4	19.5	0.06	47	55
	- supply air	19.0			48	
	- outside air	16.5			42	75
F	- offices: 1.1 m	26.4	24.9	0.09	41	55
	- supply air	24.9			37	
	- outside air	14.7			54	66

***Table E.6** Average values of thermal and noise measurements in Switzerland.*

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	22.3	21.1	0.16	34	46
	- outside air	11.5			65	
B	- offices: 1.1 m	23.0	21.5	0.14	50	45
	- outside air				72	53
C	- offices: 1.1 m	23.1	21.1	0.09	47	45
	- outside air	8.6			70	
D	- offices: 1.1 m	23.0	22.1	0.11	36	47
	- outside air	5.5			61	53
E	- offices: 1.1 m	23.6	20.7	0.09	28	49
	- outside air					53
F	- offices: 1.1 m	22.1	21.1	0.10	40	45
	- outside air	5.0				
G	- offices: 1.1 m	23.2	21.9	0.15	33	43
	- outside air	5.4			62	55
H	- offices: 1.1 m	22.9	21.5	0.11	42	41
	- outside air				75	63

Table E.7 Average values of thermal and noise measurements in Finland.

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices	21.0	20.8	0.10	18.0	38.5
	- supply air	21.3			11.0	
B	- offices	22.7	23.6	0.09	15.0	39.5
	- supply air	19.7			13.2	
C	- offices	21.5	21.6	0.09	17.4	37.0
	- supply air	22.2			12.5	
D	- offices	22.9	22.7	0.08	19.9	39.6
	- supply air	21.2			18.8	
E	- offices	23.1	22.9	0.07	21.1	42.1
	- supply air	29.7			13.3	
F	- offices	22.6	22.5	0.06	20.9	36.6
	- supply air	17.0			20.9	

Table E.8 Average values of thermal and noise measurements in Norway.

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	21.8	22.6	0.04	20	40
	- supply air	19.7				
	- outside air	-3.4				
B	- offices: 1.1 m	23.0	23.1	0.13	15	45
	- supply air	15.2				
	- outside air	-4.8				
C	- offices: 1.1 m	24.1	24.3	0.05	10	43
	- supply air	24.1				
	- outside air	-7.4				
D	- offices: 1.1 m	24.0	24.8	0.07	17	41
	- supply air	19.2				
	- outside air	7.2				
E	- offices: 1.1 m	23.5	23.3	0.09	17	43
	- supply air	21.0				
	- outside air	3.1				
F	- offices: 1.1 m	23.9	23.7	0.05	24	39
	- supply air	21.9				
	- outside air	2.0				

Table E.9 Average values of thermal and noise measurements in Germany.

Building	location	tair [°C]	top [°C]	Vair [m/s]	RH [%]	noise [dB(A)]
A	- offices: 1.1 m	23.1	23.3	0.06	25.8	54
	- supply air					
	- outside air					60
B	- offices: 1.1 m	21.5	21.7	0.07	48.2	56
	- supply air					
	- outside air					49
C	- offices: 1.1 m	20.6	20.8	0.04	46.7	51
	- supply air					
	- outside air					75
D	- offices: 1.1 m	20.0	20.5	0.05	29.5	53
	- supply air					
	- outside air					68
E	- offices: 1.1 m	22.9	23.2	0.09	46.9	42
	- supply air					
	- outside air					64
F	- offices: 1.1 m	22.2	22.3	0.05	50.2	47
	- supply air					
	- outside air					42

APPENDIX F VENTILATION MEASUREMENTS

***Table F.1** Average airflows per m² floor area office per investigated building in The Netherlands.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Adjacent airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	19.0	2.14	0	0.16	1.28
B	33.6	2.0	1.71	0	3.81
C	29.6	1.11	1.24	0.32	2.1
D	18.6	3.59	0	0	3.59
E	18.0	2.19	0.16	0	2.36
F	26.3	3.30	0	0.30	2.97

***Table F.2** Average airflows per m² floor area office per investigated building in Denmark.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	34	.	0.41	0.41
B	46	0.83	0.33	1.16
C	20	2.95	0.6	3.55
D	14	.	1.0	1.0
E	31	2.06	0.39	2.45
F	4526	1.06	0.46	1.52

***Table F.3** Average airflows per m² floor area office per investigated building in The United Kingdom.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Adjacent airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	234	1.1	0.57	0	0.78
B	576	2.4	0	0	0.56
C	1209	4.0	.	0	1.0
D	83	.	0.34	0.07	0.34
E	1800	11.0	0	0	1.1
F	760	4.6	0	0	2.09

***Table F.4** Average airflows per m² floor area office per investigated building in Greece.*

Building	Floor area office [m²]	Supply air flow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Adjacent airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	38.5	0.94	0	2.1	0.94[1]
B	40	0	0.8	2.4	0.8
C	50.5	0	2.4	2.9	2.4
D	16.6	2.8	0.03	0.9	2.83
E	17.5	7.1	0.27	7.4	7.37[1]
F	24.2	0	0.26	0.36	0.26

1: Including recirculated air

***Table F.5** Average airflows per m² floor area office per investigated building in France.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Adjacent airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	18.9	1.05	0	0	1.05
B	12.6	9.5	0	0	0.76
C	15.3	.	0.33	0.03	0.33
D	63.6	.	1.42	0	1.42
E	11.7	0.81	0	0	0.81
F	42.1	1.08	0	0	0.43

***Table F.6** Average airflows per m² floor area office per investigated building in Switzerland.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Adjacent airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	396	0	0.03	0.06	0.03
B	729	1.7	0	0	0.62
C	1240	0.55	0	0.02	0.55
D	17	1.20	0	2.71	1.2
E	19	2.58	0	1.04	2.01
F	36	3.85	0	1.27	1.93
G	25	2.86	0	1.27	2.86
H	48	10.1	0	0.04	8.99

***Table F.7** Average airflows per m² floor area office per investigated building in Finland.*

Building	Floor area office [m²]	Supply air flow rate [l/s.m²]	Infiltration air flow rate [l/s.m²]	Adjacent air flow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	13.3	3.12	0	0	3.12
B	13.0	2.66	0	0	2.66
C	20.3	0.56	0.11	0	0.22
D	16.2	2.81	0	0	2.81
E	24.0	1.40	1.33	0.18	2.28
F	18.4	1.03	0.16	0	1.19

***Table F.8** Average airflows per m² floor area office per investigated building in Norway.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	11.9	1.16	1.16
B	11.7	2.6	2.6
C	9.4	3.2	2.0
D	10.3	1.85	1.85
E	13.2	2.2	2.2
F	13.4	1.0	1.0

***Table F.9** Average airflows per m² floor area office per investigated building in Germany.*

Building	Floor area office [m²]	Supply airflow rate [l/s.m²]	Infiltration airflow rate [l/s.m²]	Total outdoor airflow rate [l/s.m²]
A	26.2	0	0.1	0.1
B	49.6	2.25		2.25
C	18.8	1.54		1.54
D	88.2	0	0.8	0.8
E	21.2	3.06		3.06
F	394.4	4.3		4.3

APPENDIX G WEATHER CONDITIONS

Table G.1 Weather conditions on the days of the survey for The Netherlands.

Weather conditions	Building					
	A	B	C	D	E	F
description	oversky, cloudy	cloudy	cloudy	sunny, clear sky	cloudy	cloudy, snow
temperature (°C)	1.8	5.5	2.4	4.2	5.6	-2.9
relative humidity (%)	90	80	89	92	83	93
windspeed (m/s)	2.1	9.3	6.7	3.1	7.2	3.6
winddirection	E	SSW	SE	WSW	WNW	E

Table G.2 Weather conditions on the days of the survey for Denmark.

Weather conditions 06:00 - 18:00	Building					
	A	B	C	D	E	F
description	overcast	overcast	overcast	overcast	rainy	windy
temperature (°C)	4.7	3.6	2.5	2.5	7.3	5.5
relative humidity (%)	53	58	60	59	80	59
windspeed (m/s)	5.4	5.4	4.5	2.3	6.2	8.8
global sunglare (W/m²)	207	200	199	152	21	192

Table G.3 Weather conditions on the days of the survey for The United Kingdom.

Weather conditions	Building					
	A	B	C	D	E	F
description	cloudy	sunny	cloudy	cloudy	sunny/clouds	cloudy
temperature (°C)	10.2	8.8	10.4	8.8	12.8	11.5
relative humidity (%)	92	67	88	75	78	51
windspeed (m/s)	6.5	4.6	4.5	4.7	7.1	6.5
winddirection	NE	NW-SW	SW-W			

Table G.4 Weather conditions on the days of the survey for Greece.

Weather conditions	Building					
	A	B	C	D	E	F
description	sunny	sunny, wind	overcast, wind	rain	sunny	sunny
temperature (°C)	11.9	9.5	10.3	12.3	9.5	13.3
relative humidity (%)	58.8	52.3	56.0	82.9	62.7	41.3
windspeed (m/s)	2.1	8.1	6.8	2.1	5.9	3.6
winddirection	.	.	.	.	.	.

Table G.5 Weather conditions on the days of the survey for France.

Weather conditions	Building					
	A	B	C	D	E	F
description	rainy, overcast	overcast	sunny	sunny	sunny, clear sky	cloudy
temperature (°C)	9.0	7.9	11.9	12.1	8.9	11.0
relative humidity (%)	87.5	76.5	78	61.5	60.5	75
windspeed (m/s)	4.9	3.7	4.7	10.0	2.7	5.5
winddirection	S	W	W	SW	N	W

Table G.6 Weather conditions on the days of the survey for Switzerland.

Weather conditions	Building							
	A	B	C	D	E	F	G	H
description	cloudy, windy	overcast	overcast	sunny	variable	overcast	overcast	rainy
temperature (°C)	9.7	7.7	4.1	1.9	3.4	0.9	1.7	8.2
relative humidity (%)	65	91	75	80	70	82	75	90
windspeed (m/s)	9.3	2.3	7.4	0.8	0.6	0.6	1.6	0.1
winddirection	W		W					

Table G.7 Weather conditions on the days of the survey for Finland.

Weather conditions	Building					
	A	B	C	D	E	F
Description	overcast (morning) clear sky (afternoon)	overcast	overcast	overcast (morning) cloudy (afternoon)	overcast (morning) sunny (afternoon)	cloudy
Temperature (°C)	-13.0	-12.8	-13.4	-4.2	-4.5	-3.8
Relative humidity (%)	90.5	87.5	84.3	90.8	91.5	82.0
Wind speed (m/s)	1.8	3.0	4.5	3.8	2.3	3.3
Wind direction	E	E	E	W	W	W

Table G.8 Weather conditions on the days of the survey for Norway.

Weather conditions	Building					
	A	B	C	D	E	F
description	sunny	overcast	overcast	sunny	sunny	overcast
temperature (°C)	-3.4	-4.8	-7.4	7.2	3.1	2
relative humidity (%)	86	87	66	34	58	99
windspeed (m/s)	2	3	9	9	7	4

Table G.9 Weather conditions on the days of the survey for Germany.

Weather conditions	Building					
	A	B	C	D	E	F
description	cloudy	rainy	cloudy, rainy	cloudy	cloudy, rainy	cloudy, rainy
temperature (°C)	3	4	5	-1.3	10.1	12
relative humidity (%)	89	95	93	90	77	80
windspeed (m/s)	1	2	1	0.7	1.4	0.8
winddirection	W	NW	SW	NW	SW	W

APPENDIX H ENERGY CONSUMPTION

Table H.1: Energy use in audited buildings in 1993 (or 1992), expressed in GJ.

Building	Built in	Floor area ×1000 m²	Heating oil GJ	Natural gas GJ	Electricity GJ	District heat GJ	Total GJ
CH A	1972	7.41			4 614	8 635	13 248
CH B	1980	21.28	6 699		12 046		18 745
CH C	1990	38.44	2 874	28 055	37 829		68 758
CH D	1991	12.00	484		5 008	3 757	9 248
CH E	1974	9.07	507		5 246	3 935	9 689
CH F	1958	34.98		34 211	17 014		51 225
CH G	1976	42.00		34 211	17 014		51 225
CH H	1973	11.31			1 363	10 036	11 399
D A	1955	47.98			3 600	14 258	17 858
D B	1977	4.00		2 304	5 185		7 489
D C	1969	10.56			2 772	9 450	12 222
D D	1990	44.00			29 531	19 541	49 072
D E	1976	47.72	97 605				97 605
D F	1983	68.50			62 219	18 655	80 874
DK A	1970	9.38			4 500	7 002	11 502
DK B	1990	7.68	2 544		5 172		7 716
DK C	1984	19.80			10 674	9 086	19 760
DK D	1986	4.10		2 811	703		3 514
DK E	1989	4.44		1 485	1 014		2 498
DK F	1986	5.00		835	5 104		5 939
F A	1987	3.00					
F B	1984	8.00			5 009	14 799	19 808
F C	1951	3.50		2 388	835		3 223
F D	1985	3.38		225	2 276		2 501
F E	1989	42.00			24 505	17 136	41 641
F F	1986	9.60			4 396	3 540	7 936
GR A	1988	7.50	2 350		3 437		5 787
GR B	1991	9.54	1 964		6 120		8 084
GR C	1991	9.20	2 505		2 332		4 837
GR D	1989	2.41	504		461		965
GR E	1972	2.49	792		425		1 217
GR F	1963	4.63					
N A	1986	5.40			6 119		6 119
N B	1964	8.25	735		10 021		10 755
N C	1968	4.32			5 590		5 590
N D	1934	4.58			2 129	1 371	3 500
N E	1964	10.31	232		14 385		14 617
N F	1970	5.04			5 337		5 337
NL A	1990	8.50			2 281	62	
NL B	1965	10.45	4 572		2 957		7 529
NL C	1967	10.45	4 572		2 957		7 529
NL D	1989	7.50		6 810	4 140		10 950
NL E	1968	5.60		6 549	2 772		9 321
NL F	1986	35.00		13 104	15 348		28 452
SF A	1971	3.98			1 933	1 951	3 884
SF B	1991	23.00			11 017	7 337	18 353
SF C	1900	3.24			379	1 357	1 736
SF D	1989	4.87			1 037	1 517	2 553
SF E	1971	16.06			8 183	7 793	15 976
SF F	1987	12.14			19 958	2 506	22 465
UK A	1988	3.99		4 335	2 567		6 901
UK B	1975	12.10					
UK C	1990	8.00		6 963	7 728		14 692
UK D	1972	5.95		3 912	3 627		7 539
UK E	1975	52.00		6 858	88 560		95 418
UK F	1989	2.40			2 959		2 959

Table H.2: Energy indices of audited buildings in 1993 (or 1992).

Building	Energy Index Total MJ/m²	Energy Index Electricity MJ/m²	Energy Index Fuel MJ/m²	Energy/person Total GJ/person	Energy/person Electricity GJ/person	Specific power[1] W/(m²K)
CH A	1 789	623	1 166	55	19	5.73
CH B	881	566	315	25	16	2.82
CH C	1 789	984	805	57	32	5.73
CH D	771	417	353	41	22	2.47
CH E	1 069	579	490	48	26	3.99
CH F	1 464	486	978	64	21	5.47
CH G	1 220	405	815	64	21	4.55
CH H	1 008	121	887	47	6	3.07
D A	372	75	297	14	3	1.17
D B	1 872	1 296	576	37	26	6.51
D C	1 157	262	895	17	4	3.42
D D	1 115	671	444	20	12	3.63
D E	2 045			81		7.11
D F	1 181	908	272	40	31	
DK A	1 226	480	746	31	12	5.50
DK B	1 005	673	331	19	13	4.51
DK C	998	539	459	38	21	4.48
DK D	856	171	685	28	6	3.84
DK E	563	228	334	14	6	2.52
DK F	1 188	1 021	167	30	26	5.33
F B	2 476	626	1 850	38	10	12.58
F C	921	239	682	23	6	4.28
F D	740	673	67	9	8	3.44
F E	991	583	408	21	12	4.61
F F	827	458	369	12	7	
GR A	772	458	313	23	14	
GR B	847	642	206	21	16	
GR C	526	253	272	13	6	
GR D	400	191	209	8	4	
GR E	488	170	318	10	4	
N A	1 133	1 133	0	47	47	3.59
N B	1 304	1 215	89	31	29	4.14
N C	1 295	1 295	0	28	28	4.11
N D	764	465	299	20	12	2.42
N E	1 418	1 395	23	57	56	4.50
N F	1 058	1 058	0	17	17	
NL A		268			11	
NL B	720	283	438	17	7	
NL C	720	283	438	17	7	
NL D	1 460	552	908	61	23	
NL E	1 664	495	1 169	62	18	
NL F	813	439	374	27	15	2.42
SF A	977	486	491	33	17	2.73
SF B	798	479	319	22	13	2.38
SF C	536	117	419	10	2	1.60
SF D	525	213	312	25	10	1.56
SF E	995	510	485	152	78	2.96
SF F	1 850	1 643	206	97	86	10.75
UK A	1 730	643	1 086	25	9	10.05
UK C	1 837	966	871	18	10	8.76
UK D	1 267	610	657	19	9	6.04
UK E	1 835	1 703	132	24	22	8.75
UK F	1 233	1 233	0	18	18	

[1] Specific power is the energy index divided by accumulated temperature difference.

APPENDIX I DETAILED INVESTIGATIONS

I.1 Source identification

I.1.1 Investigated buildings

Three rooms in three different office buildings were selected for investigation. The rooms were selected to represent a typical mechanically ventilated room, a typical room without mechanical ventilation and a recently renovated room with low ventilation rates. Table 1 shows some important data for the investigated rooms A, B and C. The two typical rooms were chosen in two of the buildings (B and C) investigated by the Laboratory of Heating and Air Conditioning as part of the auditing project. In that study the buildings B and C were designated the codes A and E respectively. In Table I.1 some characteristics of the investigated rooms are summarized. The investigations were in all three cases performed on warm and sunny summer days.

***Table I.1** Summary of room characteristics.*

	Room A	Room B	Room C
Date of investigation	August 12	July 21-22	August 4-5
Year of completion	1973	1970	1989
Time since construction or renovation (years)	0.25	2.5	5
Depth (m)	4.1	4.7	4.3
Height (m)	2.7	2.8	2.7
Floor area (m^2)	22	22	19
Volume (m^3)	59.4	61.6	51.3
Floor material	Linoleum	Linoleum	Linoleum
Wall material	Acrylic dispersion paint on concrete and gypsum board	Acrylic dispersion paint on concrete and gypsum board	Acrylic dispersion paint on concrete and enamel paint on masonite board
Ceiling material	Acrylic dispersion paint on concrete	Acrylic dispersion paint on perforated gypsum board	Acrylic dispersion paint on sealed mineral wool
Desk material	Lacquered veneer	Lacquered veneer	Lacquered veneer
Ventilation - Principle - Type - Recirculation - Design (h^{-1}) - Measured (h^{-1})	 Natural No 0.5 0.4	 Natural No 0.5 0.9	 Mechanical CAV No 3.0 3.1
Air humidity before VOC sampling (%RH)	50	49	46
Air temperature before VOC sampling (°C)	28.0	25.0	26.8

I.1.2 Procedure

In order to get results without significant influence from users or user related activities such as smoking it was decided to perform the investigation in rooms temporarily vacated by the normal users. It were normal rooms, but during the day of investigation they were not in use.

The FLEC is a miniature exposure chamber for use on flat emission sources. Some main characteristics during experiments are listed in Table I.2. The chamber is circular with supply air entering at the periphery. The investigated plane surface shuts one side of the chamber volume. The FLEC itself shuts the other side. The chamber volume is sealed by an o-ring made from silicone rubber foam. The rest of the chamber is made of electropolished stainless steel. Air leaves the cell in the centre. The air velocity is evenly distributed in the cell due to its special shape.

In each selected room in the three different buildings the FLECs were mounted to the wall, floor and desk surface on representative places.

During the measurements the FLECs were supplied with clean, humidified synthetic air. The air was supplied from a bottle of compressed air (N_2: 77%, O_2: 23%, cleanliness: 99.9995) to three air supply units. In each of the supply units the air was filtered by activated carbon and divided into two adjustable flows. One flow was lead through an air washer filled with cleaned water and the other was kept dry. By adjusting these two airflows the humidity and total airflow rate may be adjusted. Tubing was either teflon or stainless steel. The principle of the experimental setting is showed in Figure I.1.
Shortly before mounting of the FLECs the air temperature and humidity were measured by an Asmann psychrometer. The two flows of humidified and of dry air in the air supply units were then adjusted to resemble the room air humidity at the time when the FLECs were mounted on the surfaces.

Before each test the supply air to FLECs was sampled. Each FLEC was mounted on a cleaned glass plate in the investigated room and connected to the air supply. Air from the FLEC was then sampled the same way as for the other measurements and these tubes were sent with the other tubes for analyses.

***Table I.2** Main characteristics of the FLEC during these experiments.*

Chamber volume	35 ml	Air supply rate per surface area	0,28 $l/s,m^2$
Surface area tes-ted	177 cm^2	Air change rate	514 h^{-1}
Air supply rate	300 ml/min = 0,005 l/s	Air humidity	Matching room air
Air velocity	1,05 cm/s	Air temperature	Matching room air

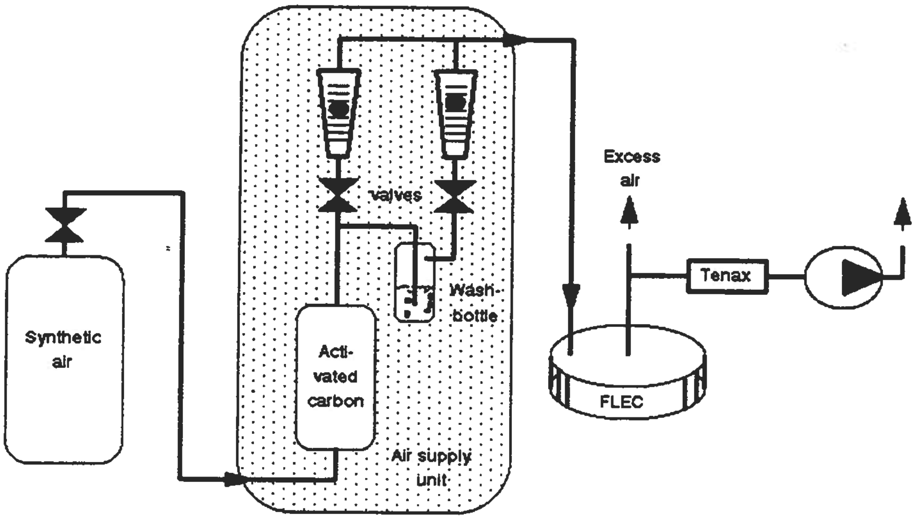


Figure I.1 *Principle of experimental setting.*

Air from the FLECs were sampled on tubes with Tenax TA sorbents at four different times after application (1 h, 3 h, 6 h and 24 h). Each sample was taken during a period of 50 minutes with a flow rate of 90 ml/min giving a sampling volume of 4.5 l. Similar samples were also taken from the room air and the outdoor air.

Air change rates in the investigated rooms were measured by tracer gas. A small volume of sulphur hexafluoride (SF_6) was introduced in the room air. The concentration of the compound was then monitored during approximately one hour with fans mixing the room air. Neither of the rooms were considered to have significant airflows to neighbouring rooms or corridors.

I.1.3 Results

A comparison between room air and outside air shows that all VOCs except toluene are found at substantially higher concentrations indoors than outdoors. It is part of the purpose of this study to identify the sources of these elevated concentrations. In order to give a picture of the extent of the study and the VOC situation in the investigated buildings the VOC measurements in room air and outdoor air are summarized in Table I.3.

Table I.3 *TVOC concentration, the sum of the most abundant VOCs and the number of VOCs identified in each of the investigated buildings.*

Building	TVOC concentration (µg/m³)		Number of VOCs identified in room air	Sum of most abundant VOCs (µg/m³)	
	Room	Outdoors		Room	Outdoors
A	360	30	31	225	25
B	190	30	12	80	19
C	110	30	18	64	12 *

* In building C this sample was taken in supply air.

The same surfaces in the different buildings are not emitting clearly similar patterns of VOCs. But some similarities may be found. Nonanal is a major compound from all linoleum floors and propanoic acid is a major compound from floors in building A and B. Acetic acid is a major compound from the acrylic wall paints in building A and B.

Temporal changes are typically in the range 1-2 $\mu g/m^3$ with a few examples of more. It is hard to find examples of consistent tendencies for specific compounds from building to building. Nonanal from floors show distinct increasing tendencies in building A while it is decreasing in building B and C. Acetic acid from walls in building A and B and desk in building B have a tendency for increased concentration in the measurement after three hours compared with the previous and succeeding measurements. Apparently the measurements after only one hour may be just as good as any of the others. Unless otherwise is indicated the following results are based on measurements after only one hour.

Figure I.2 shows calculated room air concentrations of the eight VOCs contributing the most to room concentrations according to the FLEC measurements. The contributions for one chemical compound from the three measured surfaces are calculated from the following formula:

$$C_{CR} = C_{out} + \Sigma E_i \cdot A_i / v \qquad [I.1]$$

Where:

C_{CR}	=	Calculated room concentration [$\mu g/m^3$]
C_{out}	=	Concentration in outdoor air [$\mu g/m^3$]
i	=	Surface number
E_i	=	Emission factor from measured surface [$\mu g/h.m^2$]
A_i	=	Total area of measured surface [m^2]
v	=	Ventilation rate of room [m^3/h]

Calculated FLEC concentrations of most abundant VOCs for floor, wall and desk after the times 1, 3, 6, 24 hours are showed for the three buildings in Figure I.3.

For the older buildings B and C the floors have emission factors 5-20 times higher than the other surfaces under the FLECs, while emission factors are more comparable in the newly renovated building A. Temporal changes of emissions from the linoleum floor are small for the older buildings B and C while there is a significant increased emission from the new linoleum in building A. The emissions from walls are decreasing with time in building B and C. In both cases the 24-hour values are about 60% of the 1-hour values. In building B and C the temporal change for desks is composed of an increase during the first hours followed by a decrease after 6 and 24 hours. In building A the desk value is obtained only after 1 hour. This measurement indicates that the emission factor for the desk in building A is approximately four times as high as in the other two buildings.

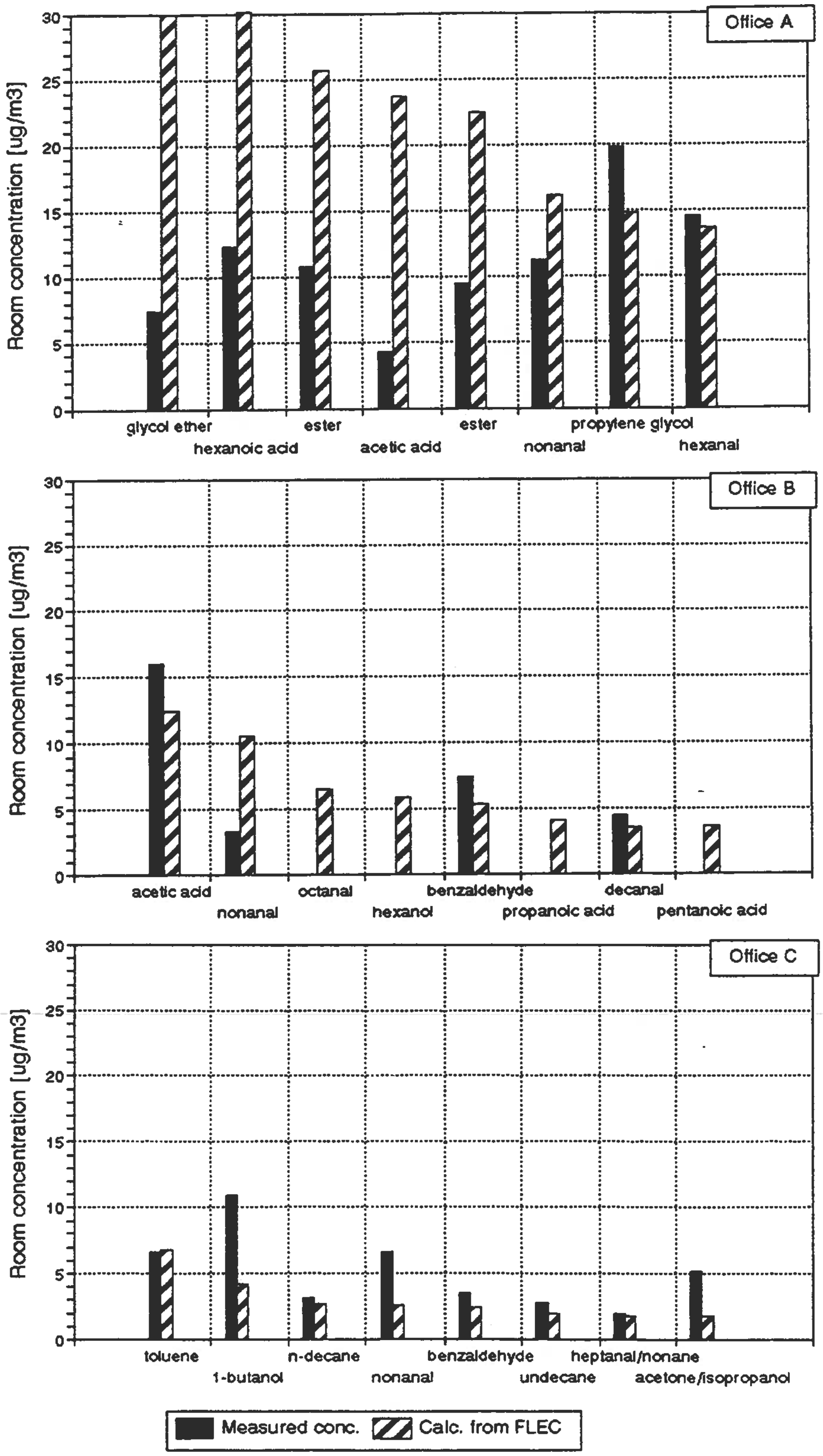


Figure I.2 *Calculated room air concentrations of the eight VOCs contributing the most to room concentrations according to the FLEC measurements. Room air measurements of the same VOCs are shown for comparison. The calculations are carried out under the assumption that the FLEC measurements are representative for average emission rates during prevailing conditions for all of the similar surfaces.*

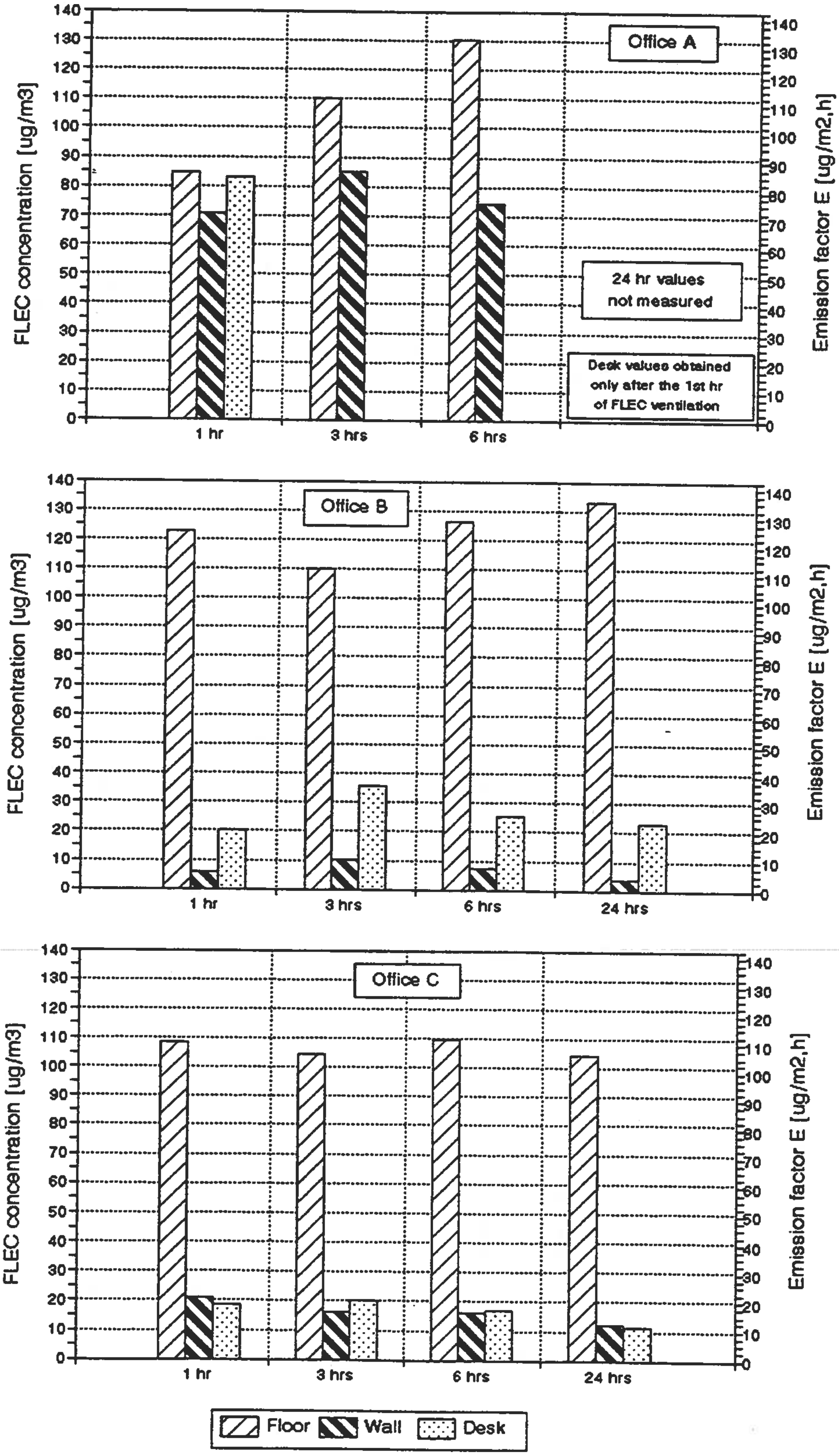


Figure I.3 *Calculated FLEC concentrations (sum of the most abundant VOCs) for floor, wall and desk for the three buildings shown for the measurements after 1, 3 ,6 and 24 hours. A secondary Y-axis based on emission factor is shown for comparison.*

In Figure I.4 results are summarized as the calculated contributions to the room air concentration (sum of most abundant VOCs) from floor, wall, desk and supply air. The contributions from the surfaces are calculated using the emission factors obtained by the FLEC measurements after 1 hour. The measured room air concentrations of the most abundant VOCs are also shown.

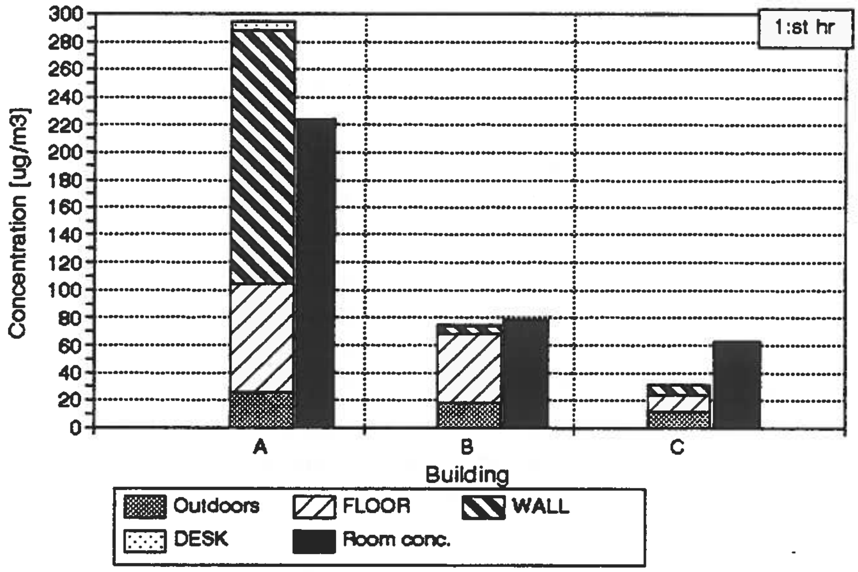


Figure I.4 *The calculated room concentration (sum of most abundant VOCs) divided into the contributions from floor, wall, desk and supply air. The sum of the most abundant VOCs measured in room air is also shown.*

I.1.4 Discussion

The chemical measurements applied in this study are only accounting for VOCs with boiling points between approximately 50 and 200 °C. This is a limitation compared to the broader range of pollution that may influence people in office buildings. Some of the very volatile chemicals in outdoor air and chemicals resulting from decomposition of larger compounds may not be quantified because they are too volatile. Other compounds may have too high boiling points to be re-emitted from the Tenax tubes.

Furthermore, this study has been designed to focus on emissions from indoor surface materials while the influence of activity dependent sources has been deliberately minimized. However, with other experimental design and other quantification methods, such as photoacoustic spectroscopy, contaminants from activity dependent sources as well as substances originating outdoors may be considered to have a major influence the indoor air quality (1). This is apparently not the case with the method applied here.

Giving these limitations the major polluters in unoccupied offices are identified as floors and walls. The majority of the identified VOCs in room air can be related to one or more of the studied surfaces. Only a few exceptions of the results indicate the presence of other sources.

Thin layers of surface materials on large surfaces such as paints may have a high initial emission rate due to the large areas and a rather fast decay of the rate due to limited source capacity in the thin layers. The linoleum on floors are thicker and have a more stable and longer lasting emission rate. Another reason for the lasting emission rate may also be the more regular cleaning with detergents and other chemicals and the wearing off of surface layers during normal use. The ageing process of surface materials have in a previous study (2) been shown to influence air quality for more than a year after renovation of offices.

The temporal variations of the emission factors observed in this study may have several explanations. A great deal of the variations may be associated with uncertainties in the method including inaccuracies in the sampled air volume as well as in the chemical quantification of VOCs. Furthermore, the application of a FLEC will change the environment for the material being tested. These changes may lead to transient sorption effects and a time dependent development of a new concentration gradient within the material.

Increased air velocity, ventilation rate per surface area and cleanliness of supply air was as stated in other studies (3) expected to introduce a significant increase in emission rates. It was expected that the changes introduced by differences in these parameters might be seen during the 24 hours of the measurements. The ventilation rate per surface area in the FLEC is 0.28 l/s, m^2, which is, as can be seen in Table I.4, up to a factor 40 lower than the normal specific ventilation rates. The specific ventilation rates during tests and during normal conditions were more comparable for the floor in building A and the wall in building B. Also the air velocity of 1,05 cm/s in the FLEC was somewhat different than over most surfaces in rooms. Air velocities around 10 cm/s are more common in rooms. But in unoccupied rooms with natural ventilation the air velocities could very well have been as low as 1 cm/s.

In spite of these often considerable deviations between the experimental conditions and the normal conditions, the temporal changes in emission rates at the times 1, 3, 6 and 24 hours were relatively small and not easily assessed in this study. The reason for this may have been that the air change rate in the FLEC is as high as 514 h^{-1} giving a very small time constant for the air concentration. Changes in emission rates will therefore be reflected in the FLEC concentration in less than one minute after the emission rate changed. If the changes were happening within the first hour they have not been detected as temporal changes during the measurements.

The best time for sampling VOCs seems to be after one hour since it is the simplest procedure. Prolonged waiting does not seem to give better results if the purpose of the measurement is to identify the possible sources of specific VOCs found in room air or if the measurement is aiming at an estimation of the relative importance different sources. It may even be possible to shorten the period before sampling further, but this study does not give data to support this assumption.

Taking the data from Table I.4 and comparing to the specific ventilation rate under the FLEC of 0.28 l/s, m^2 it may be seen that for building A the floor and wall are ventilated somewhat more with the FLEC mounted than without. It may therefore be expected that the FLEC measurements overestimate the room concentration. In building B the walls are slightly over-ventilated and the floors are under-ventilated during the FLEC measurements. The FLEC measurements in building B may therefore be expected to underestimate the room concentrations slightly. Finally all surfaces in building C are under-ventilated during FLEC measurements and the measurements may be expected to underestimate room concentrations. By comparing to Figure I.4 this is all seen to be correct. This way of looking at the data strengthens the hypothesis that increased specific ventilation rate increases emission rates. By carefully matching the specific ventilation rates during measurements with the rates before mounting of the FLEC it is possible that the accuracy of the applied model may be increased.

Table I.4 *Ventilation rate per surface area or specific ventilation rate in l/s, m^2 for the surfaces in the rooms (without FLEC).*

Data in l/s, m^2	Building A	Building B	Building C
Floor	0.27	0.70	2.33
Wall	0.10	0.25	0.78
Desk	3.0	7.7	11.5

I.1.5 Conclusions

- Among the investigated office buildings the walls are estimated to be the major emitter of VOCs to the room air in the newly built or renovated office building while the floor is the major air pollution source in older buildings.

- Emissions rates calculated on the basis of FLEC measurements and surface areas are only indicative of the actual air pollution source strengths. But the simplified method used can give a good indication of the origin of emitted volatile organic compounds in indoor air.

- The changes in emission rates during 24 hours after application of the FLEC are mostly small. A great deal of these changes may be associated with uncertainties in the method. The best time for sampling chemicals seems to be after the FLEC has been running for one hour.

- More research is needed on the causes of the temporal changes and the influence of typical variations in temperature, humidity, ventilation rate and other environmental parameters on emission rates and resulting room air concentrations.

I.1.6 References

1. Lars E. Ekberg, Airborne contaminants in office buildings, Some aspects of factors influencing the indoor air quality, Department of Building Services Engineering, Chalmers University of Technology, 1994.

2. Lars Gunnarsen and Ole Valbjørn, Air quality after renovation of offices, Indoor Air'93, Helsinki, Finland, 1993, Vol.2, pp. 57-62.

3. Lars Gunnarsen, Peter A. Nielsen and Peder Wolkoff, Design and characterization of the CLIMPAQ, Chamber for Laboratory Investigations of Materials, Pollution and Air

I.2 Ventilation performance

I.2.1 Selected buildings

Building C in the Netherlands: This 11 storey building has a total floor area of about 10000 m² and a population of about 450 occupants. It is equipped with a balanced ventilation system consisting of 1 Air Handling Units and 1 extraction units. The air is supplied in the offices through fan coil units ensuring the cooling or the heating of the rooms. In principle, no recirculation takes place. There is no heat recovery unit. The building was completed in 1967.

Building E in France: This 35 storey building has a total floor area of about 42000 m² and a population of about 2000 occupants. It is equipped with a balanced ventilation system consisting of 9 Air Handling Units and 7 extraction units. The air supplied in the offices is not used as support for cooling or heating but can be pre-heated or pre-cooled. No recirculation takes place. There is no heat recovery unit. The building was completed in 1989.

I.2.2 Global ventilation measurements

Supply and exhaust airflow rates

In the Dutch building, the exhaust air flow rate and the supply airflow rate were continuously measured during 2 weeks.

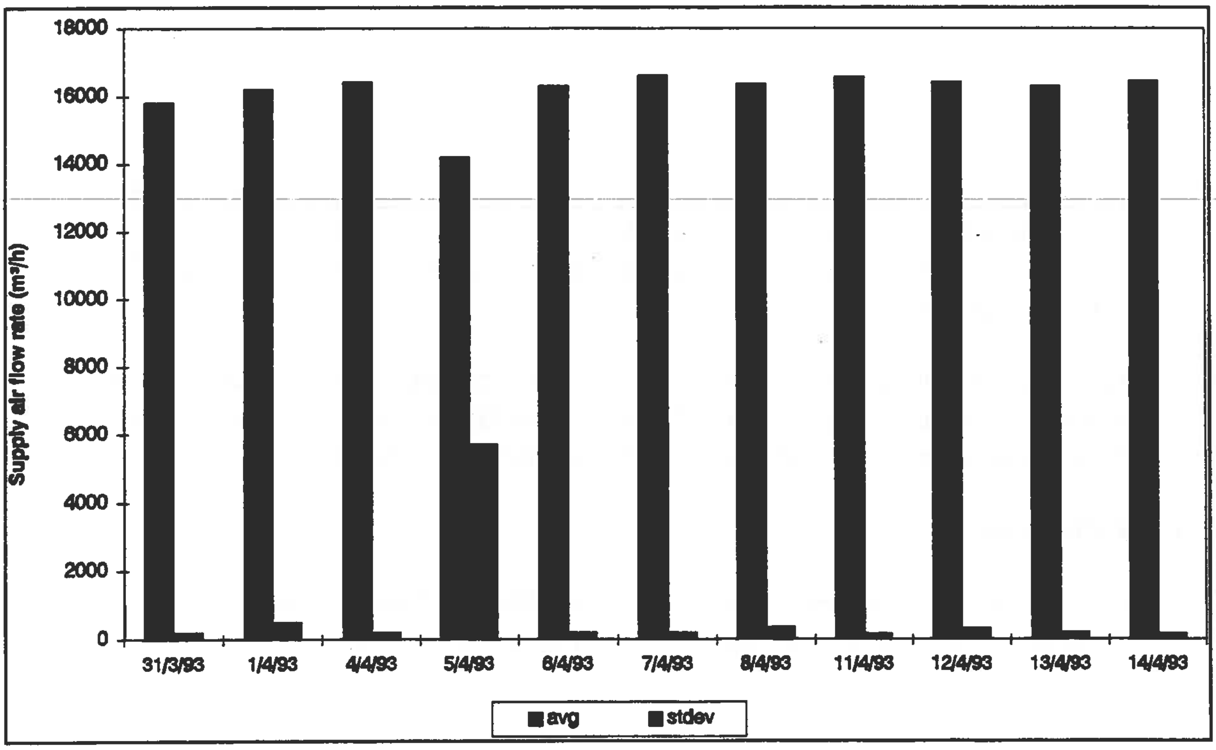


Figure I.5 *Daily averages and standard deviations of the supply airflow rate in the Dutch building during the measurement period.*

In the French building, 5 of the 7 extraction airflow rates were measured two times every day

during one month. The airflow rates did not vary significantly during those periods. This is illustrated in Figure I.5. On April 5 the ventilation system was switched off during a certain time which explains the different average value and the big standard deviation.
In August 94, the airflow rates of all AHU's (Air Handling Units) and all EF's (Exhaust fans) were measured in the French building. The next figure compares the obtained results with the measurements carried out by an independent company in May 94. Installed airflow rates are also indicated. The filters were changed between the two measurements.

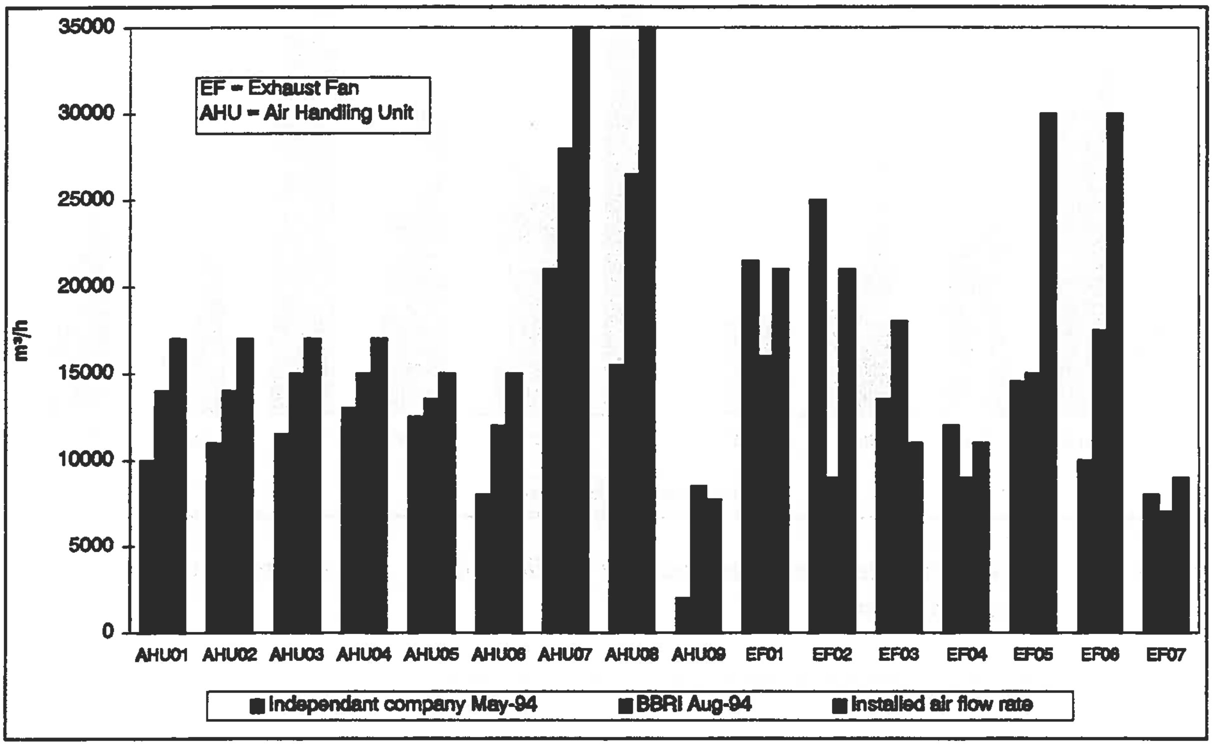


Figure I.6 *Comparison between the airflow rates measured by BBRI in August 94, the airflow rates measured by an independent company in May 94 and the installed airflow rates.*

As it can be seen, the supply airflow rates (AHU) have all increased. This is probably due to the changing of the filters. No clear trend is found for the exhaust airflow rates (EF).
A tracer gas technique was used by BBRI whereas the independent company employed a velocity profile method (Pitot tubes). It must be noted that if the accuracy of the BBRI measurements is known (about 8%), no information was given on the accuracy of the other measurements.
Figure I.6 shows also that the measured air flow rates are always lower than the installed airflow rate except for Exhaust Fan n°2. However, the building is in over-pressure as planned.
For the Dutch building it makes no sense to compare design and measured values because the airflow rates were reduced some years after the completion (noise problems due to ventilation). However, the exhaust rate was higher than the supply rate, which was not the case in the original design. Instead of being in over-pressure the building was in under-pressure.

Figure I.7 shows the installed and the measured fresh airflow rates per person in the 8 Swiss buildings and in both buildings chosen for the detailed ventilation studies.

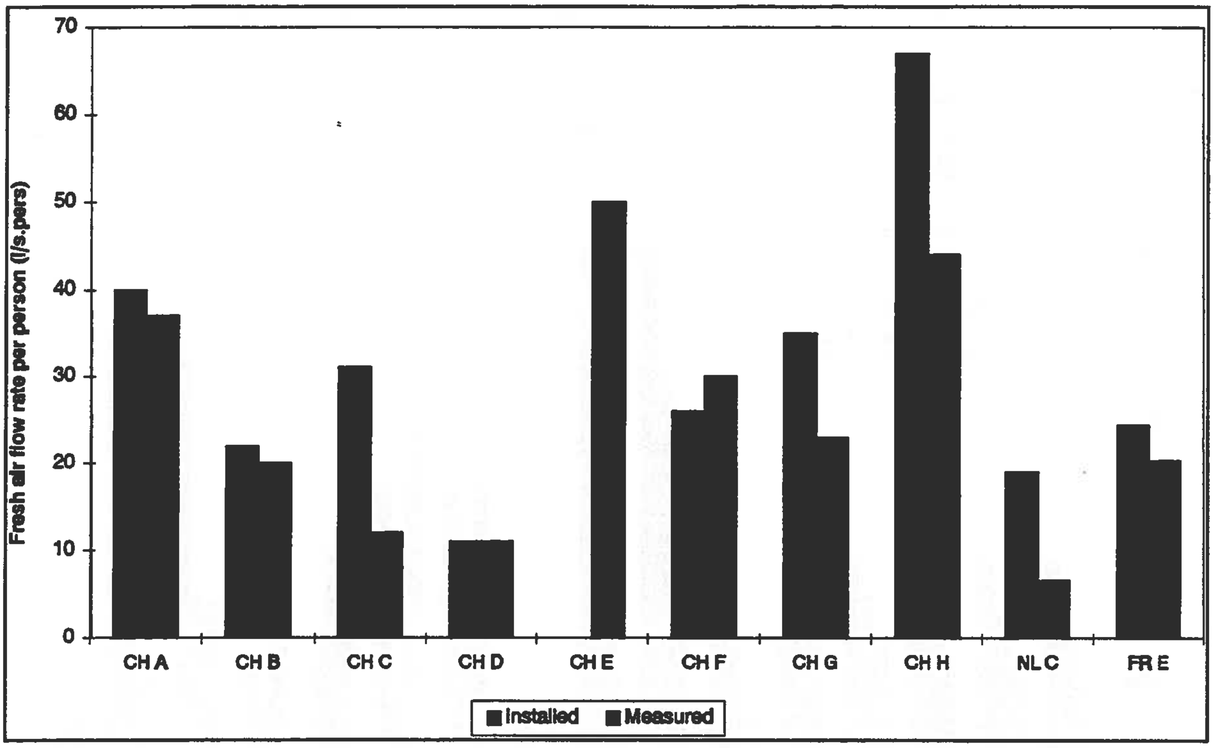


Figure I.7 *Installed and measured outside airflow rates per person (Swiss team and Belgian team).*

As it can be seen, the ventilation rates are rarely as planned.

<u>Infiltration and exfiltration</u>

The French building was in over-pressure, in first approximation one can conclude that no infiltration is taking place. Thus, the exfiltration is given by the difference between the supply airflow rate and the exhaust airflow rate. This yields an exfiltration rate of 55000 m³/h. This is about a third of the total supply air flow rate.

The Dutch building was in under-pressure, approximating that no exfiltration occurs, it provides an infiltration rate of 7000 m³/h. This about a third of the total exhaust rate.

It is evident that, in reality, both infiltration and exfiltration can occur simultaneously in the same building. That can be due, for example, to a bad distribution of the air putting some spaces in over-pressure and others in under-pressure or to the opening of windows. However, the accuracy of tracer gas techniques does not allow to derive both infiltration and exfiltration easily in the case of an occupied building.

Recirculation

As planned, no recirculation takes place in the French building.

Figure I.8 shows the measured recirculation in the Dutch building. As it can be seen the recirculation varies from day to day and also during the day. This is due to the action of an economizer damper. It should be noticed that the people in charge of the ventilation system were not aware of this fact, they were claiming that no recirculation was taking place.

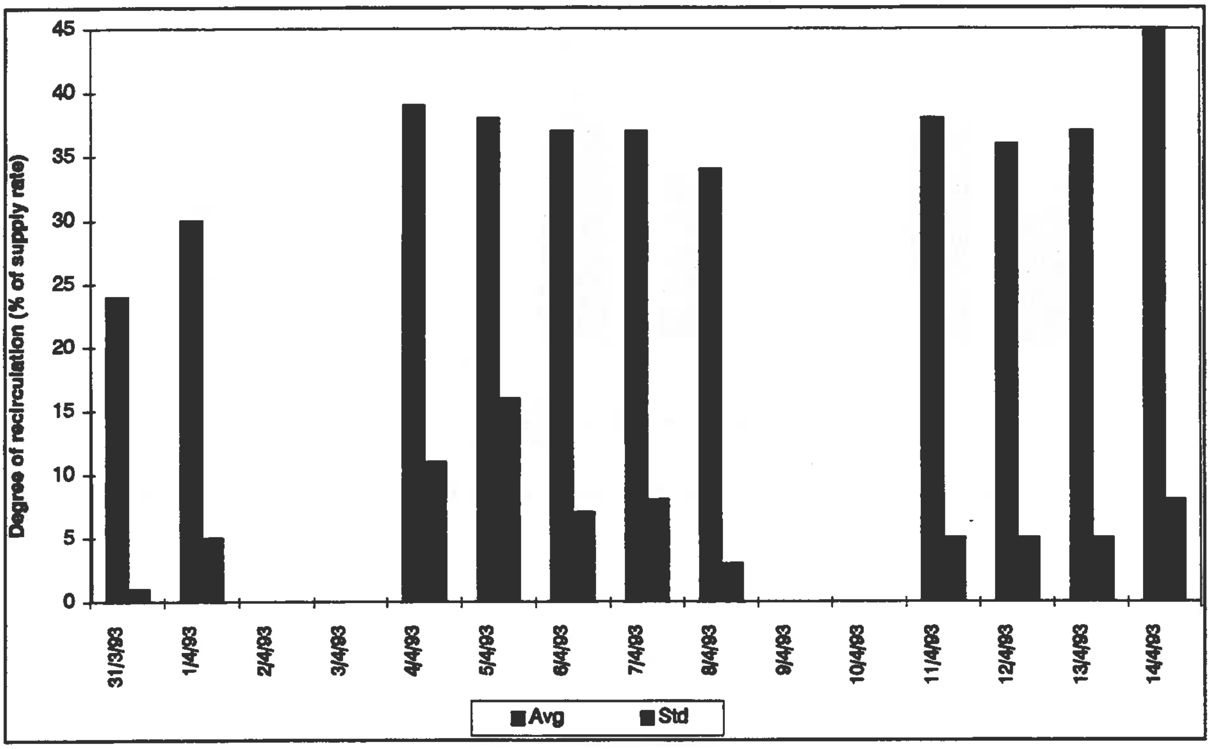


Figure I.8 *Daily averages and standard deviations of the recirculation rate in the Dutch building during the measurement period.*

Figure I.9 shows the planned and the measured recirculation rate in the 8 Swiss buildings and in both buildings chosen for the detailed studies. As shown on this figure, the recirculation is rarely conform the planned values. One can not trust the designed values of a ventilation system. The only way to know the effective recirculation is to measure it.

I.2.3 Global outside air flow rate from carbon dioxide measurements

Figure I.10 shows the CO_2 concentrations in the exhaust ducts of the ventilation system in the French building.

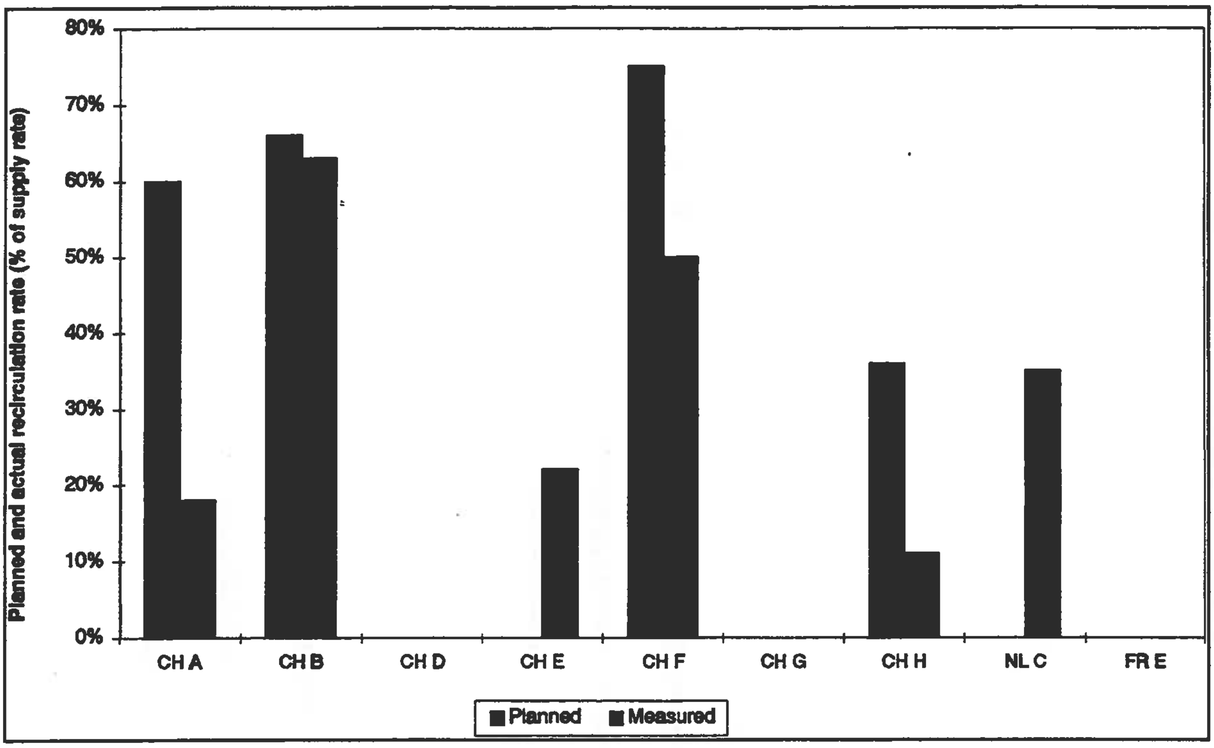


Figure I.9 *Installed and measured recirculation rates (Swiss team and Belgian team).*

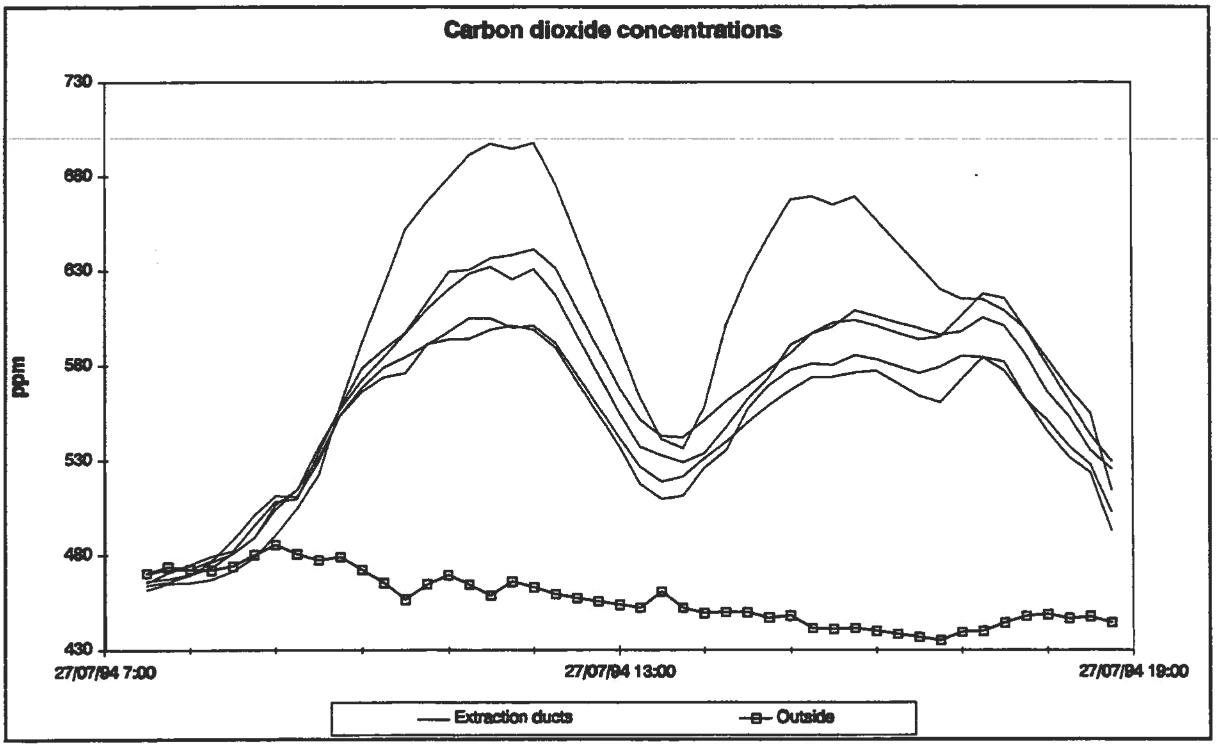


Figure I.10 *CO_2 concentrations in several extraction ducts (building E in France).*

As it can be seen, the CO_2 concentrations in the building varies strongly with the time. Moreover, it varies from extraction to extraction which means from place to place.
The average CO_2 concentration in the building can be approximated by the average of the CO_2 concentrations in the different extraction ducts. This one should be weighted by the planned airflow rates of the extraction fans in order to avoid, for example, bias due to very high CO_2 concentration in a not well ventilated zone.
The overall error on the method is estimated to be about 20% in the case of this particular building. The main sources of uncertainties are the average CO_2 emission per person and the number of occupants in the building.
The CO_2 concentration almost never reach the steady-state in the building. This must be taken into account. A dynamic analysis, that necessitates a continuous measurement of the number of people present and a continuous measurement of the average CO_2 concentration (exhaust ducts), is in practise difficult to perform. A simplified approach can be used. The information on the occupation of the building is condensed in one figure: the number people multiplied by the average time they stay in the building and the CO_2 concentration is integrated on a one day period.
Both analyses were tested and compared. It appeared that, when one day period are taken, the dynamic effects somehow compensate. The agreement between both approaches is better than 10% which is smaller than the overall error on the method.
The tracer gas measurements give a total outside flow rate of about 145 000 m^3/h and the CO_2 method a total outside flow rate of about 115 000 m^3/h. Since the error on the methods are respectively 8% and 20%, these results are not significantly different.

I.2.4 Air spreading in the building - Ages of air

Figure I.11 shows a sectional view of the French building. The components of the ventilation system which were tested are represented.
Each AHU supplies outside air to a column (35 storeys) of offices. AH01, AHU04 and AHU06 supply respectively offices 1, 2 and 3 whereas AHU09 supplies the internal zone (archives, libraries,...). Extraction is taking place in the corridors (EF01, EF02) and in the toilets (EF03, EF04). Other AHU's supply outside air in the gable ends and in the NE offices. Each gable end has its extraction fan.

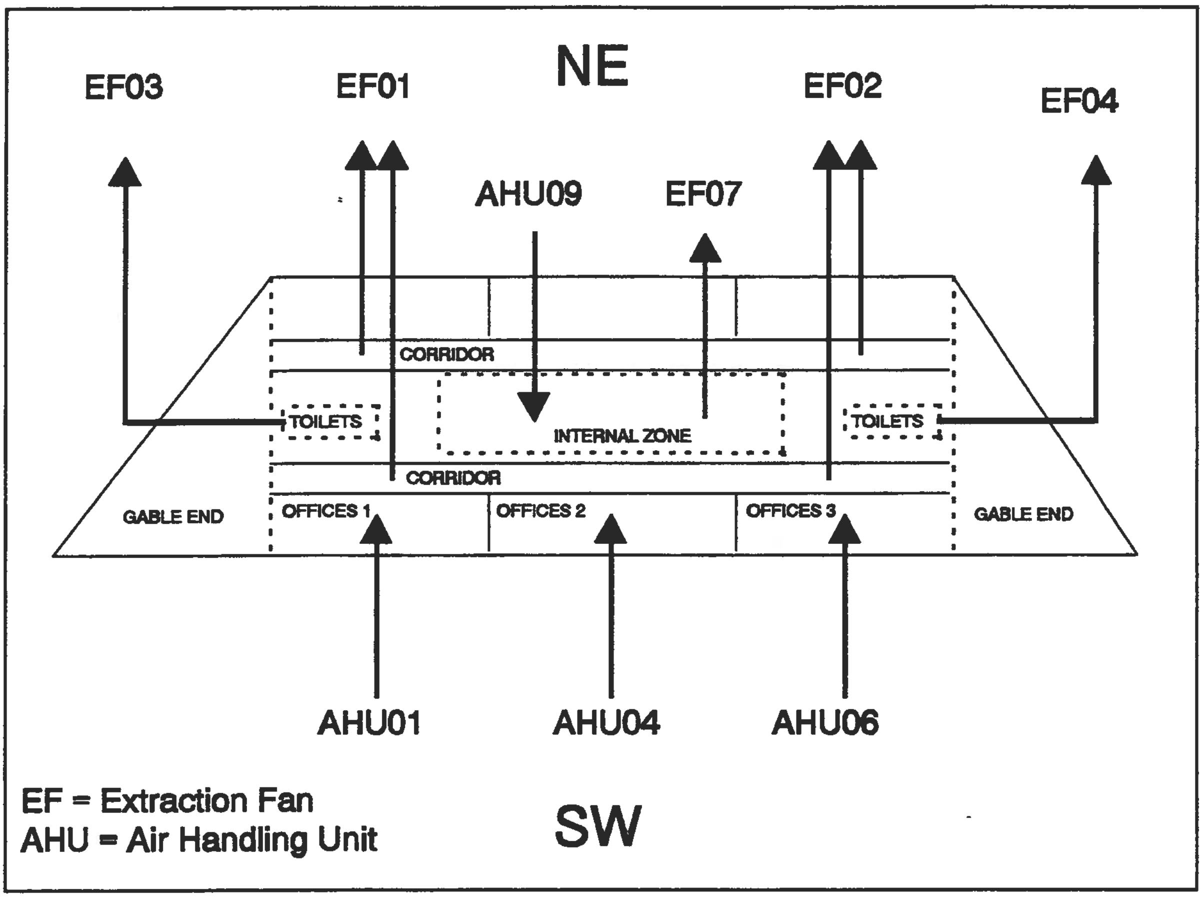


Figure I.11 *Sectional view of the French building. The air units which were measured are shown.*

This scheme repeats for the 35 floors.
With this ventilation system, no specific extraction is assigned to a specific supply. For example, the air supplied in the column of offices 1 can be extracted in the corridors, in the toilets, in the internal zone or can exfiltrate through the building envelope.
Tracer gas techniques make it possible to measure which amount of air supplied by a specific AHU is extracted by a specific EF. The principle of the method is the following: a well known amount of tracer gas is injected in an AHU and the amount of gas found back in each extraction ducts is measured. This provides an image of the air distribution in the building, it shows how a potential pollutant could spread in the building.
Tracer gas was injected in the 4 AHU's shown on Figure I.11. Its concentration was measured in the 5 EF's of the central zone of the building (without the gable ends).
Table I.5 summarizes the obtained results.

Table I.5 *Spreading of the air supplied by 4 AHU's. Airflow rates are given in m^3/h. The accuracy of the airflow rates is about 13%.*

		SW Offices	SW Offices	SW Offices 3	Internal zone	
	Units	AHU01	AHU04	AHU06	AHU09	Sum
NW	**EF01**	4000	1800	500	500	6800
NW Toilets	**EF03**	1700	800	200	300	3000
SE Corridors	**EF02**	1000	2000	3600	800	7400
SE Toilets	**EF04**	500	1000	1300	500	3300
Internal zone	**EF07**	400	600	600	5000	6600
	Sum AHU	7600	6200	6200	7100	

For example, it can be read in this table that 4000 m^3/h supplied by AHU01 are extracted by EF01, 1700 m^3/h by EF03, 1000 m^3/h by EF02, 500 m^3/h by EF07 and 400 m^3/h by EF07. The positions of the 4 extractions can explain that distribution (see Figure I.7). On the total of 14000 m^3/h supplied by AHU01, 7600 m^3/h are found back in the extraction of the central zone of the building. The rest (6400 m^3/h) can either leave through the building envelope o r go to the gable ends.
The results shows also that, for example, a pollutant emitted in the internal zone (supplied by AHU09) can be found the toilets or in the corridors.
A decay technique was used to determine the distribution of the air. It allows to measure at the same time the age of the air supplied by a specific AHU and extracted by a specific E F. Table I.6 gives the obtained results.

Table I.6 *Ages of the air (Averages are weighted by air flow rates).*

		SW Offices	SW Offices	SW Offices 3	Internal zone	
	Units	AHU01	AHU04	AHU06	AHU09	Avg
NW	**EF01**	0:40	0:56	1:33	1:10	**0:50**
NW Toilets	**EF03**	0:47	1:04	1:37	1:04	**0:57**
SE Corridors	**EF02**	1:49	1:00	0:49	0:58	**1:01**
SE Toilets	**EF04**	1:52	1:08	0:56	0:56	**1:08**
Internal zone	**EF07**	1:49	1:02	1:19	0:15	**0:30**
	Avg AHU	**0:59**	1:01	0:59	0:29	

For example, it can be seen that the air supplied by AHU01 and extracted by EF01 stays, o n average, 40 minutes in the building. The air supplied by the same unit but extracted by EF04 stays, on average, 1 hour and 49 minutes in the building. That means that a pollutant that would be emitted in a one office belonging to the zone 1 (supplied by AHU01), could be found more than 1 hour and an half later in the toilets situated in the other part of the building (EF04).

I.2.5 IAQ related parameters

The CO concentrations are generally very low (about 0.5 ppm) and difficult to measure. However, it happens that the outside concentration got higher (maximum 2 ppm). Accordingly, the average inside concentration took values of the same order of magnitude. It is not necessary to measure the CO level in extraction ducts unless specific problems are suspected (air intake close to garages or close to heavy traffic).

The average CO_2 concentration is an useful parameter. It gives information on the pollution inside the building due to the occupants but can also be used to measure the recirculation and, if the occupancy of the building is known, to derive a global ventilation rate for the building (see paragraph I.2.3).

Figure I.10 shows CO_2 concentration in several extraction ducts of Building E in France. As it can be seen these concentrations never reach the steady-state and they stay below 700 ppm. It should be noted that the CO_2 concentration is not homogenous in the building. That means that the pollution due to the occupants varies from place to place in the building. For example, the pollution due to the occupants in the internal zone (where the air is extracted by EF07) is almost the double than elsewhere.

The average CO_2 concentration stays below 1000 ppm in the building C in the Netherlands.

I.2.6 Energy related parameters

It should be noted that during the summer humidity does not vary much between inside an d outside. Therefore, the changes in humidity were not taken into account for the energy calculations.

The target for indoor temperature was 25 °C and that the ventilation system is switched off during the night.
The gain of energy due to ventilation is 27000 kWh for August 94 in the French building. The outside temperature is generally lower than the inside temperature and therefore the ventilation helps to cool the building.
It happens however that the outside temperature got higher than 25 °C. Then, an additional cooling power is necessary to evacuate the additional heat supplied in the building by the ventilation system. The maximum outside temperature reached was 35 °C. That yields an additional cooling power of about 500 kW because of ventilation. In total, 6700 kWh of cooling were used because of ventilation during August 94.

The electrical consumption of the fans can be evaluated from their characteristic curves assuming the system was designed to work at the highest efficiency. The total power for supply and exhaust fans is about 60 kW. Assuming an operation of 14 hours per day, 5 days a week, gives a total energy consumption for one month of about 17000 kWh. That means that there is still a gain of 10000 kWh thanks to the ventilation.

APPENDIX J POLLUTION LOADS

The Netherlands

Buildings B, C, D + E: mechanical, no recirculation
Buildings A + F: mechanical, with recirculation

Table J.1 *Sensory pollution load (and errors)*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.13 ± 0.02	0.65 ± 0.28	-0.03 ± 0.24	0.62 ± 0.18
	2	0.13 ± 0.01	0.14 ± 0.17	0.10 ± 0.15	0.25 ± 0.10
	3	0.11 ± 0.02	0.52 ± 0.40	0.13 ± 0.31	0.61 ± 0.22
	4	0.14 ± 0.02	0.40 ± 0.19	-0.01 ± 0.16	0.39 ± 0.12
	5	0.32 ± 0.04	1.09 ± 0.34	-0.13 ± 0.25	0.76 ± 0.20
B	1	0.02 ± 0.01	0.31 ± 0.16	0.11 ± 0.11	0.43 ± 0.14
	2	0.04 ± 0.02	0.30 ± 0.38	0.21 ± 0.20	0.51 ± 0.39
	3	0.10 ± 0.03	0.47 ± 0.42	0.18 ± 0.16	0.65 ± 0.42
	4	0.17 ± 0.07	0.68 ± 0.41	0.19 ± 0.17	0.87 ± 0.42
	5	0.09 ± 0.02	0.15 ± 0.12	0.09 ± 0.08	0.24 ± 0.12
C	1	0.19 ± 0.09	0.67 ± 0.41	0.08 ± 0.05	0.76 ± 0.42
	2	0.23 ± 0.10	0.59 ± 0.35	0.06 ± 0.04	0.65 ± 0.37
	3	0.06 ± 0.02	0.03 ± 0.13	0.07 ± 0.04	0.08 ± 0.04
	4	0.06 ± 0.03	-0.25 ± 0.27	0.38 ± 0.17	0.13 ± 0.29
	5	0.14 ± 0.06	0.12 ± 0.15	0.14 ± 0.06	0.26 ± 0.16
D	1	0.01 ± 0.01	1.11 ± 0.62	1.01 ± 0.36	2.12 ± 0.59
	2	0.07 ± 0.02	0.05 ± 0.25	0.50 ± 0.18	0.55 ± 0.22
	3	0.02 ± 0.01	0.36 ± 0.41	0.76 ± 0.28	1.12 ± 0.38
	4	0.10 ± 0.02	0.79 ± 0.43	0.58 ± 0.21	1.37 ± 0.42
	5	0.05 ± 0.01	-0.05 ± 0.16	0.39 ± 0.14	0.34 ± 0.14
E	1	0.19 ± 0.04	0.49 ± 0.24	0.30 ± 0.13	0.79 ± 0.22
	2	0.03 ± 0.01	0.19 ± 0.09	0.11 ± 0.05	0.30 ± 0.08
	3	0.05 ± 0.01	0.54 ± 0.21	0.22 ± 0.10	0.76 ± 0.21
	4	0.07 ± 0.01	0.40 ± 0.20	0.29 ± 0.13	0.69 ± 0.18
	5	0.02 ± 0.01	0.50 ± 0.25	0.29 ± 0.13	0.79 ± 0.23
F	1	0.01 ± 0.0	-0.02 ± 0.07	0.19 ± 0.06	0.17 ± 0.05
	2	0.14 ± 0.04	0.24 ± 0.46	1.10 ± 0.38	1.34 ± 0.42
	3	0.15 ± 0.02	0.37 ± 0.18	0.23 ± 0.16	0.60 ± 0.14
	4	0.04 ± 0.01	0.24 ± 0.15	0.20 ± 0.14	0.44 ± 0.12
	5	0.07 ± 0.02	0.21 ± 0.26	0.29 ± 0.18	0.48 ± 0.16

Table J.2 Chemical pollution load (and errors)

Building	Location	Chemical pollution load		
		toluene [(μg/s)/m²]		
		Office	Vent. system	Total
A	1	0.14 ± 0.13	0.16 ± 0.12	0.30 ± 0.05
	2	0.02 ± 0.08	0.15 ± 0.08	0.16 ± 0.03
	3	-0.17 ± 0.15	0.37 ± 0.15	0.21 ± 0.04
	4	-0.01 ± 0.07	0.15 ± 0.07	0.13 ± 0.02
	5	0.06 ± 0.15	0.17 ± 0.12	0.28 ± 0.05
B	1	0.16 ± 0.04	-0.11 ± 0.03	0.04 ± 0.05
	2	0.27 ± 0.14	-0.27 ± 0.06	0.0
	3	0.37 ± 0.12	-0.22 ± 0.05	0.14 ± 0.13
	4	0.65 ± 0.22	-0.24 ± 0.06	0.41 ± 0.23
	5	0.22 ± 0.07	-0.09 ± 0.03	0.13 ± 0.08
C	1	0.66 ± 0.32	-0.04 ± 0.02	0.62 ± 0.31
	2	0.81 ± 0.40	-0.03 ± 0.02	0.79 ± 0.40
	3	0.08 ± 0.12	-0.03 ± 0.02	0.07 ± 0.03
	4	0.26 ± 0.12	-0.17 ± 0.07	0.08 ± 0.14
	5	0.65 ± 0.28	-0.06 ± 0.03	0.59 ± 0.28
D	1	0.29 ± 0.06	-0.08 ± 0.02	0.21 ± 0.06
	2	0.11 ± 0.02	-0.04 ± 0.01	0.07 ± 0.02
	3	0.08 ± 0.02	-0.06 ± 0.02	0.02 ± 0.02
	4	0.31 ± 0.08	0.05 ± 0.03	0.36 ± 0.08
	5	0.04 ± 0.03	0.04 ± 0.02	0.07 ± 0.02
E	1	0.11 ± 0.03	0.05 ± 0.01	0.16 ± 0.03
	2	0.07 ± 0.02	0.02 ± 0.01	0.09 ± 0.02
	3	0.07 ± 0.03	0.04 ± 0.01	0.11 ± 0.03
	4	0.08 ± 0.03	0.05 ± 0.01	0.13 ± 0.03
	5	0.03 ± 0.02	0.05 ± 0.01	0.08 ± 0.02
F	1	0.03 ± 0.03	0.02 ± 0.02	0.05 ± 0.02
	2	0.12 ± 0.14	0.10 ± 0.12	0.22 ± 0.12
	3	0.12 ± 0.06	0.03 ± 0.05	0.15 ± 0.06
	4	0.04 ± 0.05	0.03 ± 0.04	0.07 ± 0.04
	5	-0.02 ± 0.08	0.05 ± 0.05	0.05 ± 0.05

Denmark

Buildings B, C + E: mechanical, no recirculation
Buildings A + D: natural ventilated
Building F: mechanical, with recirculation

Calculations were made using outdoor airflow rates (recirculated air was subtracted).

***Table J.3** Sensory pollution load*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.12	0.40	.	0.40
	2	0.03	0.08	.	0.08
	3	0.07	0.39	.	0.40
	4	0.05	0.33	.	0.32
	5	0.03	0.30	.	0.30
B	1	0.11	-0.36	1.03	0.67
	2	0.05	0.12	0.51	0.61
	3	0.12	0.47	0.44	0.90
	4	0.17	0.26	0.55	0.80
	5	0.10	-0.01	0.45	0.44
C	1	0.17	-0.67	2.76	2.10
	2	0.08	-0.44	2.23	1.79
	3	0.13	-0.22	2.12	1.90
	4	0.19	-1.28	2.56	1.28
	5	0.20	-0.19	1.78	1.69
D	1	0.12	1.27	.	1.27
	2	0.20	1.15	.	1.15
	3	0.03	0.22	.	0.23
	4	0.03	0.25	.	0.25
	5	0.01	0.10	.	0.10
E	1	0.15	-0.78	2.32	1.56
	2	0.13	-0.83	0.38	1.22
	3	0.10	-0.47	1.30	0.83
	4	0.07	-0.54	1.19	0.65
	5	0.12	0.09	1.39	1.51
F	1	0.06	-0.31	0.64	0.33

Table J.4 *Chemical pollution load*

Building	Location	Chemical pollution load toluene [(µg/s)/m²]		
		Office	Vent. system	Total
A	1	0.07	.	
	2	0.04	.	
	3	0.05	.	
	4	0.05	.	
	5	0.09	.	
B	1	0.12	0.0	0.12
	2	0.04	0.01	0.06
	3	0.10	0.01	0.12
	4	0.12	0.01	0.13
	5	0.14	0.0	0.14
C	1	0.0	0.08	0.08
	2	.	-0.03	.
	3	.	-0.03	.
	4	0.07	-0.03	0.03
	5	0.13	0.05	0.18
D	1	0.22	.	
	2	0.23	.	
	3	0.05	.	
	4	0.06	.	
	5	0.02	.	
E	1	0.35	0.07	0.42
	2	0.30	0.02	0.32
	3	0.16	0.04	0.20
	4	0.05	0.04	0.09
	5	0.29	0.05	0.34
F	1	0.10	0.03	0.14

United Kingdom

Buildings A, B, C, E + F: mechanical, with recirculation
Building D: natural ventilated

Calculations were made using outdoor airflow rates (recirculated air was subtracted).

Table J.5 *Sensory pollution load (and errors)*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.15 ± 0.04	0.10 ± 0.28	-0.32 ± 0.33	-0.22 ± 0.43
	2	0.14 ± 0.04	0.02 ± 0.25	-0.37 ± 0.43	-0.35 ± 0.50
B	1	0.12 ± 0.05	0.33 ± 0.80	0.56 ± 0.79	0.89 ± 1.13
	2	0.03 ± 0.01	0.11 ± 1.08	0.59 ± 1.02	1.03 ± 1.48
C	1	0.04 ± 0.06	1.28 ± 0.79	0.28 ± 0.76	1.56 ± 1.10
D	1	0.03 ± 0.02	0.17 ± 0.12	0	0.17 ± 0.12
	2	0.10 ± 0.03	0.49 ± 0.34	0	0.49 ± 0.34
	4	-0.04 ± 0.23	0.16 ± 0.31	0	0.16 ± 0.31
	5	-0.01 ± 0.03	0.18 ± 0.15	0	0.18 ± 0.15
E	1	0.13 ± 0.16	1.66 ± 1.63	-0.66 ± 3.38	0.99 ± 3.76
F	1	0.06 ± 0.07	0.67 ± 1.28	0.72 ± 1.26	1.40 ± 1.80
	2	0.04 ± 0.01	1.02 ± 0.99	0.29 ± 1.03	1.31 ± 1.42

Table J.6 *Chemical pollution load (and errors)*

Building	Location	Chemical pollution load		
		toluene [(μg/s)/m²]		
		Office	Vent. system	Total
A	1	0.08 ± 0.09	0.11 ± 0.07	0.19 ± 0.11
	2	0.09 ± 0.08	0.15 ± 0.08	0.24 ± 0.11
B	1	0.34 ± 0.17	0.12 ± 0.19	0.47 ± 0.26
	2	0.50 ± 0.21	0.13 ± 0.18	0.63 ± 0.28
C	1	0.08 ± 0.35	0.72 ± 0.45	0.80 ± 0.57
D	1	0.07 ± 0.18	0	0.07 ± 0.18
	2	0 ± 0.93	0	0 ± 0.93
	4	0.35 ± 0.12	0	0.35 ± 0.12
	5	0.34 ± 0.11	0	0.34 ± 0.11
E	1	-1.99 ± 1.67	7.50 ± 3.25	5.52 ± 3.65
F	1	0.64 ± 0.29	0.50 ± 0.34	1.13 ± 0.45
	2	1.16 ± 0.47	0.63 ± 0.46	1.79 ± 0.66

Greece

Buildings A + E: mechanical, with recirculation (not included in calculation)
Buildings B, C + F: natural ventilated
Building D: mechanical, no recirculation

***Table J.7** Sensory pollution load (and errors)*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.18 ± 0.11	1.0 ± 0.84	0.0 ± 0.0	1.0 ± 0.0
	2	-0.06 ± 0.08	1.57 ± 0.0	0.0 ± 0.0	1.57 ± 0.0
	3	-0.08 ± 0.03	1.46	1.01 ± 0.25	2.45 ± 1.96
	4	0.0 ± 0.01	0.10 ± 0.08	0.0 ± 0.0	0.1 ± 0.0
	5	-0.02 ± 0.02	0.63	0.75 ± 0.18	1.37 ± 1.09
B	1	0.11 ± 0.02	0.76 ± 0.31	.	0.43 ± 0.33
	2	0.08 ± 0.05	0.01 ± 0.78	.	0.58 ± 0.45
	3	-0.12 ± 0.24	0.95 ± 0.84	.	0.95 ± 0.0
	4	0.46 ± 0.15	0.01 ± 0.93	.	0.58 ± 0.45
	5	0.07 ± 0.01	0.19 ± 1.88	.	0.74 ± 0.58
C	1	0.10 ± 0.01	0.59 ± 0.73	.	0.75 ± 0.59
	2	0.50 ± 0.03	6.61 ± 1.31	.	6.61 ± 5.04
	3	0.33 ± 0.02	2.53 ± 0.64	.	1.11 ± 0.83
	4	0.11 ± 0.01	1.44 ± 0.81	.	1.76 ± 1.35
	5	0.19 ± 0.01	2.59 ± 0.52	.	2.58 ± 1.96
D	1	0.23 ± 0.03	0.51	-0.14 ± 1.15	0.35 ± 0.46
	2	0.23 ± 0.02	1.53	-0.34 ± 2.75	1.19 ± 1.17
	3	0.14 ± 0.02	2.07 ± 0.58	0.0 ± 0.0	0.13 ± 0.10
	4	0.18 ± 0.04	0.33 ± 0.13	0.0 ± 0.0	0 ± 0.0
	5	0.13 ± 0.0	0.32	-0.1 ± 0.79	0.221 ± 0.27
E	1	0.54 ± 0.12	7.64	0.46 ± 0.21	4.42 ± 3.44
	2	-0.35 ± 0.13	2.75	0.91 ± 0.41	5.38 ± 4.29
	3	-0.68 ± 0.12	-5.54	0.59 ± 0.26	1.84 ± 1.44
	4	0.27 ± 0.06	8.48	1.36 ± 0.61	8.81 ± 7.0
	5	-0.03 ± 0.04	1.25	0.97 ± 0.44	2.21 ± 1.77
F	1	0.02 ± 0.01	0.21 ± 0.10	.	0.02 ± 0.29
	2	0.10 ± 0.01	0.42 ± 0.04	.	0.42 ± 0.32
	3	0.09 ± 0.01	0.52 ± 0.05	.	0.52 ± 0.45
	4	-0.01 ± 0.01	-0.05 ± 0.08	.	-0.05 ± 0.08
	5	0.10 ± 0.01	0.10 ± 0.06	.	0.1 ± 0.15

Table J.8 Chemical pollution load (and errors)

Building	Location	Chemical pollution load		
		toluene [(μg/s)/m²]		
		Office	Vent. system	Total
A	1	0.41 ± 0.40	0.0 ± 0.0	0.41 ± 0.0
	2	1.0 ± 0.37	0.0 ± 0.0	1.0 ± 0.0
	3	2.35 ± 0.55	-0.37 ± 0.12	1.97 ± 0.16
	4	0.0 ± 0.04	0.0 ± 0.0	0.0 ± 0.0
	5	0.65 ± 1.64	-0.28 ± 0.09	0.38 ± 0.03
B	1	0.30 ± 0.12	.	0.16 ± 0.01
	2	0.02 ± 0.30	.	0.22 ± 0.02
	3	-1.49 ± 2.11	.	-1.49 ± 0.0
	4	9.48 ± 3.39	.	3.00 ± 0.0
	5	0.06 ± 0.03	.	0.06 ± 0.0
C	1	0.26 ± 0.16	.	0.17 ± 0.01
	2	0.98 ± 0.29	.	0.98 ± 0.08
	3	0.22 ± 0.15	.	0.14 ± 0.01
	4	-0.50 ± 0.30	.	0.30 ± 0.02
	5	1.35 ± 0.32	.	1.34 ± 0.10
D	1	0.35 ± 0.40	0.19 ± 0.17	0.71 ± 0.11
	2	2.76 ± 1.05	0.46 ± 0.40	3.21 ± 0.38
	3	-0.46 ± 0.69	0.0 ± 0.0	0.08 ± 0.01
	4	-0.10 ± 0.31	0.0 ± 0.0	-0.1 ± 0.0
	5	-0.04 ± 0.16	0.13 ± 0.11	0.09 ± 0.04
E	1	0.64 ± 0.53	0.23 ± 0.11	0.09 ± 0.02
	2	0.14 ± 0.35	0.46 ± 0.21	-0.08 ± 0.03
	3	-1.23 ± 0.95	0.30 ± 0.14	0.05 ± 0.02
	4	1.94 ± 0.66	0.68 ± 0.32	1.14 ± 0.11
	5	0.50 ± 0.26	0.49 ± 0.23	0.09 ± 0.03
F	1	0.15 ± 0.15	.	0 ± 0.02
	2	0.25 ± 0.07	.	0.25 ± 0.02
	3	0.20 ± 0.06	.	0.20 ± 0.02
	4	0.08 ± 0.12	.	0.08 ± 0.01
	5	-0.05 ± 0.07	.	-0.05 ± 0.0

France

Buildings A + E: mechanical, no recirculation
Buildings B + F: mechanical, with recirculation
Building C: natural ventilated
Building D: only mech. exhaust

Calculations were made using outdoor airflow rates (recirculated air was subtracted when necessary)

***Table J.9** Sensory pollution load (and errors)*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.02 ± 0.01	0.72 ± 0.41	-0.52 ± 0.28	0.19 ± 0.48
	2	0.02 ± 0.01	0.39 ± 0.32	-0.68 ± 0.37	-0.29 ± 0.46
	3	0.06 ± 0.01	0.68 ± 0.45	-0.68 ± 0.37	0.0
	4	0.03 ± 0.01	0.09 ± 0.14	-0.52 ± 0.28	-0.43 ± 0.30
	5	0.07 ± 0.01	0.47 ± 0.18	-0.61 ± 0.33	-0.14 ± 0.38
B	1	0.83 ± 0.13	1.56 ± 1.54	-1.48 ± 0.78	0.17 ± 0.16
	2	0.22 ± 0.08	1.43 ± 1.12	-0.78 ± 0.44	0.11 ± 0.09
	3	0.06 ± 0.06	1.15 ± 0.86	-0.68 ± 0.41	0.13 ± 0.11
	4	0.01 ± 0.05	0.16 ± 0.6	-0.51 ± 1.80	0.03 ± 0.07
	5	0.11 ± 0.12	0.62 ± 1.37	-1.24 ± 2.70	0.07 ± 0.13
C	1	0.07 ± 0.01	0.05 ± 0.03	.	0.05 ± 0.03
	2	0.04 ± 0.01	0.27 ± 0.09	.	0.25 ± 0.09
	3	0.04 ± 0.01	0.12 ± 0.07	.	0.12 ± 0.07
	4	0.02 ± 0.00	0.17 ± 0.09	.	0.17 ± 0.09
	5	0.01 ± 0.00	0.30 ± 0.06	.	0.30 ± 0.06
D	1	0.01 ± 0.00	0.02 ± 0.01	.	0.02 ± 0.01
	2	0.19 ± 0.04	2.17 ± 0.62	.	2.17 ± 0.62
E	1	0.06 ± 0.01	-0.03 ± 0.19	0.20 ± 0.18	0.17 ± 0.21
	2	0.02 ± 0.01	0.08 ± 0.18	0.21 ± 0.20	0.29 ± 0.20
	3	0.03 ± 0.01	0.44 ± 0.13	0.12 ± 0.11	0.56 ± 0.14
	4	0.05 ± 0.01	0.36 ± 0.11	0.08 ± 0.08	0.44 ± 0.44
	5	0.01 ± 0.00	0.06 ± 0.07	0.07 ± 0.07	0.13 ± 0.13
F	1	0.06 ± 0.01	0.42 ± 0.07	-0.37 ± 0.21	0.04 ± 0.09
	2	0.13 ± 0.02	0.16 ± 0.27	-0.14 ± 0.550	0.03 ± 0.10

Table J.10 Chemical pollution load (and errors)

Building	Location	Chemical pollution load toluene [(µg/s)/m²]		
		Office	Vent. system	Total
A	1	0.0	0.08 ± 0.02	0.08 ± 0.02
	2	-0.02 ± 0.03	0.11 ± 0.03	0.08 ± 0.04
	3	0.25 ± 0.07	0.11 ± 0.03	0.36 ± 0.07
	4	-0.02 ± 0.03	0.08 ± 0.02	0.06 ± 0.03
	5	0.11 ± 0.05	0.09 ± 0.03	0.20 ± 0.05
B	1	0.26 ± 1.60	0.67 ± 1.9	0.58 ± 0.12
	2	1.66 ± 1.33	0.48 ± 0.40	0.42 ± 0.08
	3	0.31 ± 1.01	0.42 ± 2.55	0.42 ± 0.08
	4	-1.07 ± 0.65	0.32 ± 0.13	0.18 ± 0.04
	5	-1.07 ± 1.69	0.76 ± 0.58	0.44 ± 0.09
C	1	0.07 ± 0.02	.	0.08 ± 0.02
	2	0.14 ± 0.04	.	0.15 ± 0.04
	3	0.15 ± 0.04	.	0.15 ± 0.04
	4	0.14 ± 0.03	.	0.14 ± 0.03
	5	0.08 ± 0.02	.	0.08 ± 0.02
D	1	0.06 ± 0.01	.	0.06 ± 0.01
	2	0.47 ± 0.14	.	0.47 ± 0.14
E	1	0.21 ± 0.05	0.06 ± 0.02	0.27 ± 0.06
	2	0.24 ± 0.06	0.07 ± 0.02	0.31 ± 0.06
	3	0.1 ± 0.03	0.04 ± 0.01	0.14 ± 0.03
	4	0.13 ± 0.03	0.03 ± 0.01	0.16 ± 0.03
	5	0.06 ± 0.02	0.02 ± 0.01	0.08 ± 0.02
F	1	-0.04 ± 0.05	0.01 ± 0.02	0.06 ± 0.01
	2	0.03 ± 0.09	0.26 ± 0.15	0.2 ± 0.03

Switzerland

Building A: mechanical but not on at day of audit
Buildings C, D + G: mechanical, no recirculation
Buildings B, E, F + H: mechanical, with recirculation

Calculations were made using outdoor airflow rates (recirculated air was subtracted when necessary)

Table J.11 *Sensory pollution load (and errors)*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.05 ± 0.0	-0.06 ± 0.16	0	0.04 ± 0.04
B	2	0.02 ± 0.01	0.31 ± 0.20	-0.11 ± 0.17	0.24 ± 0.12
	4	0.02 ± 0.01	0.43 ± 0.22	-0.17 ± 0.18	0.31 ± 0.13
C	1	0.06 ± 0.01	0.17 ± 0.23	0.29 ± 0.20	0.49 ± 0.17
D	1	0.08 ± 0.05	2.01 ± 1.85	0.48 ± 0.25	1.16 ± 0.32
	2	0.08 ± 0.05	-0.46 ± 0.38	1.09 ± 0.55	2.96 ± 0.61
	3	0.08 ± 0.05	-0.13 ± 0.30	0.08 ± 0.11	0.15 ± 0.18
	4	0.25 ± 0.04	-0.29 ± 0.37	0.32 ± 0.18	0.53 ± 0.22
	5	0.08 ± 0.08	-0.04 ± 0.57	0.40 ± 0.27	0.63 ± 0.38
E	1	0.06 ± 0.02	1.55 ± 0.99	0.31 ± 0.44	2.00 ± 0.54
	3	0.06 ± 0.01	0.26 ± 0.44	0.21 ± 0.20	0.67 ± 0.25
	4	0.06 ± 0.01	0.43 ± 0.60	0.15 ± 0.19	0.76 ± 0.27
	5	0.06 ± 0.02	-0.01 ± 0.69	0.46 ± 0.36	0.98 ± 0.33
F	1	0.07 ± 0.02	0.60 ± 0.90	0.32 ± 0.71	1.21 ± 0.30
	2	0.08 ± 0.02	0.87 ± 0.75	0.05 ± 0.56	1.12 ± 0.27
	3	0.08 ± 0.02	1.26 ± 0.98	-0.26 ± 0.53	1.23 ± 0.37
	4	0.08 ± 0.02	-1.14 ± 1.78	-0.03 ± 0.29	0.61 ± 0.32
	5	0.08 ± 0.02	1.50 ± 1.17	-0.16 ± 0.74	1.51 ± 0.50
G	1	0.08 ± 0.02	0.54 ± 0.56	0.47 ± 0.34	1.28 ± 0.37
	2	0.08 ± 0.02	1.20 ± 0.54	0.28 ± 0.20	1.43 ± 0.35
	3	0.08 ± 0.02	0.36 ± 0.43	0.47 ± 0.34	1.08 ± 0.28
	4	0.08 ± 0.02	1.18 ± 0.88	0.39 ± 0.31	1.62 ± 0.63
	5	0.12 ± 0.03	1.19 ± 0.84	0.42 ± 0.31	1.72 ± 0.46
H	1	0.02 ± 0.02	0.17 ± 0.41	0.45 ± 0.35	0.65 ± 0.26

Table J.12 Chemical pollution load (and errors)

Building	Location	Chemical pollution load toluene [(µg/s)/m²]		
		Office	Vent. system	Total
A	1	.	.	.
B	2	0.0 ± 0.0	0.02 ± 0.03	0.09 ± 0.02
	4	0.03 ± 0.04	0.05 ± 0.04	0.08 ± 0.02
C	1	0.02 ± 0.06	-0.10 ± 0.07	-0.07 ± 0.07
D	1	0.14 ± 0.32	-0.33 ± 0.11	-0.09 ± 0.10
	2	2.51 ± 0.45	-0.75 ± 0.24	0.55 ± 0.23
	3	0.02 ± 0.08	-0.06 ± 0.07	-0.02 ± 0.03
	4	0.05 ± 0.03	-0.08 ± 0.03	-0.02 ± 0.02
	5	1.35 ± 0.48	-0.22 ± 0.13	0.56 ± 0.29
E	1	-0.03 ± 0.14	-0.05 ± 0.24	-0.22 ± 0.22
	3	-0.04 ± 0.08	-0.04 ± 0.11	-0.04 ± 0.11
	4	-0.03 ± 0.09	-0.04 ± 0.10	-0.02 ± 0.10
	5	-0.30 ± 0.17	-0.04 ± 0.21	-0.18 ± 0.20
F	1	-0.91 ± 0.16	0.56 ± 0.14	0.30 ± 0.10
	2	1.22 ± 0.16	-0.44 ± 0.12	1.12 ± 0.09
	3	0.53 ± 0.12	0.06 ± 0.09	0.49 ± 0.06
	4	5.26 ± 1.0	-1.51 ± 0.35	1.88 ± 0.43
	5	19.1 ± 0.76	-8.67 ± 0.37	9.75 ± 0.38
G	1	0.31 ± 0.06	0.13 ± 0.05	0.40 ± 0.06
	2	0.13 ± 0.04	0.08 ± 0.03	0.20 ± 0.03
	3	0.01 ± 0.05	0.13 ± 0.05	0.17 ± 0.05
	4	0.16 ± 0.08	0.11 ± 0.05	0.25 ± 0.09
	5	0.12 ± 0.06	0.12 ± 0.04	0.24 ± 0.05
H	1	0.28 ± 0.19	1.18 ± 0.21	1.44 ± 0.23

Finland

Buildings A, B, D, E + F: mechanical, no recirculation
Building C: mechanical, with recirculation

Calculations were made using outdoor airflow rates (recirculated air was subtracted when necessary)

Table J.13 *Sensory pollution load (plus errors).*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.08 ± 0.03	0.09 ± 0.10	0.43 ± 0.14	0.52 ± 0.15
	2	0.03 ± 0.01	0.03 ± 0.04	0.17 ± 0.06	0.20 ± 0.06
	3	.	0.46 ± 0.21	0.66 ± 0.21	.
	4	0.10 ± 0.09	0.19 ± 0.51	2.06 ± 0.70	2.25 ± 0.66
	5	.	0.11 ± 0.06	0.21 ± 0.07	.
B	1	0.10 ± 0.04	-0.13 ± 0.11	0.71 ± 0.15	0.58 ± 0.10
	2	0.10 ± 0.03	0.03 ± 0.09	0.53 ± 0.11	0.56 ± 0.10
	3	0.10 ± 0.04	-0.03 ± 0.10	0.64 ± 0.14	0.61 ± 0.11
	4	0.06 ± 0.02	0.56 ± 0.13	0.58 ± 0.12	1.14 ± 0.18
	5	.	0.13 ± 0.11	0.65 ± 0.14	0.78 ± 0.13
C	1	0.01 ± 0.01	0.05 ± 0.02	-0.06 ± 0.06	0.03 ± 0.0
	2	0.00 ± 0.02	0.13 ± 0.03	-0.10 ± 0.11	0.05 ± 0.01
	3	0.03 ± 0.01	0.30 ± 0.05	-0.08 ± 0.04	0.24 ± 0.05
	4	0.00 ± 0.01	0.08 ± 0.02	-0.05 ± 0.05	0.03 ± 0.0
	5	.	0.05 ± 0.02	-0.07 ± 0.07	0.02 ± 0.0
D	1	0.10 ± 0.02	0.26 ± 0.07	0.28 ± 0.05	0.54 ± 0.08
	2	0.14 ± 0.05	0.22 ± 0.07	0.43 ± 0.07	0.65 ± 0.08
	3	0.18 ± 0.04	0.47 ± 0.10	0.39 ± 0.07	0.86 ± 0.12
	4	0.13 ± 0.05	0.85 ± 0.17	0.46 ± 0.08	1.31 ± 0.19
	5	.	0.54 ± 0.16	0.62 ± 0.11	1.16 ± 0.18
E	1	0.21 ± 0.12	0.15 ± 0.07	-0.06 ± 0.04	0.09 ± 0.07
	2	.	.	.	.
	3	.	.	-0.11 ± 0.08	.
	4	0.10 ± 0.03	0.12 ± 0.06	-0.04 ± 0.03	0.07 ± 0.06
	5	.	.	.	.
F	1	0.11 ± 0.03	0.26 ± 0.05	0.03 ± 0.02	0.28 ± 0.06
	2	0.02 ± 0.02	0.25 ± 0.04	0.00 ± 0.02	0.25 ± 0.04
	3	0.05 ± 0.02	0.24 ± 0.03	0.00 ± 0.02	0.24 ± 0.03
	4	0.09 ± 0.03	0.30 ± 0.06	0.04 ± 0.02	0.34 ± 0.06
	5	.	0.12 ± 0.02	0.01 ± 0.01	0.14 ± 0.02

Table J.14 Chemical pollution load (plus errors).

Building	Location	Chemical pollution load		
		toluene [(μg/s)/m²]		
		Office	Vent.system	Total
A	1	0.13 ± 0.06	-0.04 ± 0.03	0.09 ± 0.06
	2	0.04 ± 0.02	-0.02 ± 0.01	0.02 ± 0.02
	3	.	-0.05 ± 0.05	.
	4	0.84 ± 0.36	-0.18 ± 0.17	0.66 ± 0.34
	5	.	-0.02 ± 0.02	.
B	1	0.06 ± 0.06	0.19 ± 0.05	0.25 ± 0.07
	2	-0.05 ± 0.03	0.19 ± 0.04	0.14 ± 0.03
	3	-0.11 ± 0.04	0.17 ± 0.05	0.06 ± 0.02
	4	-0.15 ± 0.03	0.15 ± 0.04	0.00 ± 0.01
	5	-0.03 ± 0.04	0.16 ± 0.05	0.13 ± 0.04
C	1	-0.04 ± 0.02	0.02 ± 0.03	0.00 ± 0.00
	2	-0.01 ± 0.05	0.04 ± 0.05	0.02 ± 0.01
	3	0.09 ± 0.05	0.01 ± 0.02	0.09 ± 0.03
	4	-0.02 ± 0.02	0.02 ± 0.02	0.01 ± 0.0
	5	-0.08 ± 0.02	0.02 ± 0.03	-0.00 ± 0.0
D	1	0.06 ± 0.03	-0.04 ± 0.03	0.02 ± 0.04
	2	0.00 ± 0.03	-0.05 ± 0.04	-0.05 ± 0.04
	3	0.00 ± 0.03	0.05 ± 0.04	0.05 ± 0.04
	4	-0.03 ± 0.03	-0.06 ± 0.04	-0.09 ± 0.04
	5	-0.08 ± 0.04	-0.09 ± 0.06	-0.17 ± 0.06
E	1	0.00 ± 0.06	-0.01 ± 0.02	-0.00 ± 0.06
	2	.	.	.
	3	.	-0.02 ± 0.05	.
	4	.	-0.01 ± 0.02	.
	5	.	.	.
F	1	0.40 ± 0.18	0.00 ± 0.01	0.60 ± 0.17
	2	.	0.00 ± 0.02	.
	3	0.09 ± 0.04	0.00 ± 0.02	0.09 ± 0.04
	4	0.20 ± 0.06	0.00 ± 0.02	0.20 ± 0.06
	5	.	0.00 ± 0.01	.

Norway

Buildings A, B, D, E + F: mechanical, no recirculation
Building C: mechanical, with recirculation

Calculations were made using outdoor airflow rates.

Table J.15 *Sensory pollution load (and errors)*

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.05 ± 0.03	0.41 ± 0.29	0.07 ± 0.19	0.48 ± 0.35
	2	0.01 ± 0.02	0.49 ± 0.33	0.08 ± 0.22	0.57 ± 0.39
	3	0.07 ± 0.03	0.42 ± 0.32	0.08 ± 0.22	0.50 ± 0.39
	4	0.04 ± 0.03	0.47 ± 0.39	0.06 ± 0.27	0.53 ± 0.47
	5	0.08 ± 0.03	0.39 ± 0.28	0.04 ± 0.19	0.13 ± 0.33
B	1	0.08 ± 0.07	0.51 ± 0.66	0.60 ± 0.76	1.11 ± 1.01
	2	0.12 ± 0.07	-0.06 ± 0.61	0.32 ± 0.70	0.26 ± 0.93
	3	0.05 ± 0.04	0.24 ± 0.32	0.29 ± 0.37	0.53 ± 0.48
	4	0.05 ± 0.04	0.17 ± 0.39	0.21 ± 0.45	0.38 ± 0.60
	5	0.21 ± 0.10	0.32 ± 0.75	0.40 ± 0.86	0.72 ± 1.14
C	1	0.07 ± 0.06	0.03 ± 0.31	0.13 ± 0.35	0.15 ± 0.46
	2	0.05 ± 0.05	0.32 ± 0.28	0.11 ± 0.31	0.44 ± 0.42
	3	0.05 ± 0.07	0.20 ± 0.39	0.16 ± 0.44	0.36 ± 0.59
	4	0.11 ± 0.02	0.20 ± 0.11	0.03 ± 0.12	0.22 ± 0.17
	5	0.15 ± 0.03	0.16 ± 0.12	0.03 ± 0.13	0.19 ± 0.18
D	1	0.10 ± 0.04	0.28 ± 0.38	0.13 ± 0.41	0.41 ± 0.56
	2	0.10 ± 0.04	0.37 ± 0.37	0.13 ± 0.40	0.50 ± 0.55
	3	0.06 ± 0.04	0.33 ± 0.44	0.15 ± 0.48	0.48 ± 0.66
	4	0.07 ± 0.05	0.17 ± 0.49	0.17 ± 0.53	0.34 ± 0.72
	5	0.02 ± 0.04	0.26 ± 0.47	0.16 ± 0.51	0.42 ± 0.69
E	1	0.03 ± 0.04	0.19 ± 0.27	0.04 ± 0.27	0.23 ± 0.39
	2	0.23 ± 0.05	0.13 ± 0.27	0.04 ± 0.27	0.17 ± 0.39
	3	0.08 ± 0.05	0.18 ± 0.26	0.04 ± 0.26	0.22 ± 0.37
	4	0.03 ± 0.05	0.18 ± 0.29	0.13 ± 0.29	0.31 ± 0.41
	5	0.04 ± 0.05	0.02 ± 0.31	0.15 ± 0.32	0.17 ± 0.44
F	1	0.01 ± 0.01	0.01 ± 0.04	0.04 ± 0.04	0.05 ± 0.05
	2	0.0 ± 0.01	-0.01 ± 0.05	0.05 ± 0.05	0.04 ± 0.06
	3	0.03 ± 0.01	-0.02 ± 0.06	0.08 ± 0.06	0.06 ± 0.08
	4	0.09 ± 0.04	-0.12 ± 0.28	0.40 ± 0.28	0.29 ± 0.40
	5	0.08 ± 0.06	0.05 ± 0.41	0.59 ± 0.410	0.64 ± 0.58

Table J.16 *Chemical pollution load (and errors)*

Building	Location	Chemical pollution load		
		toluene [(µg/s)/m²]		
		Office	Vent. system	Total
A	1	0.92 ± 0.22	-0.17 ± 0.07	0.75 ± 0.23
	2	3.20 ± 0.71	-0.19 ± 0.08	3.01 ± 0.71
	3	3.67 ± 0.80	-0.19 ± 0.08	3.48 ± 0.81
	4	0.13 ± 0.08	-0.23 ± 0.10	-0.10 ± 0.13
	5	1.35 ± 0.31	-0.16 ± 0.07	1.19 ± 0.32
B	1	-0.32 ± 0.16	0.09 ± 0.17	-0.22 ± 0.23
	2	-0.09 ± 0.10	-0.21 ± 0.13	-0.29 ± 0.17
	3	0.35 ± 0.14	0.05 ± 0.08	0.40 ± 0.16
	4	0.08 ± 0.08	-0.13 ± 0.09	-0.06 ± 0.12
	5	-0.43 ± 0.18	0.11 ± 0.20	-0.32 ± 0.26
C	1	0.39 ± 0.12	-0.23 ± 0.09	0.16 ± 0.14
	2	-0.05 ± 0.04	-0.21 ± 0.08	-0.25 ± 0.09
	3	0.10 ± 0.08	-0.30 ± 0.11	-0.20 ± 0.13
	4	0.07 ± 0.03	-0.08 ± 0.03	-0.01 ± 0.04
	5	0.09 ± 0.03	-0.09 ± 0.03	0.0 ± 0.05
D	1	0.23 ± 0.06	0.02 ± 0.02	0.24 ± 0.06
	2	0.30 ± 0.07	0.02 ± 0.02	0.32 ± 0.08
	3	0.13 ± 0.04	0.02 ± 0.02	0.15 ± 0.05
	4	0.48 ± 0.12	0.02 ± 0.02	0.51 ± 0.12
	5	0.22 ± 0.06	0.02 ± 0.02	0.24 ± 0.06
E	1	0.04 ± 0.05	0.11 ± 0.04	0.16 ± 0.06
	2	0.08 ± 0.05	0.11 ± 0.04	0.19 ± 0.06
	3	0.32 ± 0.10	0.13 ± 0.04	0.45 ± 0.11
	4	0.13 ± 0.05	0.09 ± 0.03	0.22 ± 0.06
	5	0.14 ± 0.07	0.14 ± 0.05	0.29 ± 0.09
F	1	0.16 ± 0.04	0.03 ± 0.01	0.19 ± 0.04
	2	0.06 ± 0.02	0.04 ± 0.01	0.10 ± 0.02
	3	0.14 ± 0.04	0.05 ± 0.01	0.18 ± 0.04
	4	0.08 ± 0.07	0.24 ± 0.06	0.32 ± 0.09
	5	0.69 ± 0.21	0.35 ± 0.09	1.04 ± 0.23

Germany

Buildings B, C, E + F: mechanical, no recirculation
Building A and D: natural ventilated

Table J.17 Sensory pollution load

Building	Location	Office [olf/m²]		Vent. [olf/m²]	Total load [olf/m²]
		occupants	total		
A	1	0.02	0.17	.	
	2	0.03	0.26	.	
	3	0.03	0.21	.	
	4	0.03	0.24	.	
	5	0.01	0.25	.	
B	1	0.10	0.29	0.33	
	2	0.10	0.39	0.38	
	3	0.10	0.85	0.38	
	4	0.10	0.34	0.36	
	5	0.13	0.46	0.38	
C	1	0.04	0.58	0.41	
	2	0.08	0.46	0.37	
	3	0.07	1.03	0.45	
	4	0.06	0.78	0.41	
	5	0.05	0.75	0.41	
D	1	0.04	0.27	.	
	2	0.11	0.35	.	
	3	0.04	0.17	.	
	4	0.06	0.35	.	
	5	0.04	0.10	.	
E	1	0.22	1.62	-0.11	
	2	0.11	1.26	-0.09	
	3	0.07	0.97	-0.12	
	4	0.04	1.24	-0.12	
	5	0.08	0.88	-0.11	
F	1	0.12	-1.33	4.03	
	2	0.26	-0.67	4.04	
	3	0.27	-1.55	4.09	
	4	0.09	-1.64	4.07	
	5	0.14	-1.54	4.07	
	6	0.06	-1.75	4.04	

Table J.18 *Chemical pollution load*

Building	Location	Chemical pollution load toluene [(µg/s)/m²]		
		Office	Vent. system	Total
A	1	0.01	.	
	2	0.0	.	
	3	0.01	.	
	4	0.01	.	
	5	0.01	.	
B	1	0.17	0.11	
	2	0.17	0.11	
	3	0.17	0.11	
	4	0.30	0.10	
	5	0.11	0.11	
C	1	0.53	0.19	
	2	0.11	0.21	
	3	0.28	0.19	
	4	0.30	0.17	
	5	0.34	0.19	
D	1	0.21	.	
	2	0.26	.	
	3	0.15	.	
	4	0.14	.	
	5	0.37	.	
E	1	0.70	0.61	
	2	0.68	0.64	
	3	0.47	0.65	
	4	0.39	0.51	
	5	0.26	0.61	
F	1	0.35	0.48	
	2	0.13	0.48	
	3	0.34	0.47	
	4	0.34	0.47	
	6	0.34	0.47	
	5	0.35	0.48	

APPENDIX K REVISED CHECKLIST

EUROPEAN IAQ AUDIT PROJECT: Check list ON BUILDING, INSTALLATIONS AND ROOMS

Part 1: Questions related to the whole building

For each of the audited buildings this part should be filled in.

1. Identification

Building: ______ Country: ______ Responsible investigator: ______ Date: ______

2. Orientation of the building (sketch):

3. Where is the building situated?

[1] Industrial area [3] Suburb [5] Other

[2] Down town [4] Country side

4. The traffic situation within 200 m from the building. Indicate type of roads:

[1] Motor way [3] Busy cross road [5] Quiet road

[2] Busy through road [4] Moderate busy road

5. Are there any sources of outdoor air pollution that might influence the indoor climate?

[0] None [2] Power plant [4] Industry

[1] Parking garage [3] Cooling towers [5] Other

6. Activities in the building besides office work?

[0] None　[2] Industry　[4] Shop

[1] Garage　[3] Laboratory　[5] Other

7. Size of Building

Number of floors used for general occupancy: _____　Total area: _____m^2

Total no. of offices: _____　No. of employees: _____

8. Age of building

In which year was the building completed: _______

Totally renovated: _______　Occupied by present user: _______

9. Construction details

No. of floors beneath ground level: _____　Use of theese floors: _______________

Roof: Approx. angle to horizontal: _____°

10. Are there any solarshading devices?

[0] None　[1] Outside　[2] Between glazing　[3] Inside

[1] Solar shading factor: _____

Indicate which facades are shaded: _______________

[1] Automatic control　[2] Central down, individually up　[3] Individual　[4] Fixed

11. Type of glazing

[1] Single　[2] Double　[3] Triple

[1] Clear　[2] Reflecting　[3] Adsorbing

[1] Light transmittance _____%　[2] Insulation value _____$W/m^2 \cdot °C$

Glass area _____ % of total floor area

12. No. of Heating and ventilation systems: _____

Total supply or exhaust air flow: ___l/s

13. Energy data: Consumption of:

[1] Oil _____MWh [2] Gas _____MWh [3] Electricity _____MWh [4] Other ______MWh

Installed Power of:
Fans _____ Lighting _____ Other equipment _____

14. Have there been modifications of?

Flooring:	[0]	No	[1]	Yes, in which year: _______
Insulation:	[0]	No	[1]	Yes, in which year: _______
Wall or ceiling lining:	[0]	No	[1]	Yes, in which year: _______
Heating system:	[0]	No	[1]	Yes, in which year: _______
Ventilation system:	[0]	No	[1]	Yes, in which year: _______
Windows:	[0]	No	[1]	Yes, in which year: _______

15. Water damages now or recently ?______ Where ? _______________

Treatment ____

16. What is the furniture made of mainly?

[1] Solid wood [2] Veneered chip board [3] Metal [4] Other

Fabric covered: ______

Mean age of the furniture: [1] 3 years or less [2] older than 3 years

17. Are there large or many green plants?

[0] None [1] Flowering [2] Green leaved plants

[0] No treatments [1] Treated with "leaf shine" [2] Treated with pesticide

18. Is smoking generally allowed?

[0] no [1] only in seperately ventilated rooms [2] Yes [3] outside working hours

19. General activities and office machines:

Solvents generally used? [0] No [1] Yes, name type: _______

Other chemicals generally used? [0] No [1] Yes, name type: _______

Copying machines in offices? [0] No [1] Yes

Number of Video Display Units (VDU)?

[0] No VDU [1] 1 or more per person [2] 1-2 persons per VDU [3] 2-10 persons per VDU

Laserprinters in offices? [0] No [1] Yes

Carbonless paper extensive use? [0] No [1] Yes

20. How and how often are the rooms cleaned? (put a cross)

	[4] Daily	[3] 2-4 times a week	[2] Once a week	[1] 1-3 times a month	[0] Seldom or never
Cleaning the tables					
Cleaning the walls					
Washing the floors					
Vacuum cleaning					
Mopping					
Sweeping					
Waxing or polishing					

How often is spring cleaning done? [2] Twice a year [1] Once a year [0] Less

Time since last spring cleaning? ______ month Do floors look dirty? [0] No [1] Yes

21. Which substances are used for cleaning?

Floors:
Name: ______ Content: ______ ______ ______ pH of solution used: ______

Category: [1] Polish or wax [2] Cleaning agent leaving a film [3] Not leaving a film

Name: ______ Content: ______ ______ ______ pH of solution used: ______

Category: [1] Polish or wax [2] Cleaning agent leaving a film [3] Not leaving a film

Tables:
Name: ______ Content: ______ ______ ______ pH of solution used: ______

Category: [1] Polish or wax [2] Cleaning agent leaving a film [3] Not leaving a film

Sanitary installations:
Name: ______ Content: ______ ______ ______ pH of solution used: ______

Category: [1] Polish or wax [2] Cleaning agent leaving a film [3] Not leaving a film

Other:
Name: ______ Content: ______ ______ ______ pH of solution used: ______

Category: [1] Polish or wax [2] Cleaning agent leaving a film [3] Not leaving a film

EUROPEAN IAQ AUDIT PROJECT: Check list ON BUILDING, INSTALLATIONS AND ROOMS

Part 2: Installations

This part should cover all the rooms for special attention in the audited buildings. One or more copies should be filled in per building.

1. Identification

Building: ______ System no.___ Room(s): ______ Responsible investigator: Date: ______

2. How are the rooms heated?

[1] Hot-water [2] Air heating [3] Direct electric

Location:
[1] Radiators [2] Floor heating [3] Ceiling heating

[4] Fan coil or induction units [5] Other, Type: ______________________________

3. How are the rooms cooled ?

[0] No specific cooling [1] Cooled air [2] Local fan coil units

[3] Cooled ceiling [4] Cooling convectors i.e in induction units [5] Other

4. How is room temperature controlled?

[1] Manual (radiator valve) [2] Local thermostat at radiator/unit

[3] Local wall thermostat [4] Central

[5] Other, Type: ____________________________

Is the room temperature central reduced, outside working hours? [0] No [1] Yes

can the control be considered as indivual control ? [0] No [1] Yes

5. How are the rooms ventilated?

[1] Openable windows or other natural ventilation

[2] Exhaust system, only [3] Supply system, only

[4] Balanced system with VAV [5] Balanced system with dual ducts

[6] Balanced system with induction units [7] Simple balanced system

[8] Other

Can windows be opened? [0] No [1] Yes, but not allowed [2] Yes

---

6. Airchange rate (Average design value for supply of outdoor air to office area including corridors, stairways and other secondary rooms (not garages basements and similar))?

[1] < 0.5 times per hour [2] 0.5-1 times per hour

[3] 1-3 times per hour [4] > 3 times per hour

Total supply or exhaust(greatest) outdoor air flow _______l/s

Air flow rate per person in: building/ room _____/_____

Lowest outdoor air supply per person (design value_____l/s · p / calculated value____l/s · p)

---

7. Position of ventilation system intake?

[0] None [1] Roof [2] Facade [3] Ground

Height above ground level: ___________m

Distance from exhaust outlets: Vertical: ________m Horizontal: ________m

Distance from cooling towers: Vertical: ________m Horizontal: ________m

---

8. Is the ventilation system equipped with?

Recirculation: [0] No [1] Yes, About %: ____________ return air

Humidification: [0] No [1] Evaporation [2] Spray [3] Steam

Water purification: [0] No [1] Ozone [2] Biocides [3] High voltage [4] UV lamp

Cooling: [0] No [1] Yes, Type: ________________________________

Heat recovery: [0] No [1] Rotating wheel [2] Plate [3] Other

9. How is the on-off setting of the ventilation system controlled? [1] Manual [2] Automatic

Is the ventilation system controlled by demand sensors? [0] No [1] Yes

What type of demand sensors are used?

[1] Temperature [2] CO_2 [3] Humidity [4] Multi-gas [5] Other

The system is operating at?

Full performance: From ____ to ____ on Working days___ Weekends ___ Holidays _______

Reduced perform.: From ____ to ____ on Working days___ Weekends ___ Holidays _______

Stopped system: From ____ to ____ on Working days___ Weekends ___ Holidays _______

100% recirculation:From _____ to ____ on Working days___ Weekends ___ Holidays _______
_____ % return air:From _____ to ____ on Working days___ Weekends ___ Holidays _______

10. Duct material and insulation:

[1] Asbestos cement [2] Fabric [3] PVC [4] Galvanized steel [5] Other

Insulation: [0] None [1] External [2] Internal [3] Both

11. Specification and servicing of ventilation components?

Filters

Filter location	*Eurovent Class*	*Last replacement*	*Needing service now*
Air intake			[0] No [1] Yes
Recirculation duct			[0] No [1] Yes
Central Air Handling Unit			[0] No [1] Yes
Supply air outlets			[0] No [1] Yes
Induction/ fan-coil units			[0] No [1] Yes

Heating/cooling batteries Last cleaning: _____ Needing service: [0] No [1] Yes

Heat exchangers Last cleaning: _____ Needing service: [0] No [1] Yes

Humidifier Last cleaning: ______ Needing service: [0] No [1] Yes

Ducts Last cleaning: _____ Needing service: [0] No [1] Yes

Air outlets and inlets in rooms Last cleaning: _____ Needing service: [0] No [1] Yes

Presence and skill of maintenance personnel: ____________________________

12.Location of air supply inlets?

[1] Floor [2] Windowsill [3] Ceiling [4] High on wall [5] Low on wall

location of outlets: [1] High [2] Low

Air distribution: [1] Displacement [2] Mixing

EUROPEAN IAQ AUDIT PROJECT: Check list ON BUILDING, INSTALLATIONS AND ROOMS

Part 3: The investigated rooms

This part should cover all the rooms for special attention in the audited buildings. One copy should be filled in per room.

1. Identification

Building: ______ Room: ______ Responsible investigator: ______ Date: ______

2. What does the outer wall consist of? (Interior side of the insulation)
Add % area of each material

[1] Bricks [2] Chip board [3] Plaster board [4] Concrete [5] Metal

[6] Glass [7] Other, Material: ________________________

Insulation? [0] No [1] Yes, Material: ______ Thickness: ______ m

3. What is the floor covered with?

	Office	Corridors	Approx. % of offices or corridors covered
Felt (needle) carpet	____	____	____
Nap carpet with rubber backing	____	____	____
Nap carpet without rubber backing	____	____	____
Lacquered wood	____	____	____
Oil treated wood	____	____	____
Waxed or polished wood	____	____	____
Soap treated wood	____	____	____
Vinyl (PVC)	____	____	____
Linoleum	____	____	____
Cork	____	____	____
Other	____	____	____

4. What are the walls covered/treated with inside the building?
Add % area of each material

[1] Wallpaper [2] Enamel paint [3] Dispersion Paint

[4] Wood [5] Unpainted textiles [6] PVC

[7] Other, Material: ____________________

5. What does the ceiling consist of? (Inside surface in the room)
Add % area of each type

[1] Concrete [2] Plaster board [3] Wood

[4] Plaster ceiling [5] Acoustic tiles, Material: ____________________
(e.g. perforated plate, mineral wool, etc.)

[6] Other: ____________________

Is there an airspace above the acoustic tiles? [0] No [1] Yes

Is visible dust accumulated above? [0] No [1] Yes

Do acoustic baffles hang below the ceiling? [0] No [1] Yes

6. How is the room lit? [1] Artificial [2] Daylight [3] Both

Ceiling or general lighting: [1] Fluorescent [2] Incandescent lamps [3] Halogen

Individual adjustable lighting: [1] Fluorescent [2] Incandescent lamps [3] Halogen

Control of general lighting: [1] Automatic [2] Automatic with manual end control

[3] Manual

7. Microbiological activities:

Is there visible mould growth in the room? [0] No [1] Yes

Are there damp spots on walls/ceilings/floors? [0] No [1] Yes

Is there a mould odour in the room? [0] No [1] Yes

8. Detailed description of room:

Area: ________ m^2 Height: ________ m Number of work places: ________

Area of fleecy material: ______ m^2 Length of shelves: ______ m

Fleece factor:(Area of all fleecy materials divided with room volume). ______ m^2/m^3

Shelf factor: (Length of all open shelves with paper divided with room volume). ______ m/m^3

Window area: ________ m^2 Office dept: _______ m

No. of laserprinters: ________ No. of photocopiers: ________

No. of VDUs: ________

Acceptable access for cleaning? [0] No [1] Yes

Door to corridor generally open? [0] No [1] Yes

VDU position results in reflection? [0] No [1] Yes No. of VDUs: ________

VDU position results in glare? [0] No [1] Yes No. of VDUs: ________

9. Smoking habits: Number of cigarettes or alike per day:______

10. Lay out of office: