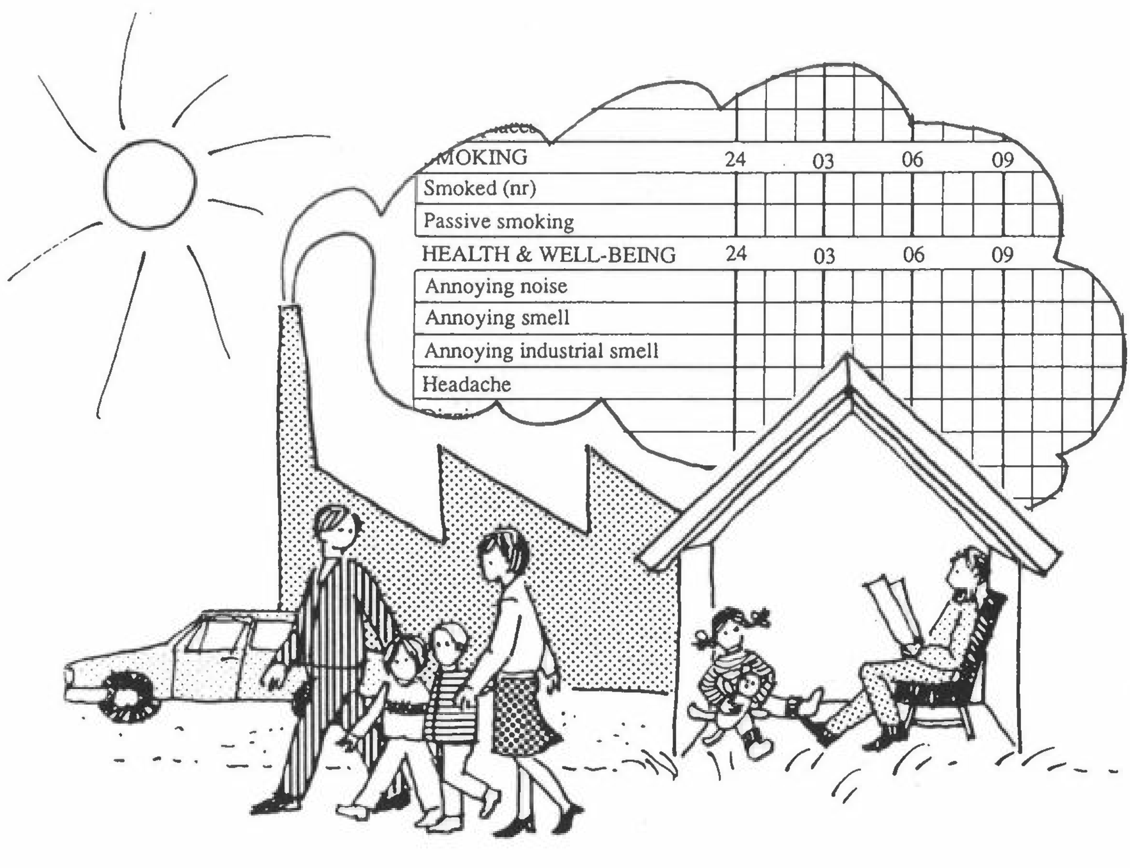
Undertaken by: Norwegian Institute for Air Research
and National Institute of Public Health

Air pollution and short-term health effects in an industrialized area in Norway

MAIN REPORT



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AIR POLLUTION AND SHORT-TERM HEALTH EFFECTS IN AN INDUSTRIALIZED AREA IN NORWAY

MAIN REPORT

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PREFACE

Grenland in Southern Telemark in Norway is an area that for the last 40 years has been polluted from the many industrial complexes in the area. Concentrations of air pollutants have been among the highest in Norway. As opposed to most other districts in Norway, air quality has been characterized by a mixture of many compounds. Air pollution concentrations were probably highest in the 1960s and early 70s when the possibility that these concentrations were leading to detrimental health effects were discussed and investigated.

The results of an earlier study indicated that air pollution, in addition to being annoying for the inhabitants, resulted in a higher incidence of bronchitis in the most polluted areas.

A new investigation seemed to be required as a basis to help establish new regulative measures. Since further measures to reduce air pollution in the area could have large economical consequences, a new study should provide rather detailed information as to which compound or compounds future measures should be directed towards.

However, many of the methods needed to address this problem have only recently been developed. A new investigation would therefore, have to further improve them.

The Norwegian State Pollution Control Authority requested therefore the Norwegian Institute for Air Research to develop and design a new research investigation where the National Institute of Public Health would be responsible for medical aspects.

The work was carried out under contract from the Ministry of the Environment, the Norwegian State Pollution Control Authority and the Royal Norwegian Council for Scientific and Industrial Research, who jointly appointed a board that had the

administrative and coordinating responsibility for the investigation.

The two institutions, the Norwegian Institute for Air Research (NILU) and the National Institute of Public Health (NIPH), appointed each their own principal investigator, Dr. Jocelyne Clench-Aas, Ph.D., Dr.-es-Sc. from NILU and Dr. Gunnar Bjerknes- Haugen, M.Sc., M.D. from NIPH.

The Norwegian Computing Center has actively participated in the investigation with their expertise and we thank them for their support.

We would also like to thank the Telemark Central Hospital in Skien and Porsgrunn for its cooperation and scientific advice.

We would also like to thank TELELAB A/S and the local division of the State Pollution Control Authority for their help in the field part of the investigation.

During the field work a large number of individuals were especially helpful and must be given their share of credit for the success of this investigation. The two participating institutions would like to thank them for their contributions. Their names and the tasks they performed are listed in Chapter 14 in the back of the report.

The Board

Sigurd Hagen (Chairman), Lasse Hansen (to 1.1.1991)
Erik Dybing, Sverre Langård (from 17.4.91)

TABLE OF CONTENTS

Page

PREFACE 1

SUMMARY 7

1 INTRODUCTION - O.F. Skogvold[1], L.S. Bakketeig[2] 13
1.1 Background - earlier investigation 13
1.2 Goal of investigation 15
1.3 Organization of investigation 15
1.4 Dissemination of results 17

2 DESCRIPTION OF THE INVESTIGATION - J. Clench Aas[1], G. Bjerknes-Haugen[2] 19
2.1 Introduction 19
2.2 Description of the geographical area 22
2.3 General description of study design 23
2.4 Determination of study population size 27

3 REPRESENTATIVITY AND BACKGROUND INFORMATION FOR THE SELECTED STUDY GROUPS - G. Bjerknes-Haugen[2], S.O. Samuelsen[2] 31
3.1 Randomly selected study population 32
3.1.1 Socio-economic variables 32
3.1.2 Clinical/physiological variables 38
3.1.3 Dropout 38
3.2 Adult population with pre-existing lung disease 40
3.2.1 Socio-economic variables 41
3.2.2 Clinical/physiological variables 41
3.2.3 Dropout 44
3.3 Child population with pre-existing lung disease 44
3.3.1 Socio-economic variables 44
3.3.2 Clinical/physiological variables 45
3.3.3 Dropout 45
3.4 Conclusion 45

4 MEASUREMENTS OF METEOROLOGICAL CONDITIONS AND AIR QUALITY - L.O. Hagen[1], K. Hoem[1] 47
4.1 Measurement program for meteorological conditions and air quality 47
4.2 Results 50
4.2.1 Meteorological conditions 50
4.2.2 Air quality 52
4.3 Conclusions 58

5 DESCRIPTION OF AIR POLLUTANT EMISSIONS IN THE REGION - I. Haugsbakk[1], K.E. Grønskei[1] 59
5.1 General overview 59
5.2 Industrial emissions 61
5.3 Emissions from home heating and small industrial plants 61

1 Norwegian Institute for Air Research
2 National Institute of Public Health
3 Norwegian Computing Center

5.4 Emissions from car traffic 62
5.5 Emissions from ship traffic 63
5.6 Total emissions 63
5.7 Application of emission data in modelling of geographic distribution of air pollutants 64

6 RESULTS OF INDOOR/OUTDOOR MEASUREMENTS - O.-A.Braathen[1] 65
6.1 Selection of the homes that were measured 65
6.2 Measurement program 65
6.3 Results 68
6.4 Application of the results in exposure assessment 73

7 MODELLING OF GEOGRAPHIC DISTRIBUTION OF AIR POLLUTANTS - K.E. Grønskei[1], S.E. Walker[1], F. Gram[1] 81
7.1 Description of the method 81
7.2 Description of the calculation method 84
7.2.1 Contribution to concentration from local sources 84
7.2.2 The boundary conditions 85
7.2.3 Correction of concentration distribution based on hourly measurements 87
7.3 Estimated concentrations in the air entering the region (background concentrations) 90
7.4 Results and model validation 90
7.4.1 Model validation for NO_x 92
7.4.2 Model validation for particles ($PM_{2.5}$) 96
7.4.3 Model validation for SO_2 96
7.4.4 Summary 99
7.5 Sulfate, nitrate and ozone concentrations and chemical reactions in the air in Grenland 99
7.6 Application of hourly concentrations in further exposure estimation 100

8 DESCRIPTION OF THE INDIVIDUAL AIR POLLUTION EXPOSURE ESTIMATES - J. Clench-Aas[1], A. Bartonova[1], A. Harstad[1], M. Johnsrud Aarnes[1] 105
8.1 Description of the model designed to estimate individual exposure 105
8.2 Description of time-use based on information provided by the diary 110
8.3 Description of estimated exposure to different air pollution components in Grenland 114
8.3.1 Exposure to pollution at different days of the investigation 114
8.3.2 Exposure to pollution at different times of day and season 115
8.3.3 Exposure to pollution in different population subgroups 115
8.3.4 Exposure to pollution in different micro-environments 120

8.4 Comparison of estimated hourly, 8-hour and 24-hour exposure to fixed site outdoor concentrations 120
8.5 Statistical properties of the exposure estimates and their possible interdependence .. 123
8.6 Application of exposure estimates in assessing the health effects of air pollution 125

9 DESCRIPTION OF SELF-REPORTED HEALTH DATA REPORTED BY THE PARTICIPANTS - A. Bartonova[1], J. Clench-Aas[1], M. Johnsrud Aarnes[1], G. Bjerknes-Haugen[2], S.O. Samuelsen[2], L.S. Bakketeig[2] 129
9.1 Frequencies and duration of responses in the study population and population with pre-existing lung disease 130
9.2 Frequencies and duration of responses by various factors 137
9.2.1 Population characterization based on biological factors 137
9.2.2 Population characterization based on lifestyle factors 140
9.2.3 Population characterization based on factors concerning physical surroundings 141
9.3 Daily and seasonal variations in the responses 142
9.4 Onset of responses by time of day and activity 146
9.5 Frequencies and duration of reporting of sickness, fever, alcohol use, and use of medication 146
9.6 Associations between responses 148
9.7 Conclusions 150

10 DESCRIPTION OF OBJECTIVE HEALTH DATA FOR THE PARTICIPANTS - G. Bjerknes-Haugen[2], S.O. Samuelsen[2], O.Aalen[2] J. Clench-Aas[1], A. Bartonova[1], M. Johnsrud Aarnes[1], L.S. Bakketeig[2] 155
10.1 Clinical examination 155
10.2 Spirometry 156
10.2.1 Test description 156
10.2.2 Statistical analysis 157
10.3 Blood tests 162
10.3.1 Carboxyhemoglobin 162
10.3.1.1 Analysis of COHb against daily smoking information obtained from the diary form 166
10.3.2 Sedimentation rate (SR) 167
10.3.3 Hemoglobin (Hb) 168
10.4 Urine tests 169
10.5 Microbiological tests 169
10.6 Daily measurements of PEF 170
10.6.1 Follow-up over the day 170
10.6.2 Variation in PEF over the day 172
10.6.3 Follow-up during the week 174
10.6.4 Variation in PEF during the week 175
10.6.5 Follow-up through the winter and summer periods 175
10.6.6 Variation in PEF level during the winter and summer periods 178
10.6.7 Comparison between PEF measurements made at daily basis and at bi-weekly health examination 178
10.6.8 Conclusion and summary 181

11 THE RELATIONSHIP BETWEEN SELF-REPORTED HEALTH DATA AND AIR POLLUTION - J. Clench-Aas[1], A. Bartonova[1], G. Bjerknes-Haugen[2], N.L. Hjort[3], K. Halvorsen[3], S.O. Samuelsen[2], L.S. Bakketeig[2] 183
11.1 Introduction 183
11.2 Overview of previous studies 185
11.2.1 Animal studies 186
11.2.2 Cross-sectional and chamber studies 188
11.2.3 Cohort studies 191
11.3 Methodology 195
11.3.1 Statistical model 195
11.3.2 Compression of data 196
11.3.3 Independent variables in the model 203
11.3.4 Autocorrelation 204
11.3.5 Statistical significance 205
11.4 Results - cumulated health response 206
11.5 Results of the relationships between air pollution exposure and the individual health symptom groups, using M-indiv compression 213
11.5.1 Symptoms of annoyance 214
11.5.2 Symptoms in the upper airways 215
11.5.3 Symptoms in the lower airways 215
11.5.4 Symptoms of decreased general health 216
11.5.5 Symptoms of stress and fatigue 216
11.6 Results of the analysis of the health effects of air pollution using the M-micro compression method 232
11.7 Results of the relationship between air pollution exposure the previous 24 hours and the individual health symptoms 232
11.8 Discussion 243
11.9 Conclusion 258

12 EFFECTS OF AIR CONTAMINANTS ON OBJECTIVE PARAMETERS OF HEALTH - S.O. Samuelsen[2], G. Bjerknes-Haugen[2], J. Clench-Aas[1], A. Bartonova[1], N.L. Hjort[3], L.S. Bakketeig[2] 263
12.1 Introduction 263
12.2 Statistical method 264
12.3 Regression models 268
12.4 Results 269
12.5 Discussion 274
12.6 Conclusion 276

13 EPILOGUE - L.S. Bakketeig[2], O.F. Skogvold[1] 279

14 PROJECT STAFF 283

15 GLOSSARY 287

16 REFERENCES 291
PUBLICATIONS RESULTING FROM THE INVESTIGATION IN GRENLAND 299
FUTURE NILU REPORTS 300

SUMMARY

The air in Grenland (an industrialized area in southern Norway) contains various pollutants such as sulfur dioxide, nitrogen dioxide, ozone, hydrocarbons and particles including acid aerosols. These originate from industry, traffic and domestic heating. The sources of emissions lie at the valley bottom. Air pollutants are also transported into the region from sources outside the area, e.g. due to long-range transport.

A cross-sectional epidemiological investigation of the relationship beween health effects and air pollution was performed in the area in 1979. Due to the results of this investigation, the Ministry of the Environment and the Norwegian State Pollution Control Authority allocated funds in 1986 for the planning of a new investigation of the short-term health effects of air pollution.

Even though subjective symptom reporting does not necessarily indicate a major health effect, it should reflect a general state of well-being which is of importance to take into account in assessing the impact of air pollutants. Therefore, both symptom reporting and objective measurements of lung function were included in the investigation.

The Grenland study began in the Spring of 1987 and has been a cooperative project between the Norwegian Institute for Air Research and the National Institute of Public Health. The work was financed by the Ministry of the Environment, the Norwegian State Pollution Control Authority and the Royal Norwegian Council for Scientific and Industrial Research, and carried out in close contact with local authorities.

The aim of the study was to investigate whether air pollutants either individually or in combination had short-term effects on health and well-being of people living in the Grenland area.

COHORT INVESTIGATION

Three population groups were chosen to participate in a longitudinal cohort study for two months in January through March and two months in April through June of 1988. During the same time period, measurements and modelling of air quality were performed. The field study was done both in winter and summer in order to account for seasonal variation in concentrations and composition of pollutants. Participants kept a diary, hour for hour each day. The three groups were:

1. Study population - persons aged 18 to 75 years that were recruited from a random sample of 800 living in the area. Sample size = 312.

2. Adults with pre-existing lung disease - persons aged 18 to 75 years with known lung disease that had lasted at least one year. Sample size = 67.

3. Children with pre-existing lung disease - persons aged 4 to 17 years with known lung disease that had lasted at least one year. Sample size = 18.

Persons with pre-existing lung disease were chosen since they were expected to be more sensitive to air pollution than others.

Four times a day the participants measured their own peak expiratory flow (PEF) as a measure of lung function. Every 14 days the participants met for control. A more complete lung function test was performed, and urine, blood and occasionally bacteriological samples were collected.

For every hour during the investigation, the participants indicated in a diary whether or not they were bothered by a set of 17 symptoms of health effects. These reflected such categories of symptoms as: symptoms of annoyance, symptoms in the upper and lower airways, symptoms of decreased general health and symptoms of stress and fatigue. The participants also indicated what daily form they had, whether or not they smoked either actively or passively, and possible medication use.

AIR QUALITY AND EXPOSURE

The main sources of air pollution in Grenland are local emissions from industry, vehicular traffic, domestic heating and boat traffic. Pollution levels during the winter of 1988 were lower than previous years due to relatively mild weather and good dispersion conditions. Higher concentrations of several types of pollutants are usually observed during cold, clear winter days. Few such days were reported that winter.

Measurements of air quality and meteorological parameters were performed during the two investigation periods at 9 locations in the area. Measurements included sulfur dioxide, nitrogen oxides, ozone, sulfate, nitrate, particles, wind, temperature, humidity and mixing heights.

A mobile unit was used for the simultaneous measurement of indoor and outdoor air quality at 15 representative homes in the area. Data on emissions from industry and from car traffic were collected. With the use of dispersion models, hourly concentrations of the different compounds in each square kilometer of the study area were calculated. Calculated concentrations were then corrected using measured data.

The corrected spatial distribution of concentrations was used as a basis for the estimating of individual exposure for the participants in the study. Exposure estimates were calculated for each compound, for each hour and for each participant. The estimates were calculated based on information from the diary on the location of each individual at each hour.

RESULTS, HEALTH EFFECTS AND AIR QUALITY

There were no proven, substantiated relationships between peak expiratory flow (PEF) and concentrations of different air pollutants in either the study population or the children or adults with pre-existing lung disease.

There were few significant relationships found between subjective reporting of health effect symptoms in adults with pre-existing lung disease. The population with pre-existing lung disease was, however, possibly not homogenous enough with respect to medication use or selection criteria to reveal significant effects. The results presented below therefore concern only those found in the randomly selected study population.

Statistical analysis of self reported symptoms of health effects shows an association in the winter between symptoms in the upper airways and nitrate exposure. In the summer, the data suggest an association between nitrate exposure and symptoms of annoyance, symptoms in the upper and lower airways and symptoms of decreased general health. Nitrates originate both from local industrial sources and from long-range transport.

In the winter, ozone exposure covaries with symptoms in both the upper and lower airways, and in the summer with symptoms from the lower airways, fatigue and annoyance.

In addition to the observed relationships between exposure to nitrates and ozone and the reporting of symptoms of health effects, weaker associations were found between exposure to sulfates, suspended particles - fine fraction, sulfur dioxide, nitrogen oxides, chlorine and some of the subjective health effect parameters. In addition, there were significant relationships between all the health symptom groups and pollen exposure in the summer.

A group of individuals seem to indicate positive significant relationships between reporting of symptoms and exposure to air pollution. These individuals can be considered as more sensitive than others to pollution in Grenland. Together, this group represents from 1 to 15% of the study population, dependent on effect parameter and pollutant. Further research is necessary to describe this group in a more satisfactory way.

LEVELS OF POLLUTION AND MEASURABLE HEALTH EFFECTS

The level of exposure to air pollution that is associated with a health effect can be calculated based on an average estimated regression coefficient in the study population, and on a quantification of a health effect. Health effects can be characterized by the per cent increase in probability of reporting symptoms of a health effect. A measurable health effect was thus defined as a 50% increase in probability of reporting symptoms. The levels of pollution that lead to such an effect were calculated for the different compounds. Calculations were done both for the entire population and for those defined as sensitive. The resulting concentrations were then compared to international and Norwegian proposed air quality guidelines.

The results indicate increased reporting of certain health effect symptoms by the sensitive population at levels of exposure clearly below these air quality guidelines.

AIR POLLUTION AND SHORT-TERM HEALTH EFFECTS IN AN INDUSTRIALIZED AREA IN NORWAY

MAIN REPORT

1 INTRODUCTION

O.F. Skogvold and L.S. Bakketeig

1.1 BACKGROUND - EARLIER INVESTIGATION

The Grenland area (Skien/Porsgrunn) in the county of Telemark is a highly industrialized region that includes petrochemical, fertilizer, cement, ferrosilicium and cellulose factories.

These industries are located in a long (15 km) and narrow (3 km) valley. Air pollution in the area includes different components such as sulfur dioxide, nitrogen oxides, hydrocarbons, and particles. There are two main urban centers in the area: Skien, with the Union factory and Porsgrunn, near the Herøya industrial complex.

A cross-sectional epidemiological study focusing on possible health effects from air pollution was performed in the Skien-Porsgrunn region in 1979 by the Norwegian Institute for Air Research (NILU). In this study over 5 800 individuals were interviewed and their state of health related to air pollution, controlling for age, gender and smoking habits. The region was divided into four subregions that represented different concentrations of different components. In addition, inhabitants from two subregions from the town of Larvik in the nearby county Vestfold were used as control.

The results of this initial study indicated that air pollution in the area could have an impact on the health and well-being of the population. This was the case for symptoms of lung disease and headache. The relationship was most evident for women (Siem and Skogvold, 1981). This study was primarily aimed at investigating the state of health the 14 days previous to the performed interview. There was a tendency for increased prevalence of asthma in children and bronchitis in adults in the most contaminated regions.

Other national studies support these observations. The National Health Screening Service has done a study in several counties in Norway that showed a relationship between air pollution (especially SO_2) and coughing and phlegm in adult men (Bjartveit et al., 1983). A smaller study in Skien (Claussen and Oland, 1981) showed the same tendencies.

Human exposure to air pollution depends both on outdoor and indoor exposure. Air quality may play a role in the development of serious diseases, such as asthma, cancer, heart and lung disease.

A study of health effects of air pollution is costly and time consuming. It is therefore necessary to judge the possibilities of being able to measure an effect on health variables prior to beginning the study. This can be done by comparing previous investigations done in other countries. Such a comparison shows that the concentrations of air contaminants in the Grenland area has in recent years been higher for some components than those that caused a health effect in other studies. For a comprehensive review of published work, see Chapter 11.3.

The earlier cross-sectional investigation done in 1979 (Siem and Skogvold, 1981) could not answer the question as to which components were most likely to be causing health effects. To provide an answer, the current study was designed as a more detailed investigation to concentrate on the effects of air pollution while holding other possible explanatory factors as gender, age, smoking habits, level of education, diet, etc. constant.

The study should include, in addition to healthy people, the population groups that are probably the most sensitive, as for example children, the elderly, and individuals with pre-existing lung disease. From the many possibilities it was chosen to use a cohort design, where each participant serves as his/her own control. In addition, air pollution monitoring in the area was substantially expanded. Air quality measurements together with knowledge about emissions of different pollutants were then used to model the geographic distribution of air pollution in the region.

1.2 GOAL OF INVESTIGATION

The goal of the project is to investigate whether air pollutants, either singly or in combination, have short-term effects on human health and well-being of the inhabitants of the Skien-Porsgrunn area.

The questions that should be investigated are:

1) Do the components SO_2, NO_x, O_3, particles, sulfates or nitrates affect measurably human health and well-being on a short-term basis?

2) Which combinations of air pollutants and meteorological parameters have an effect on human health and well-being?

1.3 ORGANIZATION OF INVESTIGATION

The project was directed by a Board consisting of:

Sigurd Hagen, Chairman, State Pollution Control Authority
Jan Lasse Hansen, Ministry of the Environment
Erik Dybing, Royal Norwegian Council for Scientific and Industrial Research, The Norwegian Research Council for Science and the Humanities

At a request from the Board, Sverre Langaard, Head of the Department of Occupational Medicine, Telemark Central Hospital, joined the Board on 17 April 1991.

The Board consisted of members of the contracting institutions. In addition Jocelyne Clench-Aas, from the Norwegian Institute for Air Research (NILU) and Gunnar Bjerknes-Haugen, from the National Institute of Public Health (NIPH), participated at the Board meetings as principal investigators from the two main research institutions and Odd F. Skogvold (NILU) and Leiv S. Bakketeig (NIPH), represented the administration of the same two institutions.

A number of experts and representatives from the local authorities in Telemark formed an Advisory Committee connected to the Board.

In addition to the two main research institutions the Norwegian Computing Center (NCC) has been used as adviser in statistical matters.

The Norwegian Institute for Air Research (NILU) was responsible for air measurements indoors and outdoors, meteorological measurements, emission inventories, modelling and exposure estimates.

The National Institute of Public Health (NIPH) was responsible for medical aspects of the study, including selection of participants, selection of inclusion and exclusion criteria, testing of lung function and medical evaluation and follow-up of participants during the study period.

The data analysis and reporting was divided between the two institutions.

1.4 DISSEMINATION OF RESULTS

The results are published in several reports (mostly in the Norwegian language) that can be found under "References" in this report. After finishing the project, results will be presented at seminars and conferences both in Norway and abroad, in addition to being published in scientific journals.

singly important to document them (American Thoracic Society, 1985). The challenge in investigating subjective symptoms of health effects is to be able to separate the effect of air pollution from other known factors that have influence on disease, such as age, smoking habits, nutrition, pre-existing disease and genetic constitution.

When studying the health effects of air pollution one may concentrate on acute or short-term effects on the one hand, or chronic effects on the other. If acute or short-term effects are not totally reversible or persist over a longer period, they can develop into chronic or long-term ailments.

Air quality guidelines for pollutant concentrations are meant to assure with a certain security margin that as long as air contaminant concentrations remain under the guidelines, human health is unaffected.

Air pollution in a region is composed of emissions from both local sources and long-range transport. In a town or industrial region, local sources usually predominate. The primary local sources are industry, traffic and home heating. Primary contaminants (SO_2, NO_2, CO, etc.) vary more in space and time dependent on the location of the emissions and meteorological conditions, than do secondary pollutants that are more regional in character (sulfates and nitrates). It is therefore important that air quality measurements account for possible large variations in space and time.

An investigation performed in 1979 in an industrialized area of Norway, the Grenland area, indicated that pollution was leading to possible adverse health effects. Pollution seemed to especially influence symptoms involving the airways, such as coughing or wheezing, however, there were also more cases of headaches in participants from areas with heavier air pollution (Siem and Skogvold, 1981). This earlier study was a cross-sectional epidemiological study. Similar findings have been later observed in a cross-sectional study done in an area of Oslo with heavy traffic (Clench-Aas et al., 1989, 1991).

2 DESCRIPTION OF THE INVESTIGATION

J. Clench-Aas and G. Bjerknes-Haugen

2.1 INTRODUCTION

That air pollution may increase morbidity and even mortality has been known for many years. High pollution in 1948, resulted in increased mortality in Donora Pennsylvania where half of the population of 12 000 were sick and 20 (as opposed to an expected mortality of 2.0) died during the high pollution episode. In 1952, in London, an episode of high SO_2 (3.8 mg/m^3) and soot (4.5 mg/m^3) led to 4 000 more deaths than expected (Brinton, 1949; Schrenk et al., 1949; Wilkens, 1954). These situations, however, reflect exposures to extremely high concentrations of certain components together with adverse climatological conditions.

It has been more difficult to demonstrate that exposures to lower concentrations of air contaminants can lead to impaired health in exposed individuals. The first and primary problem is to clearly define "health". World Health Organization defines good health as "a state of full physical, psychological and social well-being and not simply as an absence of disease or deformity" (WHO, 1985). It is a natural consequence of this definition that adverse health effects should include reduced physical, psychological or social well-being.

The choice of parameters to measure adverse health effects of air pollution can include morbidity or mortality. Biological changes, e.g. in lung function, have often been reported after exposure to air pollution. Increased presence of morbidity symptoms such as coughing or wheezing, or simply other subjective symptoms of general well-being such as headache, burning eyes, sneezing or fatigue have been studied only in the later years. Since such symptoms of adverse health affect so many more people than the more serious ones, it has become increa-

Since the first Grenland study was a cross-sectional epidemiological study, it was impossible to clearly separate whether the effects were in reality due to air pollution or rather to such confounding factors as age and socio-economic status. If the effect was due to air pollution, it was impossible to identify which compound was responsible for the effect, and to quantify at which concentration the pollutant caused effects.

A follow-up investigation was therefore designed to attempt to identify the compound or components, if any, responsible for adverse short-term health effects in the Grenland area. If possible, the threshold concentration necessary to cause a measurable health effect would be determined. A cohort study, where a group of individuals is followed over time, offers a better method to study this problem. Since each individual is his/her own control, the problem of confounding factors is reduced. The study was designed to follow two groups of individuals, one suffering from pre-existing lung disease, and the other a randomly selected group representative of the population living in the Grenland area. Since pollutants originate from several sources in the area, the components should vary independently of each other. Therefore it should be possible to identify and quantify individual contaminants.

In the latter years emphasis has been placed on describing air quality exposure, that is, the actual concentrations of pollutants individuals are exposed to over certain periods of time. In order to do this it is necessary to identify and measure the various air contaminant concentrations in micro-environments used by the population. A micro-environment can be a city side walk, inside a car, inside a house, outdoors in the garden, etc. Air pollutant concentrations indoors, for example, can be substantially different from those outdoors and people can spend 90% of their time indoors. In addition, people may be exposed to different components indoors than outdoors e.g. due to smoking, insulation materials, use of fireplace or oven, etc. Standing in a street leads to totally different exposure than standing in park.

Current trends in measuring external exposure has been to use portable personal sampling equipment. The use of such equipment limits the number of components that can be investigated, the length of time each person can be studied, and probably influences the individual's normal routine. This investigation chose therefore to estimate exposure using the diary method originally described by Duan (1982). This method entails calculation of contaminant concentrations in different micro-environments and then following individuals movements through these micro-environments.

2.2 DESCRIPTION OF THE GEOGRAPHICAL AREA

The main valley in the Skien-Porsgrunn area lies in a northwesterly-southeasterly direction (see Figure 4.1). The topography combined with climate creates local temperature inversions with poor conditions for spreading. This is especially true for winter nights. In the summer, the land-sea breeze leads the wind into the valley during the day and out to sea at night.

The three most important sites of industrial emissions in the Grenland area are at Skien (a pulp and paper mill), and at Herøya (petrochemical and chemical industry, magnesium and ferrosilicium production) and at Rafnes (petrochemical). Emissions from Herøya include ammonia, chlorine, hydrochloric acid, nitrogen oxides and particles. In addition, there is a cement factory at Brevik. Other sources of air pollution encompass long-range transport and traffic.

The components that are usually described as important contaminants in the region are: sulfur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, photochemical oxidants such as ozone and peroxyacetylnitrates (PAN), toxic metals (lead, mercury, manganese), sulfates, nitrates, particles, polycyclic aromatic hydrocarbons (PAH), and traces of chlorinated organic compounds such as dibenzofurans and dioxins.

Haze in Grenland leading to reduced visibility is a well known phenonmenon. Industrial emissions of hydrochloric acid, ammonia and chlorine lead to the formation of haze, even though humidity is not high enough to lead to normal fog. The industrial haze is often accompanied by an unpleasant industrial smell, which is considered offensive by the local population. This phenomenon occurs in practice only on warm days in conjunction with the land-sea breeze, mainly from June to August.

2.3 GENERAL DESCRIPTION OF STUDY DESIGN

A cohort type investigation was chosen as the optimal study design to study the short-term effects of air pollution on human health. The underlying principle was to relate individual exposure to a set of air pollution contaminants, to health status on an hourly basis.

The cohort study was designed so that two populations were followed hour by hour for two months in the winter (January to March) and two months in the spring/summer (April to June). One population was a group with pre-existing lung disease (85 individuals), and the other was a randomly selected sub-sample of the population living in the region (312 individuals) (see Chapter 3 for details). Necessary sample sizes were based on statistical methods described in 2.4. An overview of field work is given in NILU/NIPH (1989).

Each participant described on an hourly basis, through a special diary, his/her location and whether or not the individual was bothered by a set of symptoms (see Figure 2.1). Each participant also noted health status and medication use on a daily basis (Figure 2.2). In addition to self-reporting of symptoms, each individual measured peak expiratory flow (PEF) four times a day using a Mini-Wright Peak Flow Meter (see Chapter 10).

The principal compounds measured were SO_2, NO_2, NO_x, O_3, sulfate (SO_4), nitrate (NO_3), chloride (Cl_x), suspended particles (fine fraction) and pollen (see Glossary in Chapter 15 for definitions and abbreviations). The measuring sites where air quality and meteorological parameters were measured are shown in Figure 4.1. The measuring program is described together with the results of air quality measurements in Chapter 4.

Personal exposure reflects both local variations in pollution concentrations and each individual's movements through different micro-enviroments. In order to handle this, exposure modelling was incorporated into the study (see Chapter 8). The outdoor air pollution model (dispersion model) for the entire geographic area is based on emission inventories, combined with information on meteorological conditions in the geographic area (see Chapter 4). A detailed overview of emissions was made for all major sources in the area (see Chapter 5). The outdoor concentrations of each of these pollutants that are estimated by the model were then corrected based on the measured values in the five square kilometers where the measuring stations were located (Chapter 7).

People spend generally more than 80% of the time indoors. Therefore it is of primary importance to know indoor air quality. It is important to quantify how much of outdoor air pollution penetrates into the home, and to describe possible indoor sources of air pollution. In Norway, gas cooking and heating is not used, and is therefore a minor indoor source of nitrogen oxides. The single most important factor for indoor pollution is in homes where tobacco is smoked. In order to determine the percentage of outdoor pollution that penetrates into the home, in addition to indoor concentrations due to indoor sources (e.g. smoking), measurements outdoors and indoors were made simultaneously for a three day period for 15 homes, both in

NILU SIFF

DATE [ ] YOUR I.D. NR. [ ]

WHERE ARE YOU?	24 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Where are you (use code)	
Are you indoors	
Is the window open where you are	
Are you outdoors	

WHAT ARE YOU DOING?	24 03 06 09 12 15 18 21 24
Sleeping	
Daily activities	
Hard work/training	

HAVE YOU TRAVELLED (minutes)	03 06 09 12 15 18 21 24
Much traffic	
Average traffic	
Little traffic	

HAVE YOU BEEN SHOPPING (minutes)	06 09 12 15 18 21 24
In Skien	
In Porsgrunn	
Other places	

SMOKING	24 03 06 09 12 15 18 21 24
Smoked (nr)	
Passive smoking	

HEALTH & WELL-BEING	24 03 06 09 12 15 18 21 24
Annoying noise	
Annoying smell	
Annoying industrial smell	
Headache	
Dizziness	
Nausea	
Eye irritation	
Sneezing/running nose	
Feeling feverish	
Throat irritation	
Coughing	
Wheezing/tight chest	
Difficult breathing	
Muscle pains (neck/back)	
Stomach pains	
Nervous/restless	
Fatigue	

Figure 2.1: Diary used in study.

DAILY FORM

How have you felt today? Write a number from 1(bad) to 5(very good) ☐

LUNG FUNCTION TEST

Try three times, note the highest value

App. time	Time	Result
08.00		
12.00		
16.00		
20.00		

GENERAL HEALTH

Have you been sick today? Yes ☐

Ordered home by doctor ? ☐ Chose yourself to be home ? ☐

Have you had a fever today Yes ☐

Have you coughed up more sputum than usual? Yes ☐

What color was it? Yellow/green ☐ Clear/white ☐

Have you drunk alcohol today? Yes ☐

ACTIVITIES LEADING TO EXPOSURE TO EXTRA POLLUTION

Have you during the day been exposed to unusual amounts of dust, smoke, steam or other similar things (F. example if you have been fixing up the house, painting, varnishing , shaking carpets, preparing skis, burning trash or a bonfire, emptying vacuum cleaner bags). If yes, write here what kind of activity this was. Write also the time of day you did this.

Activity	Time

MEDICATION USE

Write here the names of the medications you have taken today in addition to those you regularly take and that are listed in the folder. Write also the strength (of for example each tablet), amount and time of day you took them.

Name of medication	Strength	Amount	Time	Do not write here

You do not need to write down if you have taken vitamins, iron tablets, fiber tablets, cod liver oil or other nutritional additives.

Figure 2.2: Backside of the diary.

winter and summer. Three measuring periods per day were performed in each home, both in winter and summer period (see Chapter 6).

Information from these detailed sub-studies together with information in the diary was then combined in an air pollution exposure model to calculate hourly exposure concentrations for each component for each individual (see Chapter 8).

Methods of multiple regression were used to study the relationship between reporting of symptoms of health and well-being and air pollution exposure hour by hour for each individual. The regression coefficients thus generated were studied, using a modified regression analysis to establish on a population basis, which compounds have an effect on health (see Chapters 11 and 12).

2.4 DETERMINATION OF STUDY POPULATION SIZE

The necessary size of a participant group for the study can be determined by statistical methods. The group of participants with known lung disease is supposed to be relatively homogeneous, with symptom response rate higher than in the general population. Using data already available from a similar study on asthmatics from Houston, Texas, USA (Holguin et al., 1985), the necessary size of the group of patients with chronic obstructive lung disease was estimated to be 80 (Clench-Aas et al., 1986).

It was desirable to establish a control group. This group should be representative for the total population of the Grenland area. When considering symptoms from the lung, this group has probably a lower response rate than individuals with known lung disease. For this reason, the estimate of necessary group size was re-evaluated (Hjort, 1989).

To simplify the situation, the exposure to air pollution was categorised. A Poisson-type model was used as a basis for the calculation. The following two types of exposure patterns were considered:

- often bad situation, with 85% of time in "low" exposure, 10% of time in "medium" exposure and 5% of time in "high" exposure.
- mostly good situation, with 93% of time in "low" exposure, 5% of time in "medium" exposure and 2% of time in "high" exposure.

The "low", "medium" and "high" exposures were defined based on their expected short-term effects on health. Let p_0 symbolize the response rate in a low-exposure situation. Two types of increase of p_0 were considered to be of health-related importance:

- slight effect: response rate p_0 in "low", 1.5 p_0 in "medium" and 2 p_0 in "high" exposure.
- moderate effect: response rate p_0 in "low", 2 p_0 in "medium" and 5 p_0 in "high" exposure.

Let us further suppose that each individual is going to participate in the study for 60 days per uninterrupted study period.

Table 2.1 shows the calculated group sizes necessary to establish the presence of the indicated increase in response rate under the indicated different situations. The examples of response rate values were taken from the previous Grenland study (Siem and Skogvold, 1981):

After an evaluation of possible situations, four hundred participants in the group based on the general Grenland population was chosen as a target sample size.

After the recruitment of participants was finished, the group with known lung disease comprised 17 children and 67 adults, and the study population based on a random sample from the population comprised 312 participants. The groups are defined in more detail in Chapter 3.

Table 2.1: Number of participants (N) necessary to establish short term effects of air pollution on subjectively reported symptoms (for assumption see text).

	Response rate p_o			
	1% N	2% N	5% N	10% N
Often bad situation:				
slight health effect	800	400	160	80
moderate health effect	159	80	32	16
Mostly good situation:				
slight health effect	1818	910	364	182
moderate health effect	375	188	75	38

3 REPRESENTATIVITY AND BACKGROUND INFORMATION FOR THE SELECTED STUDY GROUPS

G. Bjerknes-Haugen, S.O. Samuelsen

The study individuals in the Grenland project were selected to address two main relationships. Firstly, the participants should be studied to clarify whether the air pollution had any untoward effects on the population in general. Secondly, the investigation aimed at examining a group of persons that might be particularly sensitive to minor changes in the air pollutant levels. It was assumed that people suffering from pre-existing lung disease were more sensitive to changes in air quality than was the general population, and that within this group children would be especially sensitive. With this in mind, three study groups were established.

- a randomly selected study population aged 18-75 years belonging to a specified geographical area (from Brevik and up to the valley to Skien, see Figure 3.1) where it was possible to generate acceptable exposure data.

- adults aged 18-75 years with pre-existing disease.

- children aged 4-17 with respiratory allergy/pre-existing lung disease.

As a reference to check the representativity and other background data for these cohorts, the national 1980 census by the Central Bureau of Statistics (CBS) for Skien and Porsgrunn was used. Further, clinical-chemical reference values from Valentin Fürst's Laboratory, Oslo, were used, which are based on a Norwegian reference population (1983). Spirometric values were calculated as based on an equation given by Gulsvik (1985). As reference for the SCL-90 test, a questionnaire of 90 items relating to psychological state using data from Derogatis (1974), were used.

3.1 RANDOMLY SELECTED STUDY POPULATION

In order to get the most appropriate exposure data for the study individuals, the study populations were restricted to residents within the school districts of Lunde, Gimsøy, Bratsberg/Kleiva, Klosterskogen, Strømdalsjordet and Klyve in Skien; Vestsida, Østsida, Grønli, Stridsklev and Klevstrand in Porsgrunn; and Heistad and Brevik in Brevik. These districts comprise the geographical area from Brevik and up the valley to Skien (see Figure 3.1). The study subjects were from 18 to 75 years and randomly selected from the CBS Person Registry. In all, 800 persons (more than twice as much as needed based on statistical considerations) were invited to participate in the study, but only 312 persons (39%) were willing to participate. The response rate was less than expected, especially when taking into account that the local newspapers/radio station provided a good coverage of the plans for the study. Figure 3.2 gives the distribution of reasons for not participating.

The only criteria for exclusion from the randomly selected study population, were somatic or psychological illnesses that the study physician judged to be so serious that the individuals would not be able to complete the study.

3.1.1 Socio-economic variables

The 312 participants of the study population were evenly distributed among the genders, consisting of 163 (52%) males and 149 (48%) females (Table 3.1). The age distribution of the participants showed that there were fewer young (20 -29) and old (60 +) compared to the general population in the municipalities of Skien and Porsgrunn.

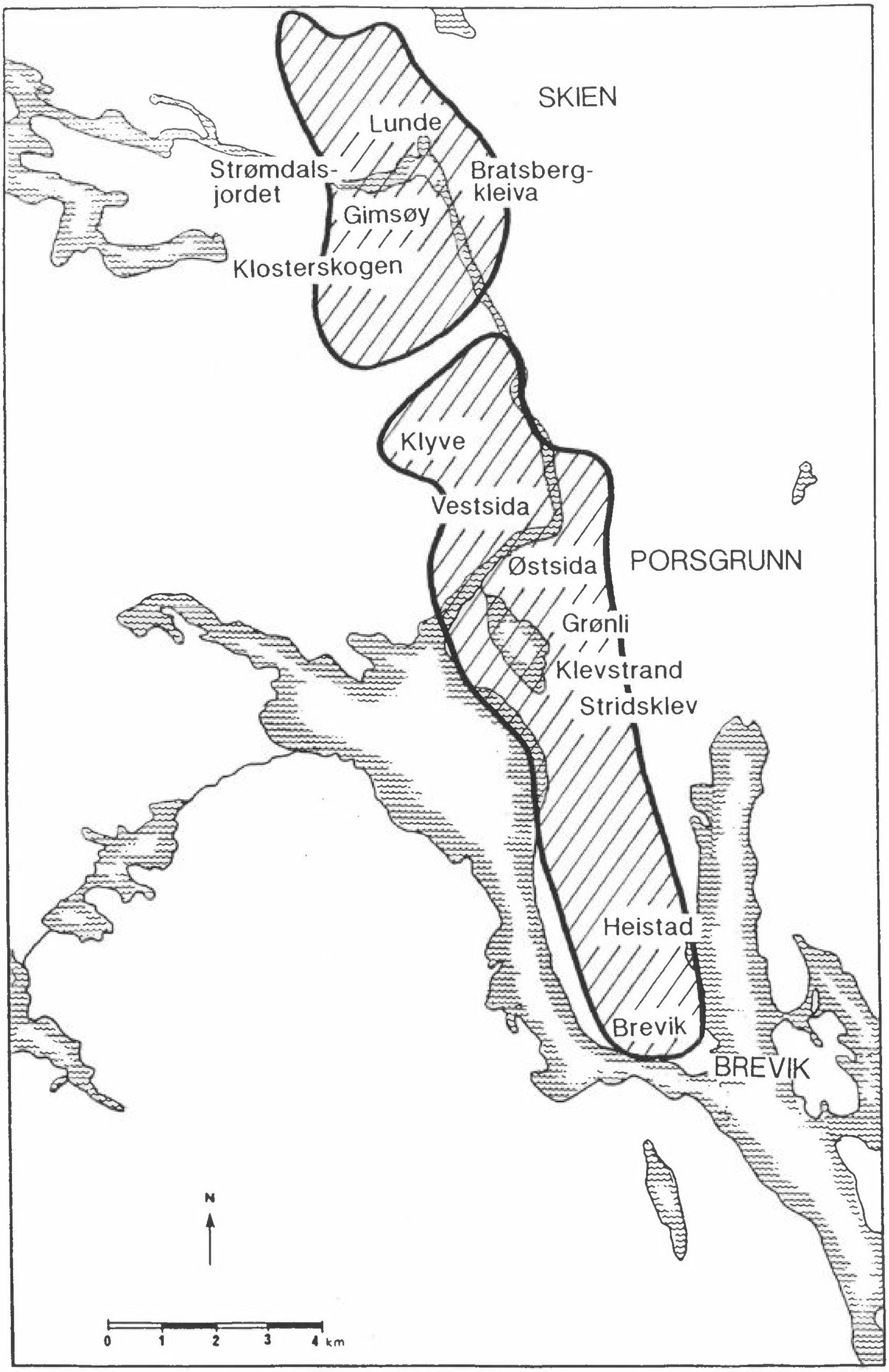


Figure 3.1: The geographical area of Grenland in which the random study population was selected.

Table 3.1: Age distribution of the randomly selected study population compared with the general population in Grenland (in %).

	Population in Grenland per September 1987	Invited participants	Met at first examination	Completed (9 or more controls)
Males age				
18-19	4.6*	3.5	0.7	0.0
20-29	21.7	23.5	16.1	12.1
30-39	21.0	19.0	21.5	19.8
40-49	18.9	17.5	25.5	27.6
50-59	13.0	16.3	20.1	20.7
60-66	10.7	11.5	10.1	12.1
67-74	10.2**	8.8	6.0	7.8
	100.1	100.1	100.1	100.1
Total	27 573	400***	149	116
Females age				
18-19	4.2*	4.6	3.1	2.3
20-29	20.5	16.5	16.6	13.1
30-39	19.8	21.4	28.8	32.3
40-49	17.9	13.5	19.0	20.8
50-59	13.4	15.0	14.7	14.6
60-66	11.8	13.5	12.8	11.5
67-74	12.4**	15.5	4.9	5.4
	100.0	100.0	99.9	100.0
Total	28 141	393***	163	130

*Estimated based on numbers for 16-19 year olds, September 1987.
**Estimated numbers based on the national census of 1980, corrected for mortality.
***Among the invited participants gender was estimated based on first names. In all, 7 individuals were not classified.

Table 3.2 shows the relationship between age, gender and marital status. There is a certain overrepresentation of married men aged 30-69. Apart from this, there is a good correspondence between the study population and the general population.

Table 3.2: Marital status of the randomly selected study population of the Grenland project compared with the general population based on the national census carried out by the Central Bureau of Statistics in 1980.

		General population	Study population*	
		Per cent married	Per cent married	Total
Age group	20 - 69	70.2	77.2	267
Males	20 - 30	39.1	35.3	17
Females	20 - 30	57.8	65.0	20
Males	30 - 69	82.4	91.2	102
Females	30 - 69	78.2	76.3	114

*Information based on a questionnaire filled out in the middle of the study. 267 of 312 gave information on marital status, including 3 under 20 years. Information on marital status is mainly missing from young individuals (30% for <30 years, 10-15%>30 years).

Table 3.3 shows the relationship with level of education and gender. There seems to be an overrepresentation of well educated females, which may be explained by the fact that there is an overrepresentation of relatively young females.

Table 3.4 shows vocational activity in the study population as compared with the general population. There is a certain overrepresentation of vocationally active among the young (20- 49) and an underrepresentation among the middle aged (50-69). The overrepresentation is most pronounced among young females. In part, this may be due to the fact that the background data are from the census of 1980 and that the proportion of vocationally active females has increased during the 1980s.

With respect to the type of vocation (Table 3.5) there seems to be a high proportion from the service sector. However, this classification is performed subjectively and is thus uncertain.

Table 3.3: Level of education and gender of the randomly selected study population as compared with the general population.

Level of education	General population		Expected distribution based on age distribution recorded at examination		Real distribution based on examination	
	Male	Female	Male	Female	Male	Female
1- 9 years	25.7	32.3	28.0	32.3	24.2	14.2
10-12 years	57.5	53.7	54.5	52.9	59.1	61.1
13 + years	16.8	14.0	17.5	14.6	16.7	24.8
	100.0	100.0	100.0	99.8	100.0	100.1
Total*	22838	22907	-	-	132	113

* Numbers are based on individuals from 20-66 år.

Table 3.4: Vocational activity in the randomly selected study population compared with the general population.

	Study population		General population	
	Total	Per cent vocationally active	Total	Per cent vocationally active
Males 20 - 49	75	92.0	15092	83.1
Males 50 - 69	43	62.8	8279	71.1
Males 20 - 69	118	81.4	23371	78.8
Females 20 - 49	94	70.2	14667	49.1
Females 50 - 69	40	17.5	9659	28.8
Females 20 - 69	134	54.5	24326	41.0

Non-smokers constituted 57% of the study population as compared with 59% in the general population.

From Table 3.1 it is evident that there is a certain deviation, especially among the females, of the age distribution among the invited participants in comparison with the total population in Grenland. However, this deviation is not so large that it can be stated that the selection was markedly skewed.

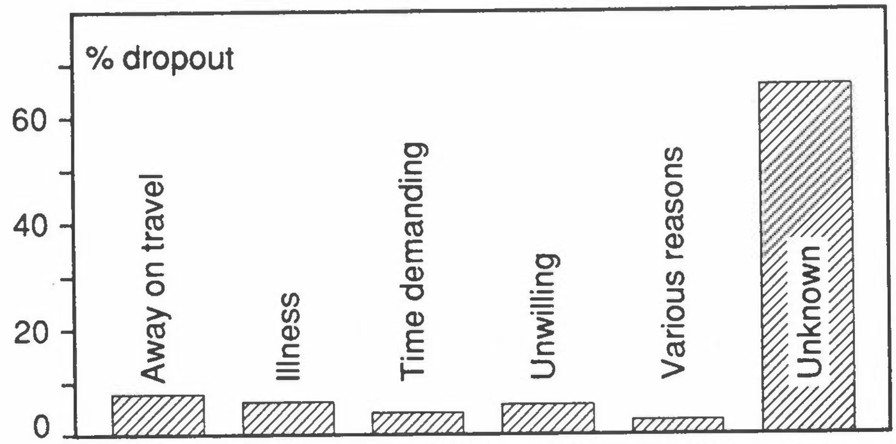


Figure 3.2: Reasons for dropping out among those who were randomly selected from the Central Bureau of Statistics.

Table 3.5: Distribution of vocations in the randomly selected study population compared with the general population.

Type of vocation	Males		Females	
	Study population	General population	Study population	General population
Technical/scientific/ humanistic/artistic	17.7	17.7	19.2	27.1
Administrative/ regulatory	10.4	6.5	4.1	2.3
Office work	7.3	3.6	17.8	21.3
Commercial	6.3	6.0	13.7	15.5
Industry/building/ mining/construction	43.8	47.5	9.6	7.3
Service	8.3	4.0	34.2	19.7
Transport/communication	2.1	8.2	0.0	3.3
Other/not given	4.2	6.2	1.4	3.4
Sum (per cent)	100.1	99.7	100.0	99.9
TOTAL NUMBER	96	19334	73	10529

3.1.2 Clinical/physiological variables

Table 3.6.1 shows the 10% fractile, median and 90% fractile for the 312 subjects with respect to the variables heart rate, respiration frequency, Forced Vital Capacity (FVC), Forced Expiratory Volume in one second ($FEV_{1.0}$), Peak Expiratory Flow (PEF), Hemoglobin (Hb), Sedimentation Rate (SR) and Carboxy-hemoglobin (COHb). All the values were within reference values for a "normal" population. This means that more than 80% of the study population have values within the expected range. Concerning urine samples, as much as 97% were without any form of pathology, and among the remaining 3% (9 persons) only two persons had a verified illness (the others were contaminated samples). Using the equation of Gulsvik (1985) for predicting spirometric values, more than 80% were within 10% of the predicted value. Only 14% had an expectorate, 23% reported coughing.

3.1.3 Dropout

Taking into consideration the relatively large effort and time the participants had to put into the study, a dropout rate of 30% was not unexpected. The reasons for dropping out were mainly the same as for those who did not want to participate at the start of the study. The young and old were the most likely to drop out. A few elderly people also found it too complicated to participate in the study. Table 3.7 shows the successive dropout during the investigation in the study population and in the adults and the children with pre-existing lung disease, as based on information from the diaries.

Table 3.6.1: Physiological variables for the randomly selected study population of the Grenland project (N=312).

Variable	10%-fractile	median	90%-fractile
Pulse (beats/min)	60	70	84
Respiratory frequency	12.6	16	20.0
FVC (1) (BTPS)	2950	4200	5800
FEV (1) (BTPS)	2160	3400	4690
PEF (1/min)	400	510	675
Hemoglobin (g/100 ml)	12.0	13.4	15.0
Sedimentation rate (mm/h)	2	7	20
HbCO	1.2	1.7	5.9

Table 3.6.2: Physiological variables for adult participants with pre-existing lung disease (N=66).

Variable	10%-fractile	median	90%-fractile
Pulse (beats/min)	60	76	98
Respiratory frequency	14.0	18.0	22.0
FVC (1) (BTPS)	2400	4000	5995
FEV (1) (BTPS)	1170	2450	4490
PEF (1/min)	250	428	630
Hemoglobin (g/100 ml)	11.9	13.7	15.3
Sedimentation rate (mm/h)	2	7	20
HbCO	0.6	1.4	3.8

Table 3.6.3: Physiological variables for participating children in the Grenland project with pre-existing lung disease (N=17).

Variable	10%-fractile	median	90%-fractile
Pulse (beats/min)	63	82	108
Respiratory frequency	14.0	23.0	28.2
FVC (1) (BTPS)	1420	2200	4660
FEV (1) (BTPS)	953	1800	3855
PEF (1/min)	145	1323	510

Table 3.7: Successive dropout in the Grenland project in the randomly selected study population and those with pre-existing lung disease (adults and children) based on the diary information.

	Study population	Pre-existing lung disease	Total
Total registered - Not met to receive diary	312 9	85 3	397 12
MET AT START OF FIRST PERIOD	303	82	385
- Not delivered any diary	13	6	19
Included in first period - Stopped during first period	290 8	76 2	366 10
COMPLETED FIRST PERIOD	282	74	356
- Not met for second period + Met for second period. Not included in first period	24 1	6 1	30 2
MET AT START OF SECOND PERIOD	259	69	328
- Stopped during second period	18	1	19
COMPLETED SECOND PERIOD	241	68	309
- Not delivered diary cover	2	0	2
COMPLETED DIARY RECORDING	239	68	307
- Not delivered PEF-meter	17	9	26
COMPLETED DIARY, CONTROLLED PEF	222	59	281

3.2 ADULT POPULATION WITH PRE-EXISTING LUNG DISEASE

This study group was selected by Dr. Lien from the Central Hospital in Telemark, Skien, Department of lung diseases. One hundred and eleven persons who had consulted the department the last 3 years (62 men and 49 women), and who had been diagnosed as having chronic obstructive lung disease (COLD) or asthma, received an invitation letter to an introductory meeting. At this meeting the study was outlined and people were asked to volunteer. A total of 66 persons (60%) wanted to take part in the study. Of these 66 persons 57 had been diagnosed with asthma, 12 with COLD and 3 with both diagnoses. All the diagnoses were based on clinical examination and spirometric measurements. Asthma was diagnosed based on 10-15 % reversibility of spirometric values using bronchodilatator spray. COLD was applied as diagnosis whenever reduced spirometric values and/or clinical findings for more than two years could not be reversed when using bronchodilatator. Twentynine had further been examined for suspected allergies, and 10 had their diagnoses ascertained only after periods of therapeutic regimens (Table 3.8). No other exclusion criteria were applied.

3.2.1 Socio-economic variables

There were 25 females and 41 males among the 66 adult participants with pre-existing lung disease. The age distribution was somewhat skewed towards higher ages compared with that of the general population. Concerning other socioeconomic variables, this group was very similar to the normal population, except that in this group 30% were smokers. This could also be expected, because cigarette smoking would clearly affect their illness.

3.2.2 Clinical/physiological variables

A similar tabulation to that of the randomly selected group is shown in Table 3.6.2. Here, also all fractile values lie within the normal reference values (more than 80% of this group lie within the normal reference values), except for FEV and PEF, as these two measurements are directly related to the diagnoses of the individuals in this study group. As for the urine samples 95% were without any pathological findings and the remaining 5% had no clinical significance. In this group, 35% had some expectorate and nearly half of the group (48.5%) were coughing.

Table 3.8: Diagnostic criteria for adults with pre-existing lung disease. (1 = yes, - = no).

Year of birth	Asthma	Chronic obstructive lung disease	Year of diagnosis	Allergy tested	Clinical examination	Spirometry	Therapeutic regimen	Other tests
47	1	-	84	-	1	1	-	-
31	1	-	77	1	1	1	-	-
21	1	-	79	-	1	1	-	-
14	-	1	89	-	1	1	1	-
26	-	1	79	-	1	1	1	-
55	1	-	82	1	1	1	-	-
58	1	-	78	1	1	1	-	-
18	1	1	77	-	1	1	-	-
36	1	-	80	-	1	1	-	-
41	1	-	77	-	1	1	-	-
37	1	-	86	-	1	1	-	1
48	1	-	81	1	1	1	-	-
17	1	-	81	-	1	1	-	-
58	1	-	83	-	1	1	-	-
43	1	-	87	-	1	1	-	-
49	1	-	84	1	1	1	-	-
25	1	-	77	-	1	1	-	-
54	1	-	87	1	1	1	-	-
47	1	-	82	-	1	1	-	-
46	1	-	83	-	1	1	-	-
57	1	-	77	1	1	1	-	-
22	1	-	81	-	1	1	-	-
43	1	-	82	-	1	1	-	-
59	-	1	83	-	1	1	1	-
50	1	-	82	1	1	1	-	-
45	1	-	89	-	1	1	-	-
46	1	-	79	1	1	1	-	-
69	1	-	83	-	1	1	-	-
25	1	-	79	-	1	1	-	-
59	1	-	84	1	1	1	-	-
35	1	-	77	1	1	1	-	-
24	1	-	79	-	1	1	-	-
30	1	-	82	-	1	1	-	-
54	1	-	78	1	1	1	-	-
30	1	-	82	-	1	1	-	-
47	1	-	79	1	1	1	-	-
23	1	1	82	1	1	1	1	-
22	1	-	80	1	1	1	-	-
12	1	1	79	1	1	1	-	-
37	1	-	80	1	1	1	-	-
21	-	1	80	-	1	1	1	-
59	1	-	77	1	1	1	-	-
50	1	-	82	-	1	1	-	-
64	1	-	81	1	1	1	-	-
49	1	-	80	1	1	1	-	-
34	-	1	81	-	1	1	1	-
11	1	-	81	1	1	1	-	-
51	1	-	82	1	1	1	-	-
46	1	-	77	1	1	1	-	-
67	1	-	81	-	1	1	-	-

Table 3.8 cont.

Year of birth	Asthma	Chronic obstructive lung disease	Year of diagnosis	Allergy tested	Clinical examination	Spirometry	Therapeutic regimen	Other tests
26	1	-	82	-	1	1	-	-
42	1	-	81	1	1	1	-	-
57	1	-	80	-	1	1	-	-
60	1	-	81	1	1	1	-	-
16	-	1	87	-	1	1	1	-
67	1	-	87	1	1	1	-	-
17	-	1	87	-	1	1	1	-
56	1	-	87	1	1	1	-	-
47	1	-	85	-	1	1	-	-
45	-	1	86	-	1	1	1	-
57	1	-	76	1	1	1	-	-
29	1	-	80	-	1	1	-	-
50	1	-	81	1	1	1	-	-
43	1	-	81	-	1	1	-	-
30	-	1	87	-	1	1	1	-

Table 3.9: Diagnostic criteria for children with pre-existing lung disease.

Year of birth	Asthma	Chronic obstructive lung disease	Year of diagnosis	Allergy tested	Clinical examination	Spirometry	Therapeutic regimen	Other tests
72	1	-	73	1	1	1	-	-
79	1	-	80	1	1	1	-	-
81	1	-	84	1	1	1	-	-
81	1	-	85	1	1	1	-	-
73	1	-	75	1	1	1		-
82	1	-	86	-	1	-	1	-
75	1	-	86	1	1	1	-	-
80	1	-	83	1	1	1	-	-
71	1	-	76	1	1	1	-	-
80	1	-	84	1	1	1	-	-
74	1	-	76	1	1	1	-	-
78	1	-	80	1	1	1	-	-
73	1	-	79	1	1	1	-	-
70	1	-	76	1	1	1	-	-
76	1	-	78	-	1	1	-	-
70	1	-	75	1	1	1	-	-
73	1	-	78	-	1	1	-	-
78	1	-	81	1	1	1	-	-

3.2.3 Dropout

There were fewer dropouts within this group than in the randomly selected group, only 14 (20%), probably because this group, to a great extent, felt that the problems that the project was focusing on, could be of some concern to themselves. Otherwise, the reasons for declining participation during the study period were more or less the same, it was felt that it was a time- and labor-demanding study. One person in the group was hospitalized during the study because of exacerbation of the disease.

3.3 CHILD POPULATION WITH PRE-EXISTING LUNG DISEASE

This group (aged 4 - 17 years), was recruited from the Section of lung and allergic diseases, Department of pediatrics, Central Hospital in Telemark, headed by Dr. Steen Johnsen. This clinic offered space for the investigation of the patients, and thus, the children were familiar with the surroundings where they were examined. The same procedures were applied as for the adults and the 35 children and their parents received a letter of invitation to an introductory meeting, where they jointly met the investigators. Here, an overview of the study was presented in a calm and joyful atmosphere. Nineteen children (with parents) volunteered, but one child was killed in a traffic accident before the study started, leaving 18 participants.

3.3.1 Socio-economical variables

There were 8 girls and 10 boys. The youngest was 5 years and the eldest 17, and nearly all age levels were represented. One of the children had a mother with pre-existing lung disease who was included in the adult group. One child had parents that were selected in the random study population.

3.3.2 Clinical/physiological variables

Table 3.6.3. shows some variables for the children in comparison to the other groups. Several of the children refused blood sampling. One therefore refrained from taking such samples to keep the participants in the study. Thus, the blood data for the children are incomplete. The urinary values did not reveal any abnormal findings. It was difficult to perform the spirometric determination among the youngest children. More than 90% of the values showed less than 10% deviation from the individuals without lung disease (Table 3.6.3).

3.3.3 Dropout

In this group three (20%) children dropped out of the study. This low drop-out rate is probably due to enthusiastic parents who followed up their children's participation closely. Medium aged and older children were those who dropped out, and the reasons given were related to the demanding study design.

3.4 CONCLUSION

It is concluded that within their own categories the different study groups are representative with respect to the study goals. Psychologist Vassend, at the University of Oslo, concluded for the SCL-90 questionnaire that the study groups did not seem to have particularly negative psychological characteristics or to be psychopathologically skewed. The study population rather included individuals with higher positive psychological scores than average for the general population. This is not surprising taking into consideration the demanding project design and that only 39% of the randomly selected individuals were willing to participate.

4 MEASUREMENTS OF METEOROLOGICAL CONDITIONS AND AIR QUALITY

L.O. Hagen and K. Hoem

4.1 MEASUREMENT PROGRAM FOR METEOROLOGICAL CONDITIONS AND AIR QUALITY

Measurements were taken of both air quality and meteorological parameters. The measurements were taken during the period of 1 January to 11 March, and 18 April to 24 June, 1988 and parts of the air quality and meteorological measurement programs continued during the interim period as well. The location of the stations is shown in Figure 4.1.

A summary of the measurement program for air quality is shown in Table 4.1. The program was carried out by NILU in co-operation with the Norwegian State Pollution Control Authority's local division.

Table 4.1: Measurement program for air quality during the investigation of health effects of air pollution in Grenland, Norway, winter and summer 1988.

Measuring period 1.1.-11.3.1988 and 18.4.-24.6.1988	Continuous registration, hourly averages							12 hour averages, day (0800-2000) and night (2000-0800)			24-hour averages (0800-0800)						
Station	SO_2	NO	NO_x	NO_2	O_3	Haze	Pollen	Particles	Aldehydes	Denuder-samples	SO_2	SO_4	NO_3	NH_3	NH_4	Soot	Pb
1. Ås	x	x	x	x	x	x		x		x[1]	x	x	x	x	x	x	
2. Klyve	x	x	x	x	x	x	x	x	x	x[1]							
3. Georg Stangsgt	x	x	x	x		x		x									
4. Nenset	x	x	x	x				x									
5. Frednes	x	x	x	x				x									
6. Skien brann-stasjon	x	x	x	x													
7. Herre											x	x			x	x	
8. Rådhuset, Porsgrunn											x	x				x	
9. Kongens gt, Skien											x	x	x			x	x

1 Measurements included nitric acid (gas), nitrate (particles), hydrogen chloride (gas), chloride (particles), ammonia (gas), and ammonium (particles). Together with aldehydes, these samples were taken in selected 24 hour periods in each measuring period.

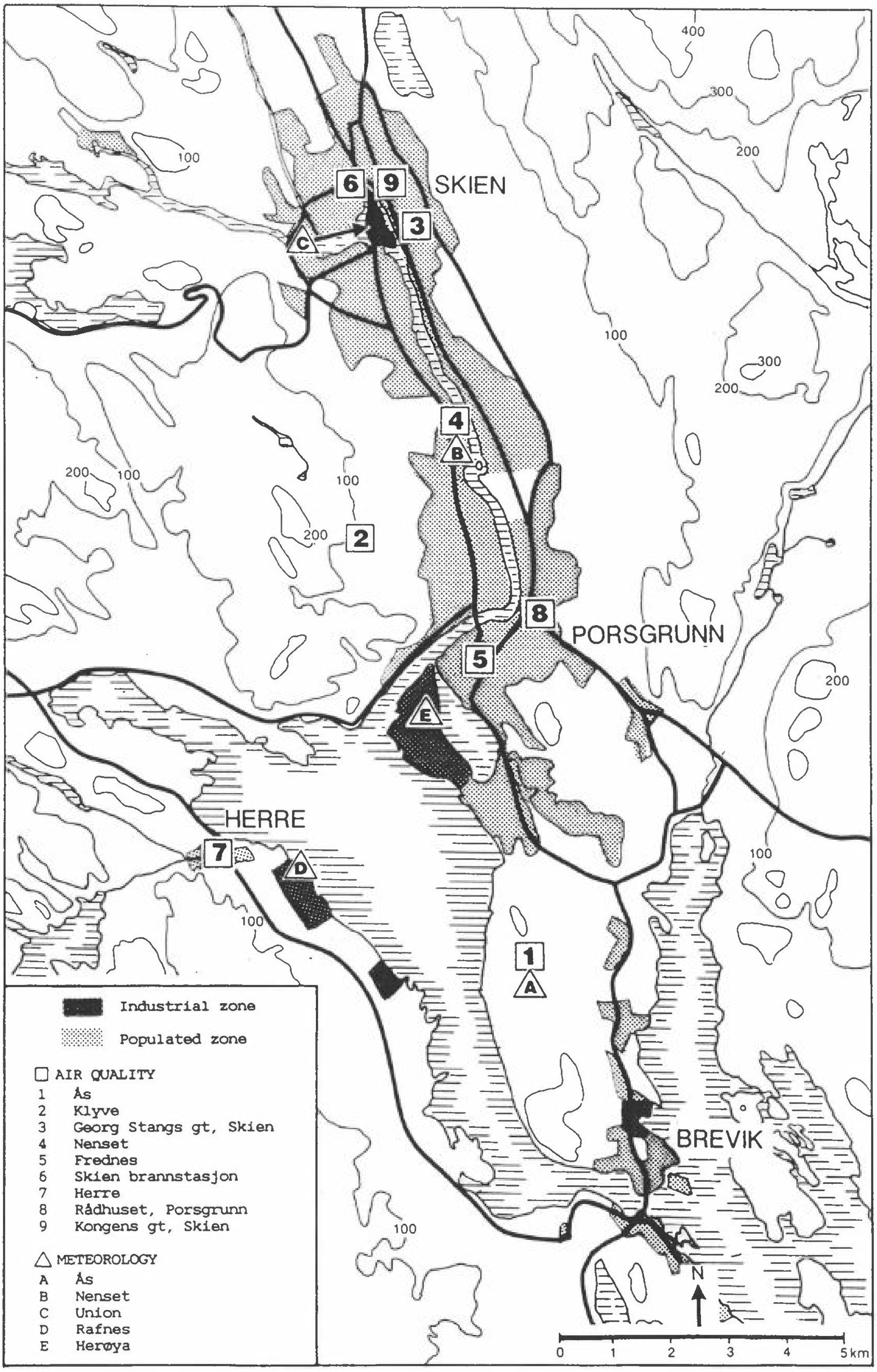


Figure 4.1: Location of stations for measuring air quality and meteorological conditions in the Grenland area.

The instruments used during air quality sampling are shown in Table 4.2.

The continuously recording instruments were equipped with data loggers, and data were transferred over a dial-up system.

Earlier studies have shown that a major part of aerosols (particles in the air) consists of ammonium chloride, ammonium sulfate and ammonium nitrate. These salts have a high vapor pressure. Therefore it was necessary to use special sampling procedures to get a correct picture of the pollution situation in the area. This is called denuder sampling. Denuder and aldehyde samples were taken for a few selected days in each measuring period.

Table 4.2: Instrumentation used during the air quality monitoring program.

	Continous sampling (1 h mean values)	12 h or 24 h sampling
SO_2	Monitor Labs Model 8850 and Dasibi Model 4108 Fluorescence SO_2 Analyzer	
NO, NO_x, NO_2	Monitor Labs Model 8840 Nitrogen Oxides Analyzer	
O_3	Dasibi Model 1008 Ozone Analyzer	
Haze (scattering coefficient)	MRI Model 1597 and UoW Model Ahlquist Nephelometer	
Suspended particles		Sierra Instruments Series 245 Automatic Dichotomous Sampler
SO_2, NO_2, SO_4, NH_3, NH_4, soot and Pb		NILU Sequential Sampler, FKI
HNO_3/NO_3^-, HCl/Cl^-, NH_3/NH_4^+		NILU Sampler, EK1 (modified) (impregnated denuder and filter)
Aldehydes		NILU Sequential Sampler, FKI (modified)
Pollen	Pollen Trap	

A summary of the meteorological measurement program is shown in Table 4.3.

Table 4.3: Measurement program for meteorology of the different stations. All parameters are given as hourly averages.

Measuring period: 1.1.-30.6.88	Wind direction		Wind speed		Tempe-rature		Tempe-rature diffe-rence	Relative humidity	Maximal wind speed (Gust)		Turbu-lence	SODAR: Wind direction and wind speed every 25 m up to 200 m
	10 m	25 m	10 m	25 m	2 m	25 m	25-10 m	2 m	1 s	3 s	25 m	
A Ås		x		x	x	x	x	x	x	x	x	
B Nenset	x		x		x			x				x^1
C Union	x		x		x			x				
D Rafnes	x		x									
E Herøya												x^2

1) Winter period: 8.1.-27.2.1988
2) Summer period: 3.5.-4.7.1988

Measurements at Ås were performed using NILU's Automatic Weather Station (AWS) which was equipped with a data logger and a dial-up system. Mechanical wind measurement equipment was used at Nenset and Union (Lambrecht Woelfle type) and at Rafnes (Fuess type). SODAR (Sonic Detection and Ranging) was used at Nenset and Herøya.

4.2 RESULTS

4.2.1 Meteorological conditions

Meteorological conditions were measured at five stations. Measurements included wind direction, wind speed, temperature, temperature difference with height, humidity, gust, and fluctuation in wind direction.

Wind direction was measured at Ås, Rafnes, Herøya, Nenset and Union. The results show that wind is canalized because of the local topographical nature of the terrain. However, at a height of 100-125 meters, wind direction is no longer affected by the underlying terrain. In the winter of 1988 (January to March), wind measurements at Ås showed that wind came more often from the southeast than is normal in the winter, especially in January and February. This winter was also unusually mild. In the summer of 1988 (April-June) the frequency of wind from the southeast and northwest was greater than normal.

Wind speed was greater (3.2 m/s) than normal (2.8 m/s) during the winter. In the summer, wind speed was as expected (2.8 m/s). Wind speed increased evenly with height in both winter and summer. In the summer, wind speed was greater during the day and during the afternoon than at night because of the land-sea breeze. Table 4.4 summarizes wind speed measured for each month at Ås, at a height of 25 m above ground.

Table 4.4: Meteorological conditions at Ås, based on hourly averages of wind speed, temperature and humidity.

Station: Ås	Wind speed (m/s)			Air temperature (^0C)			Relative humidity (%)		
	Average	Max	Min	Average	Max	Min	Average	Max	Min
January 1988	3.2	7.6	0.1	0.9	6.4	-7.6	91	99	77
February 1988	3.4	9.6	0.1	-0.2	6.6	-10.2	84	99	51
March 1988	3.0	8.0	0.0	-0.4	7.5	-7.3	77	98	37
April 1988	3.2	10.4	0.1	3.6	13.1	-3.3	72	96	21
May 1988	2.7	6.1	0.1	12.1	25.0	2.2	73	98	35
June 1988	2.6	6.7	0.0	17.9	32.4	6.6	80	97	36

Short-term variation in wind speed and direction is very important for the dispersion of air pollutant emissions. The highest measured wind speeds (measured for a period of 3 seconds) were about twice as high as the hourly averages. The standard deviation of the fluctuation in wind direction was typically $20-30^0$ and was greatest when the wind came from the west.

The average measured temperature in January and February 1988 was between 0 and 1^0C, that is 5 to 6^0C warmer than normal. This led to a major reduction in the emissions from domestic heating. Temperatures were also 2 to 3^0C warmer than usual in the summer months of May and June.

Relative humidity was highest in the winter, gradually decreasing through the spring. There were small differences between stations.

Differences between temperatures at different heights are important in vertical dispersion of pollutants. In the winter of 1988, there was a greater frequency of unstable or neutral weather situations than is normal for this time of year. This led to much better pollution dispersion than in a normal winter. Stable weather situations occurred mostly during the nights in the summer. However, dispersion was on the average quite good in the summer.

4.2.2 Air quality

Air quality was measured at nine stations. Measurements included sulfur dioxide, nitrogen oxides, ozone, haze (dispersion coefficient b_{scat}), suspended particles, sulfate, nitrate, chloride, soot, lead, ammonia, ammonium, aldehydes and pollen. Not all compounds were measured at each station.

Air quality measurements in 1988, as determined from the regular monitoring program in the area, revealed lower concentrations of air pollutants than were measured in 1986 and 1987. This was primarily due to reduced emissions from heating because of the mild winter and to the better than usual dispersion conditions.

A summary of the results of the air quality measurements is given in Tables 4.5 and 4.6. In Table 4.5 the maximum concentrations measured at the different stations are given for each of the different averaging times. Table 4.6 shows how often air quality guidelines for Norway and for the World Health Organization (WHO) were exceeded during the investigation periods (Norwegian State Pollution Control Authority, 1982; WHO, 1987).

Table 4.5: Summary of maximum values of different air pollution components during the period January to June 1988.

Component	Averaging time	Ås	Herre	Frednes	Klyve	Rådhuset Porsgrunn	Nenset	G.Stangs gt. Skien	Skien brannst.	Kongensgt. Skien
SO_2 ($\mu g/m^3$)	1 hour	147		338	474		203	872	2027	
	24 hours	32	23	37	55	26	63	134	320	121
NO_x ($\mu g/m^3$)	1 hour	296		761	326		820	463	551	
	24 hours	110		320	104		273	167	229	
NO_2 ($\mu g/m^3$)	1 hour	192		119	191		125	102	121	
	24 hours	84		70	75		61	47	59	90
Haze (10^{-6} m^{-1})	1 hour	764			1061			572		
	24 hours	116			71			58		
O_3 ($\mu g/m^3$)	1 hour	185			150					
	8 hours	179			141					
Suspended particles ($\mu g/m^3$)	12 hours	69		89	74		93	94		
SO_4 ($\mu g/m^3$)	12 hours	16,7		16,2	17,8		16,3	15,3		
NO_3 ($\mu g/m^3$)	12 hours	10,7		9,8	12,7		6,4	5,9		
Cl ($\mu g/m^3$)	12 hours	6,6		4,7	3,3		4,6	5,0		
Soot ($\mu g/m^3$)	24 hours	31	30			79				104
Lead ($\mu g/m^3$)	24 hours									1,21
NH_3 ($\mu g/m^3$)	24 hours	9,6								
NH_4 ($\mu g/m^3$)	24 hours	8,7	5,3							
Formaldehyde ($\mu g/m^3$)	24 hours				0,7					

Table 4.6: Number of hours and days when air quality guidelines for SO_2, NO_2, O_3, soot and suspended particles were exceeded during the winter (W), January-March, and during the summer (S), April-June 1988.

Component	SO_2		NO_2		O_3		Soot	Suspended particles
Averaging time	1 hour	24 hours	1 hour	24 hours	1 hour	8 hours	24 hours	24 hours
Air Quality Guideline	350 $\mu g/m^3$ WHO	100 $\mu g/m^3$ Norway	200 $\mu g/m^3$ Norway	100 $\mu g/m^3$ Norway	100 $\mu g/m^3$ Norway	100 $\mu g/m^3$ WHO	100 $\mu g/m^3$ Norway	70 $\mu g/m^3$ WHO
Ås (W)	0	0	0	0	0	0	0	0
(S)	0	0	0	0	406	35	0	0
Herre (W)		0					0	
(S)		0					0	
Frednes (W)	0	0	0	0				0
(S)	0	0	0	0				1
Klyve (W)	1	0	0	0	0	0		0
(S)	0	0	0	0	325	25		0
Rådhuset, (W)		0					0	
Porsgrunn (S)		0					0	
Nenset (W)	0	0	0	0				0
(S)	0	0	0	0				0
G. Stangs gt, (W)	6	1	0	0				0
Skien (S)	0	0	0	0				0
Skien (W)	6	2	0	0				
brannstasjon (S)	0	0	0	0				
Kongens gt, (W)		1		0			2	
Skien (S)		0					0	

Sulfur dioxide

Tables 4.5 and 4.6 show that SO_2 concentrations exceeded air quality guidelines during the winter 1988 in Skien. This is due to industrial emissions. The highest hourly average of SO_2 was measured at Skien brannstasjon (2 027 $\mu g/m^3$) and was nearly six times higher than the WHO air quality guideline of 350 $\mu g/m^3$. The highest daily average of 320 $\mu g/m^3$ was more than three times higher than the Norwegian proposed guideline of 100 $\mu g/m^3$.

The measuring stations were very little influenced by the industrial emissions at Herøya in Porsgrunn.

Nitrogen dioxide

The highest daily average of NO_2 was measured in Kongens gt. in Skien and was caused by traffic pollution there. Average values for one and three months show lower values for stations that are less influenced by traffic pollution. However, the highest hourly averages were registered at stations Ås and Klyve, at hours when these stations were influenced by industrial emissions from Herøya. However, the air quality guidelines were not exceeded.

Haze

Small particles in the atmosphere spread light. Measurement of the dispersion coefficient (b_{scat}) is a convenient method for characterizing the haze caused by various concentrations of particles. Measurements indicated approximately the same average degree of haze in winter and in summer. There were also only small differences between stations. The highest values of haze corresponded to the lowest meteorological visibility of around 4 km.

Ozone

The concentration of ozone was, as expected, highest in the summer. Measurements showed the same values at Klyve and at Ås. Both the Norwegian and WHO guidelines for air quality were exceeded rather often during the summer. The source of ozone is primarily long-range transport of air pollutants.

Pollen from birch and grass

There was intensive flowering of birch for one week in the middle of May with pollen values being highest in the morning. Grass had just begun to bloom when the study was finished at the end of June.

Suspended particles

The concentrations of suspended particles (particles with a diameter of less than 10 μm) differed only slightly between stations. Values measured in the winter were only slightly higher than those measured in the summer. Most of the dust was represented by the smallest particles (diameter less than 2.5 μm). Such respirable particles are of interest in relation to possible health effects. Only once was the WHO guideline of 70 $\mu g/m^3$ exceeded.

Sulfate, nitrate and chloride in suspended particles

Concentrations of sulfate were generally lower in 1988 than in 1986 and 1987. There were small differences between stations. The highest values were measured between 15 to 17 February, during a period of long-range transport of air pollutants. On an average more than 90% of all sulfate was found in the smallest particle class.

The highest daily averages of nitrates and chlorides were measured at Klyve and Ås when wind came from the industrialized area of Herøya. A relatively large proportion of nitrate and chloride was found in the largest particle class.

Soot and lead

Automobile traffic is the primary source of soot and lead in the study area. The highest values were measured at Kongens gt. in Skien. The Norwegian proposed air quality guideline for soot is a daily average of 100 $\mu g/m^3$, and was exceeded twice in the winter. Lead concentrations in Kongens gt. approached the WHO guidelines.

Ammonia and ammonium

Concentrations measured in 1988 were approximately the same as those measured in 1986 and 1987. The highest daily averages coincided with wind from Herøya.

Aldehydes

Concentrations of formaldehyde and acetaldehyde were substantially below the WHO guidelines and also much lower than corresponding values measured indoors in this study.

Denuder sampling

A major part of the aerosols (particles in air) consists of ammonium chloride and ammonium sulfate. When using denuders, the gases HCl, HNO_3 and NH_3 are absorbed on the inner walls of a tube, and separated from the aerosols such as NH_4NO_3, and NH_4Cl which are trapped on a filter at the end of the tube. By using traditional methods for measuring suspended particulate matter, the gases are lost from the filter.

The denuder sampling confirms the assumption that concentrations in the gas phase can be quite sizeable when compared to the particulate phase.

4.3 CONCLUSIONS

Measurements of air quality in Grenland during the period January to June 1988 showed that proposed air quality guidelines for SO_2, NO_2, O_3, soot, and suspended particles were exceeded in some instances. Ozone was the compound that exceeded guideline values most frequently. For SO_2, the guidelines were exceeded most frequently in Skien in the winter. The compound that exceeded guideline values most frequently was SO_2 at Skien brannstasjon. This was due to industrial emissions from a local factory.

Improved dispersion conditions during the unusually mild winter of 1988, resulted in improved air quality in 1988 compared to a more "normal" winter. Air pollution concentrations (except for O_3) were lower in the summer than in the winter.

Long-range transport of air pollutants from sources located in different parts of Europe resulted in episodes of elevated concentrations of NO_2, soot, O_3, haze, suspended particles and sulfate. The overall highest sulfate concentrations were measured at all stations during just such an episode in the middle of February, 1988.

5 DESCRIPTION OF AIR POLLUTANT EMISSIONS IN THE REGION

I. Haugsbakk and K.E. Grønskei

5.1 GENERAL OVERVIEW

Hourly emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), carbon monoxide (CO) and suspended particles were estimated for car and ship traffic, industry and home heating in Grenland. Emission data were collected from an area of 16 x 23 km^2, including the three main urban centers Skien, Porsgrunn and Brevik. Industrial and residential areas are located adjacent to the urban centers. Ship traffic included shipping of raw materials and industrial products across Frierfjorden and also along the waterway to Skien.

Hourly emission data were estimated/reported for two periods:

Period 1: 1 January-15 March 1988.
Period 2: 18 April-24 June 1988.

Table 5.1, Table 5.2 and Figure 5.1 show average emission intensities of SO_2, NO_x, CO and suspended particles.

Table 5.1: Emissions, period 1 (1 January-15 March 1988), in kg/h, and as per cent of total emissions.

Source group	SO_2	NO_x*	CO	Suspended particles
Area sources, oil	12.3 (7.5%)	8.5 (1.2%)	10.2 (0.3%)	0.7 (0.3%)
Area sources, wood	1.4 (0.9%)	2.5 (0.4%)	360.7 (9.8%)	38.6 (18.4%)
Point sources	131.6 (80.4%)	343.9 (50.8%)	1863.0 (50.7%)	154.4 (73.6%)
Car traffic	14.8 (9.0%)	268.4 (39.6%)	1437.6 (39.1%)	14.9 (7.1%)
Ship traffic	3.6 (2.2%)	54.1 (8.0%)	5.8 (0.1%)	1.1 (0.5%)
Total	163.7	677.5	3677.3	209.7

* given as NO_2

Table 5.2: Emissions, period 2 (18 April-24 June 1988), in kg/h and as per cent of total emissions.

Source group	SO_2	NO_x*	CO	Suspended particles
Area sources, oil	1.7 (0.9%)	1.2 (0.2%)	1.4 (0.1%)	0.1 (0.1%)
Area sources, wood	0.2 (0.1%)	0.3 (- %)	48.2 (1.4%)	5.2 (2.8%)
Point sources	161.6 (88.7%)	448.4 (59.2%)	2140.3 (62.5%)	162.0 (88.3%)
Car traffic	14.8 (8.1%)	247.3 (32.7%)	1227.0 (35.8%)	14.9 (8.1%)
Ship traffic	4.0 (2.2%)	60.1 (7.9%)	6.5 (0.2%)	1.2 (0.7%)
Total	182.3	757.4	3423.4	183.4

* given as NO_2

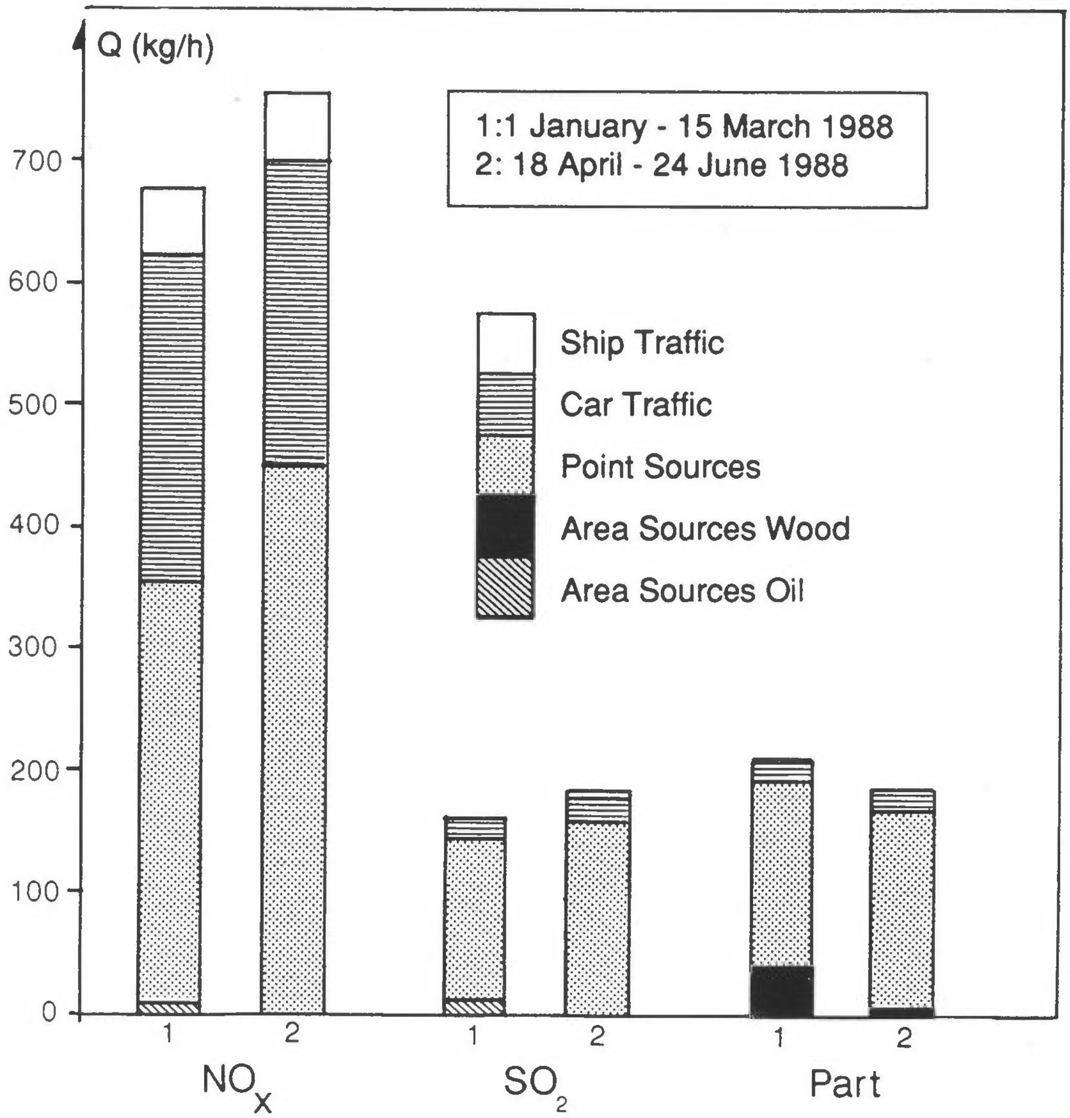


Figure 5.1: Average total emission intensity (Q) of SO_2, suspended particles and NO_x from different source groups in period 1 and period 2.

5.2 INDUSTRIAL EMISSIONS

An emission database for industrial sources has been developed in co-operation with the Norwegian State Pollution Control Authority in Southern Telemark and the industries. Industrial production in the area includes pulp and paper production in Skien, fertilizer, magnesium and metal alloy factories at Herøya in Porsgrunn, the Norcem cement plant in Brevik, and petrochemical plants in Bamble on the west side of the Frier fjord.

Industrial emission data are mainly based on measurements. Control measurements were carried out for typical emission conditions for point sources. For some industrial stacks, continuous emission measurements have been available in addition to the control measurements. Industrial sources were considered as point sources and emission conditions were described by detailed data on position, height, emission rates, gas exit velocity and temperature.

In the first period (winter) 10 single factories emitted 80% of the total SO_2 emissions and about 50% of the NO_x emissions. In the second period (summer) the contribution from industry was 90% for SO_2 and 60% for NO_x (see point sources in Table 5.1 and 5.2).

The effect of industrial emissions on air quality at ground level depends on the stack height, transport and dispersion conditions in addition to emission rates. Emissions from each single source were below the maximum allowable levels set by the state pollution control authorities.

5.3 EMISSIONS FROM HOME HEATING AND SMALL INDUSTRIAL PLANTS

Emission data were based upon information on consumption of oil and wood and from process industry. Small point sources were accounted for by defining their average emissions for each km^2.

Estimates of the total consumption of oil in the area were based upon information from the oil companies. Estimates of the total consumption of wood were based on data on wood consumption per inhabitant from other areas (Oslo and Elverum).

Total emissions from local home heating were distributed in the area according to residential distribution. Emissions from home heating vary from day to day, according to the variation in the average daily temperature, and in accordance with the knowledge about the need for home heating. The emissions from home heating also vary from hour to hour during the day according to empirical data.

In Tables 5.1 and 5.2, emissions from wood burning and oil burning furnaces are differentiated. Emissions from the use of oil in small furnaces in winter contributed about 7.5% of the total SO_2-emissions and use of wood for home heating contributed about 18% of total emissions of particles. SO_2 emissions from oil-burning in the summer period contribute about 1% of total SO_2 emissions. Other emissions from area sources were of minor importance.

5.4 EMISSIONS FROM CAR TRAFFIC

The road authorities in Telemark have given data for mean daily traffic along the main roads in the area. Data for the variation in traffic intensity is given for each day of the week and hour of the day. These data were used to estimate expected hourly traffic intensity along all main roads in the area of investigation. Hourly emissions from all major roads in the area were estimated using traffic data and emission factors. Emissions were small during the night (10-20% of the average emissions). Maximum emissions from car traffic occurred during the afternoon rush hour (about 200% of the average emissions).

5.5 EMISSIONS FROM SHIP TRAFFIC

Hourly emissions from ship traffic are based upon hourly data from the control office for ships in the area. Emission factors used are differentiated between ships at sea and ships in the harbor.

The pollutant contribution to NO_x from ships in the area was calculated as about 8% of the total emissions during both periods of registration. Emissions of SO_2 were about 2% of the total SO_2 emissions in both periods. For other pollution components the emission from ships were of minor importance.

5.6 TOTAL EMISSIONS

Total emissions of SO_2 were dominated by point sources; about 80% in the winter period and about 90% in the summer period. Total emissions of NO_x were dominated by two main groups of sources; in winter ca. 50% from point sources (large industry) and ca. 40% from car traffic, in summer ca. 60% from point sources and 30% from car traffic. Eight per cent of the total emissions of NO_x were caused by ships, and this source may dominate NO_x concentrations close to the water-ways.

Total emissions of particles were dominated by point sources (ca. 75%), and by wood combustion (ca. 20%) in the winter. In summer, the main sources for total emissions were the point sources (ca. 88%) and car traffic (ca. 8%).

The influence of different groups of sources on the concentration values close to the ground varies with hour of the day, wind and dispersion conditions. For instance, emissions from car traffic were of minor importance at night while traffic intensity determined air quality along roads with heavy traffic during the day. Emissions from point sources (large industry) influenced air quality in limited areas determined by the actual emission and dispersion conditions.

5.7 APPLICATION OF EMISSION DATA IN MODELLING OF GEOGRAPHIC DISTRIBUTION OF AIR POLLUTANTS

Emission data was used to calculate hourly concentrations of air contaminants in the entire area, which were in turn used in estimating human exposure. The study of possible health effects of air pollutants in Grenland is focused on acute or short-term health effects. Therefore, the following components were selected: SO_2, NO_2, NO, O_3, suspended particles and CO.

Measurements of hourly variations in emissions were not available for many sources. It was thus necessary to use mean emission values based on measurements under typical emission conditions. Extreme emission rates were not described. On an hourly basis, measurements from up to five stations were used to correct for insufficient data on emission and dispersion conditions. Hourly measurements were performed for SO_2, NO_2, NO_x, O_3 and suspended particles.

It was necessary to account for traffic pollution in streets with high traffic intensity. Considerable amounts of carbon monoxide are emitted from a high stack in one point source. However, the impact at ground level of the contribution of CO from high stacks is of minor importance compared to heavy traffic. Other pollutants from vehicular exhaust include NO_x, suspended particles and organic compounds.

Industrial sources also contribute to the air quality by emissions of components such as chlorine (Cl), polyaromatic hydrocarbons (PAH), polychlorinated dibenzo(p)dioxins and heavy metals.

Emissions from the chemical complex at Herøya in Porsgrunn include ammonia, nitric acid, chlorine and hydrochloric acid that interact in a complex way to produce aerosols of the ammonium salts (Semb, 1984) and to increase the photochemical activity in the plume (Hov, 1983).

6 RESULTS OF INDOOR/OUTDOOR MEASUREMENTS

O.-A. Braathen

6.1 SELECTION OF THE HOMES THAT WERE MEASURED

When the participants in the study had been selected, a questionnaire was sent to everyone. This questionnaire mainly asked for information about the homes of the participants. Based on the answers, 15 homes were selected for measurements. The homes were selected so that the set of homes were as representative as possible of types of homes in the Grenland area. The locations of the 15 homes are shown in Figure 6.1.

6.2 MEASUREMENT PROGRAM

The purpose of including indoor/outdoor measurements in the study in addition to the extensive outdoor air measurement program, was to improve the calculation of exposure of the participants to various air pollutants. This meant that the indoor/outdoor and outdoor measurement programs had to include the same set of air pollutants.

The indoor/outdoor measurement program is shown in Table 6.1.

In each home the measurement program was carried out once in the winter and once in the summer of 1988. The indoor measurements were done in the living room of the home, and the outdoor measurements were done just outside the home. A mobile unit equipped with all the necessary equipment and instruments, was used for this purpose.

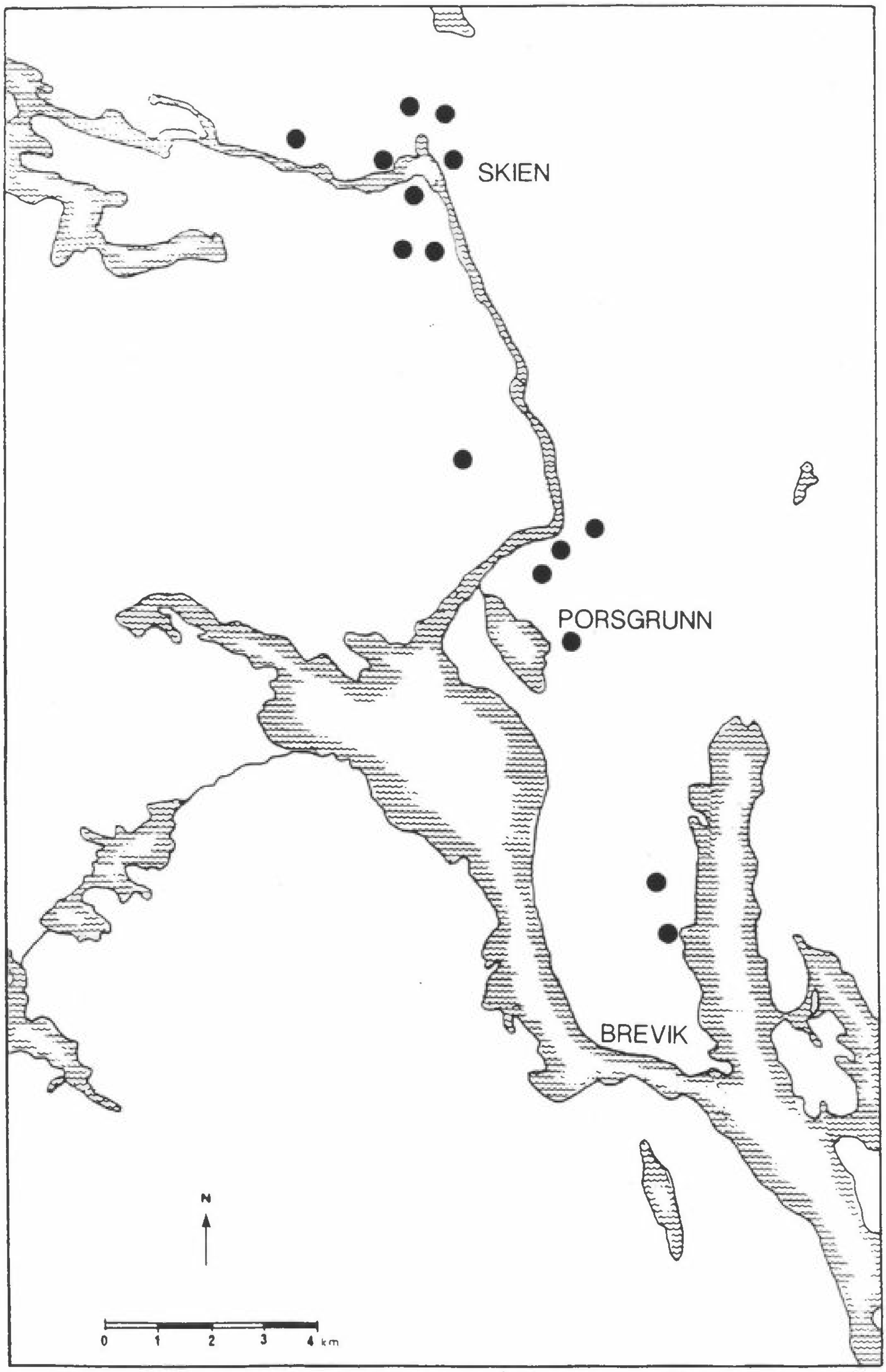


Figure 6.1: The locations of the 15 homes where the indoor/ outdoor measurements were carried out.

Table 6.1: The indoor/outdoor measurement program.

Air pollutant	Locations	Averaging time	Number of measurements
Suspended particles Fine fraction[a]	Indoors[d]	12 hours	6
	Outdoors[d]	12 hours	6
Suspended particles Coarse fraction[b]	Indoors	12 hours	6
	Outdoors	12 hours	6
Cl^- (chloride)[c]	Indoors	12 hours	6
	Outdoors	12 hours	6
NO_3^- (nitrate)[c]	Indoors	12 hours	6
	Outdoors	12 hours	6
SO_4^{2-} (sulfate)[c]	Indoors	12 hours	6
	Outdoors	12 hours	6
NO_2 (nitrogen dioxide)	Indoors	8 hours	8
	Outdoors	8 hours	8
SO_2 (sulfur dioxide)	Indoors	8 hours	8
	Outdoors	8 hours	8
HCOH (formaldehyde or methanal) CH_3COH (acetaldehyde or ethanal)	Indoors	1-2 hours	2
CO (carbon monoxide)[e]	Indoors	Continuous	-

a) Particles with diameter less than 2.5 µm.
b) Particles with diameter larger than 2.5 µm.
c) Measured on both fractions of the suspended particles.
d) The indoor and outdoor measurements were carried out simultaneously.
e) Due to practical problems, all CO measurements were discarded.

6.3 RESULTS

Sulfur dioxide

Table 6.2 shows the 64-hour averaged concentrations of SO_2 measured in the indoor air of the 15 homes. The table clearly shows that the SO_2-concentrations inside the homes were low. Some of the homes were located close to the main industrial source of SO_2-emissions in the Grenland area, Union A/S, in Skien. The concentrations in these homes were also low. This was probably because each home was not located in the plume long enough to significantly raise the indoor air concentrations.

In general there were no significant differences between the SO_2-concentrations in the indoor and outdoor air of the homes.

Nitrogen dioxide

Table 6.2 also shows the measured indoor air concentrations of NO_2 in the homes averaged over 64 hours. Indoor air concentrations of NO_2 were lower than the corresponding outdoor air concentrations. This was probably due to chemical reactions between NO_2 and active surfaces, such as textiles and concrete surfaces, inside the home. In many homes, the indoor air concentration was higher in the summer than in the winter. This was probably because the air exchange rate was higher in the summer.

Carbon monoxide

Due to a series of technical problems and due to variations of the temperature inside the model unit, the CO-monitor did not function as planned. It was therefore decided to discard the results of the CO-measurements indoors.

Table 6.2: Indoor air concentrations of SO_2 and NO_2 in the 15 homes, averaged over 64 hours. Unit: $\mu g/m^3$.

Home number	Season	SO_2	NO_2
1	W	11	21
	S	5	18
2	W	7	16
	S	16	15
3	W	9	20
	S	3	14
4	W	10	14
	S	5	22
5	W	7	13
	S	7	32
6	W	12	9
	S	-	-
7	W	10	14
	S	6	28
8	W	-	10
	S	9	30
9	W	10	7
	S	5	20
10	W	7	4
	S	5	21
11	W	9	22
	S	14	17
12	W	-	14
	S	-	-
13	W	12	13
	S	6	18
14	W	19	9
	S	9	22
15	W	6	16
	S	5	29

W = Winter S = Summer

Suspended particles, fine fraction

The fine fraction of suspended particles contains particles with a diameter less than 2.5 μm. Results of the measurements of indoor air concentrations of the fine fraction of suspended particles in the 15 homes averaged over 72 hours, are shown in Table 6.3. In the homes numbered 1, 2, 3, 6, 9, 13 and 15 smoking of 4 or more cigarettes per day were reported. These homes were those with the highest concentrations of the fine fraction measured in indoor air. For these homes, indoor air concentrations were also significantly higher than outdoor air concentrations. For homes where no smoking was reported, there were no significant differences between indoor and outdoor air concentrations. The results of the measurements therefore clearly show that tobacco smoking is the most important source of the fine fraction of suspended particles in indoor air of Norwegian homes.

Suspended particles, coarse fraction

The coarse fraction of the suspended particles contains particles with diameter larger than 2.5 μm and smaller than about 15μm. Table 6.3 also shows the results of the measurements of indoor air concentrations of the coarse fraction of the suspended particles in the 15 homes averaged over 72 hours. In general, concentrations of the coarse fraction were lower than concentrations of the fine fraction. Indoor air concentrations of the coarse fraction of the suspended particles where slightly higher than the corresponding outdoor air concentrations for most of the homes. The daytime concentrations were generally higher than the nighttime concentrations, probably because of more human activity inside during the day.

Table 6.3: The concentrations of the two fractions of suspended particles in the indoor air of the 15 homes averaged over 72 hours.
Unit: μg/m^3.

Home number	Season	Suspended particles Fine fraction	Suspended particles Coarse fraction
1	W	125	30
	S	58	12
2	W	52	26
	S	77	18
3	W	128	18
	S	-	-
4	W	17	12
	S	12	11
5	W	13	18
	S	12	21
6	W	93	13
	S	69	18
7	W	14	13
	S	-	16
8	W	18	12
	S	21	17
9	W	43	39
	S	35	45
10	W	26	22
	S	27	21
11	W	18	15
	S	11	9
12	W	10	9
	S	-	-
13	W	83	18
	S	-	-
14	W	13	6
	S	12	15
15	W	44	11
	S	48	8

W = Winter S = Summer

Chloride

In both measurement seasons, the concentrations of Cl^- associated with the two size-fractions of the suspended particles in the indoor air, were about equal. In most homes, indoor air concentrations of Cl^- on both fractions were less than 0.6 µg/m³.

Nitrate

The measured indoor air concentrations of NO_3^- on the fine fraction of the suspended particles were higher than the concentrations on the coarse fraction. Indoor air concentrations were lower than outdoor air concentrations in both seasons, and measured concentrations in the summer were lower than in the winter.

Sulfate

The measured concentrations of SO_4^{2-} on the fine fraction of the suspended particles were higher than on the coarse fraction both outdoors and indoors. Outdoor air concentrations were generally higher than indoor air concentrations.

Formaldehyde (methanal)

Concentrations of HCOH were only measured inside the homes. Measured concentrations were generally higher in the summer than in the winter, probably because of higher temperature and therefore higher emissions from various materials. 109 µg/m³ was the highest concentration that was measured, and this was the only concentration that was higher than 65 µg/m³.

Acetaldehyde (ethanal)

Concentrations of CH_3COH were only measured inside the homes. All concentrations were lower than 40 $\mu g/m^3$, and there were no significant differences between concentrations in the summer and in the winter.

6.4 APPLICATION OF THE RESULTS IN EXPOSURE ASSESSMENT

The results of this measurement program were used to establish linear relationships between indoor and outdoor air. These relationships were used in the model that estimates individual exposure to air pollution when the individual indicated in the diary that he/she was indoors with window closed.

The established relationships were all linear expressions of the type:

$$C_{in} = a \cdot C_{out} + b$$

where

C_{in} = indoor concentration ($\mu g/m^3$), and
C_{out} = outdoor concentration ($\mu g/m^3$).

"a" is called the penetration-coefficient and is a measure of how strongly C_{in} depends on C_{out}. "b" is a measure of the total source strength of indoor sources. "a" and "b" were calculated using linear regression on the sets of measurements indoors and outdoors in the 15 homes in Grenland in the winter and in the summer. The concentration unit used throughout this report is $\mu g/m^3$ unless otherwise stated.

Sulfur dioxide

All the measured concentrations of SO_2, both inside and outside of the homes, were rather low. In order to establish a relationship between indoor and outdoor concentrations of SO_2 that could also be used at higher outdoor concentrations, values taken from the literature had to be utilized. The resulting relationship was:

$$C_{in} = 0.49 \cdot C_{out} + 5.05$$

This means that the C_{in}/C_{out}-ratio was about 1 when C_{out} was low and about 0.5 when C_{out} was high. This is in accordance with previous studies in other countries.

Nitrogen dioxide

In many countries, gas stoves and other gas-burning appliances lead to rather high NO_2-concentrations in indoor air, and in many cases indoor air concentrations are significantly higher than outdoor air concentrations. In Norway there are, generally, no important NO_2-sources indoors, and therefore the C_{in}/C_{out}-ratio is usually smaller than 1 in Norwegian homes since NO_2 reacts with active surfaces.

Table 6.4 shows the relationships between the indoor (C_{in}) and outdoor (C_{out}) concentrations of NO_2.

The penetration-coefficients of all the lines of regression for NO_2 were smaller than 1. The coefficients in homes with inhabitant(s) suffering from lung disease were larger than in homes without such inhabitants. This was presumably due to higher air exchange rates in homes where one of the inhabitants was suffering from lung disease.

Table 6.4: Relationships between indoor (C_{in}) and outdoor (C_{out}) concentrations of NO_2 in Norwegian homes (r = correlation coefficient).
Unit: $\mu g/m^3$.

Season	Time interval	Home with inhabitant(s) suffering from LD[1]	Home without inhabitant(s) suffering from LD[1]
Winter	00-16	$C_{in} = 0.28 \cdot C_{out} + 6.30$, r = 0.67	
	16-24	$C_{in}=0.35 \cdot C_{out}+6.50$ r=0.49	$C_{in}=0.21 \cdot C_{out}+10.50$ r=0.69
Summer	00-08	$C_{in} = 0.56 \cdot C_{out} + 7.50$, r=?	
	08-24	$C_{in}=0.81 \cdot C_{out}+1.50$ r=0.89	$C_{in}=0.34 \cdot C_{out}+9.55$ r=0.67

1) LD = Pre-existing Lung Disease.

Suspended particles, fine fraction

The fine fraction of the suspended particles have both indoor and outdoor sources, and especially tobacco smoking in the indoor environment may increase the concentration of the fine fraction substantially.

In order to assess the penetration of fine particles from outdoor air into indoor air of the homes, it is presumably best to study the concentrations of fine fraction SO_4^{2-} (sulfate) indoors and outdoors. The reason for this is the absence of important indoor sulfate sources. The penetration coefficients of the regression lines for fine fraction sulfate (see below) were therefore also used for the fine fraction itself.

Source strength for indoor sources of fine particles was estimated as follows. The average indoor air concentrations were calculated, and the lines were adjusted so that, with an outdoor air concentration of 25 $\mu g/m^3$, the calculated indoor air concentrations would be equal to the average concentrations.

The average indoor air concentrations that were used, are shown in Table 6.5.

Table 6.5: Average indoor air concentrations of the fine fraction of suspended particles in 15 homes in Grenland.
Unit: $\mu g/m^3$.

Season	Time interval	Home with smoking of more than 10 cigarettes a day	Home with smoking of 1-10 cigarettes a day	Home with no smoking
Winter	08-20	116	55	17.5
	20-08	78	40.5	14.5
Summer	08-20	64	27	19
	20-08	55	23	13

The resulting relationships between C_{in} and C_{out} for the fine fraction of the suspended particles are shown in Tables 6.6 and 6.7.

Table 6.6: The relationships between indoor (C_{in}) and outdoor (C_{out}) concentrations of the fine fraction of the suspended particles in homes in Grenland in the winter.
Unit: $\mu g/m^3$.

Time interval	Home with smoking of more than 10 cigarettes a day	Home with smoking of 1-10 cigarettes a day	Home with no smoking
08-20	$C_{in}=0.73 \cdot C_{out}+97.75$	$C_{in}=0.73 \cdot C_{out}+36.75$	$C_{in}=0.73 \cdot C_{out}-0.75^a$
20-08	$C_{in}=0.70 \cdot C_{out}+60.50$	$C_{in}=0.70 \cdot C_{out}+23.00$	$C_{in}=0.70 \cdot C_{out}-3{,}00^a$

a) If a negative value is calculated, C_{in} is set equal to 0.

Table 6.7: The relationships between indoor (C_{in}) and outdoor (C_{out}) concentrations of the fine fraction of the suspended particles in homes in Grenland in the summer.

<table>
<tr><th>Time interval</th><th>Home with inhabitant(s) suffering from LD[a]</th><th>Home with smoking of more than 10 cigarettes a day</th><th>Home with smoking of 1-10 cigarettes a day</th><th>Home with no smoking</th></tr>
<tr><td rowspan="2">08-20</td><td>Yes</td><td>$C_{in}=0.87\cdot C_{out}+42.25$</td><td>$C_{in}=0.87\cdot C_{out}+5.25$</td><td>$C_{in}=0.87\cdot C_{out}-2.75$[b]</td></tr>
<tr><td>No</td><td>$C_{in}=0.75\cdot C_{out}+45.25$</td><td>$C_{in}=0.75\cdot C_{out}+8.25$</td><td>$C_{in}=0.75\cdot C_{out}+0.25$</td></tr>
<tr><td rowspan="2">20-08</td><td>Yes</td><td rowspan="2">$C_{in}=0.72\cdot C_{out}+37.00$</td><td rowspan="2">$C_{in}=0.72\cdot C_{out}+5.00$</td><td rowspan="2">$C_{in}=0.72\cdot C_{out}+5.00$[b]</td></tr>
<tr><td>No</td></tr>
</table>

a) LD = Pre-existing Lung Disease
b) If a negative value is calculated, C_{in} is set equal to 0.

Sulfate, fine fraction

In outdoor air, the concentration of fine fraction SO_4^{2-} is generally considerably higher than coarse fraction SO_4^{2-}. Since there is no important indoor sources of SO_4^{2-}, the same is expected to be true for sulfates in indoor air, and this was found in the present study.

For the fine fraction, the regression lines of the indoor concentrations of SO_4^{2-} on the outdoor concentrations are shown in Table 6.8.

Nitrate, fine fraction

It was assumed that SO_4^{2-} and NO_3^- on the fine fraction of the suspended particles reacts very much in the same way both in indoor and outdoor air. The regression lines that were established for SO_4^{2-} were therefore also used for NO_3^-.

Table 6.8: Regression lines of the indoor concentration (C_{in}) of SO_4^{2-} on the outdoor concentration (C_{out}) for SO_4^{2-} (sulfate) on the fine fraction of the suspended particles (r = correlation coefficient). The same lines were used for NO_3^- (nitrate) on the fine fraction.
Unit: µg/m³.

Season	Time interval	Home with inhabitant(s) suffering from LD[a]	Home without inhabitant(s) suffering from LD[a]
Winter	08-20	$C_{in} = 0.73 \cdot C_{out} + 0.32$, r = 0.89	
	20-08	$C_{in} = 0.70 \cdot C_{out} - 0.23$[b], r = 0.73	
Summer	08-20	$C_{in}=0,87 \cdot C_{out}+0.94$ r=0.95	$C_{in}=0.75 \cdot C_{out}+0.43$ r=0.92
	20-08	$C_{in} = 0.72 \cdot C_{out} - 0.26$, r = 0.98	

a) LD = Pre-existing Lung Disease.
b) If the calculated C_{in} is negative, it is set $C_{in}=0$.

Carbon monoxide

No measurement results of concentrations of CO in indoor air were obtained. Therefore, values taken from the literature had to be utilized. The resulting relationship was:

$$C_{in} = 0.7 \cdot C_{out}$$

(for many cases, CO is given in mg/m³).

Ozone

No measurements in indoor air were carried out in this study. However, O_3 is rather reactive and the air exchange rates in Norwegian buildings are comparatively low. It was therefore assumed that the indoor air concentration of O_3 would be significantly lower than the outdoor concentration. In the literature, values of the C_{in}/C_{out}-ratio between 0.1 and 0.8 have been reported. Because of the rather low air exchange rates, a value of 0.2 was chosen, giving the following relationship:

$$C_{in} = 0.2 \cdot C_{out}$$

Pollen

The concentrations of pollen in indoor air in the homes in Grenland were not measured, and only a few measurements of indoor air concentrations have been reported in the literature. There are, however, good reasons to believe that indoor air concentrations generally are significantly lower than outdoor air concentrations. The following relationship was therefore chosen:

$$C_{in} = 0.2 \cdot C_{out}$$

Other components

Tentative relationships for the coarse fraction of the suspended particles, SO_4^{2-} (sulfate) on the coarse fraction and NO_3^- (nitrate) on the coarse fraction have also been established. These components were not included in the exposure calculations.

7 MODELLING OF GEOGRAPHIC DISTRIBUTION OF AIR POLLUTANTS

K.E. Grønskei, S.E. Walker and F. Gram

7.1 DESCRIPTION OF THE METHOD

The population of an area is exposed to a number of air pollution components that fluctuate in time and space. It is not possible to measure pollution concentrations in all places in the area. It is therefore necessary to use a combination of measurements and model calculations to describe the exposure to air pollutants for individuals.

Fluctuations in pollutant concentrations of several components are continuously measured at selected measuring stations in the area. Their location is chosen so that the measurements can be considered representative for large parts of the area. Model calculations are necessary, however, to describe concentrations between the measuring points. In this study, measurements were carried out at five measuring stations, and model calculations were performed in a grid of 16 x 23 km^2.

Emissions of pollutants from the different sources follow the wind field and are diluted as a result of turbulence and variations in wind conditions. Emissions can vary substantially in time. High concentrations occurring near large point sources possibly do not get measured at the stations. By combining measurements and dispersion model calculations, a better description of spatial concentrations in the area is achieved for estimating exposure.

Additional modelling was done for hourly pollution values on main roads in the area.

Each participant in the project registered his/her location in a diary on an hourly basis. These positions were coded by square kilometer. It was also registered when a person travelled through or stayed near a main road or street (see figure 7.1). The results of the modelling of the spatial distribution of air pollutants, together with information from each participants diary was used to calculate individual exposure (see chapter 8).

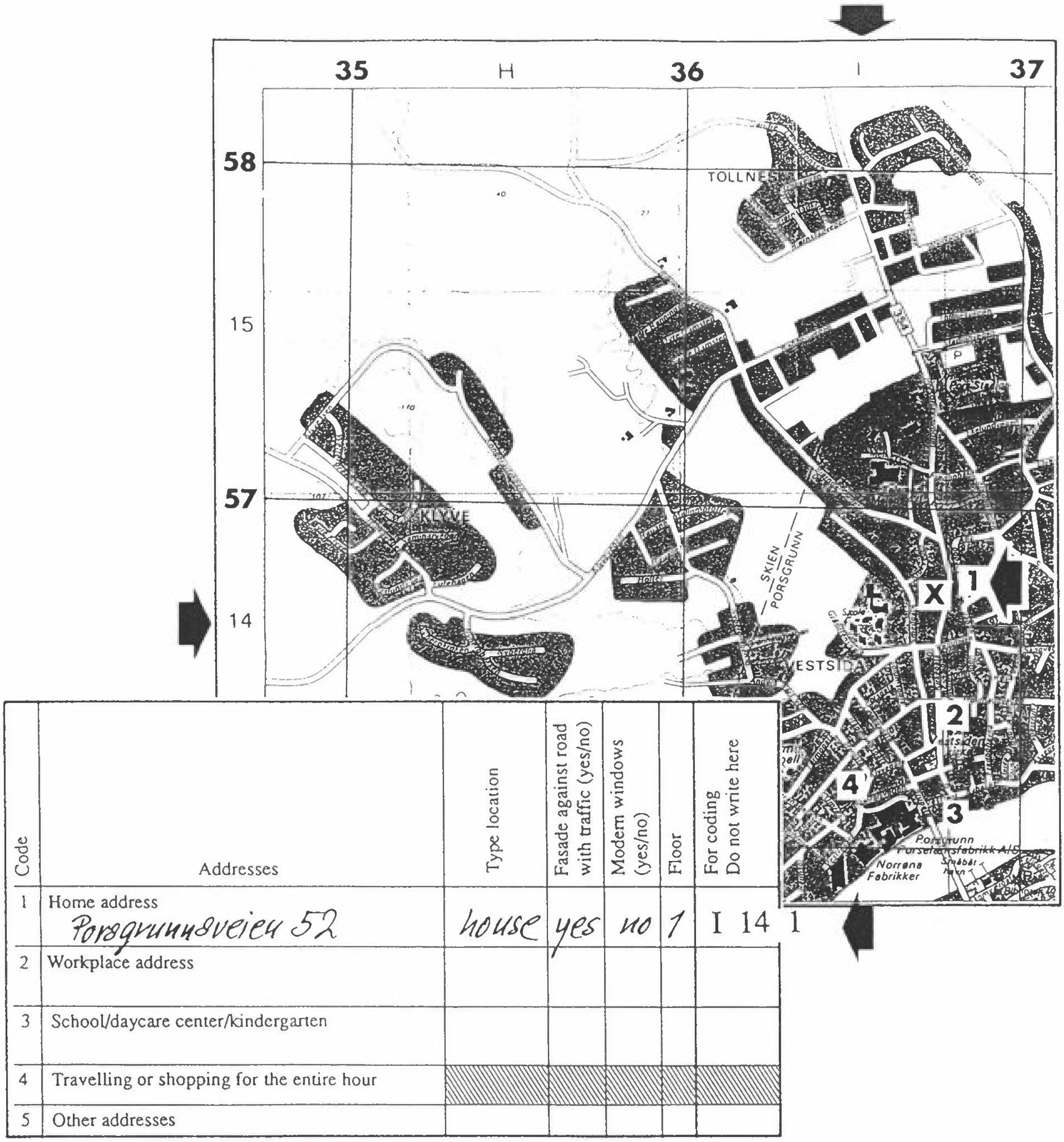
Measurements of wind, turbulence and emissions constitute the most important data for the description of spatial distribution of pollution components. The data are combined in a time dependent, mass consistent dispersion model. Average concentrations are calculated in each square km for three layers above the ground. By selecting the finite difference approximation of the time dependent dispersion model in the square kilometer system, emphasis is given to a mass consistent formulation. For a more detailed description of terms, see Glossary, Chapter 15.

As a result of numerical diffusion the extreme concentration values and gradients are not described in the finite difference approximation.

To account for subgrid gradients and concentration maxima of certain pollutants, a road/street model has been used to calculate concentrations along the main roads in the area on an hourly basis. Further, emissions from point sources are treated separately by a subgrid puff-model. Single puffs of pollution follow the air trajectories in the specified height and grow as a result of diffusion until the size of the puff is larger than half the side of the grid cell horizontally or vertically. The mass of pollution is then mixed into the grid cell where the puff is located.

Most of the puffs originate at elevated levels and do not contribute to ground level concentrations except in situations with high turbulence. Subgrid concentration distributions that should be accounted for as a result of low level point sources, include:

- SO_2-concentrations in the Skien area.
- Concentrations of nitrogen oxides and particles near the Herøya area in Porsgrunn.



Code	Addresses	Type location	Fasade against road with traffic (yes/no)	Modern windows (yes/no)	Floor	For coding Do not write here
1	Home address Porsgrunnsveien 52	house	yes	no	1	I 14 1
2	Workplace address					
3	School/daycare center/kindergarten					
4	Travelling or shopping for the entire hour					
5	Other addresses					

Figure 7.1: Example of coding system used to geographically situate each house.

Subgrid variations may also occur as a result of temporarily increased emissions in a neighbouring source. These subgrid fluctuations in space and time may be considered as a stochastic part of the concentration level to be used for exposure estimation.

The model validation shown in Chapter 7.4 indicates that the polluted zone close to roads should be described more accurately by a subgrid model. On the other hand, the level of detail of data required to improve these estimates would increase considerably.

In addition to lack of spatial resolution the following sources of error are considered in the presentation of results:

- error in input data (emissions and meteorological conditions)
- error in model description, in particular the description of vertical exchange in inversion situations.

7.2 DESCRIPTION OF THE CALCULATION METHOD

7.2.1 Contribution to concentration from local sources

To describe fluctuations in time and space as a result of local emissions, the advection-diffusion equation is solved with a horizontal grid distance of 1 km. The atmosphere close to the ground is divided into three layers to account for variations in emissions, wind and dispersion conditions. The three layers (0-50, 50-100, 100-200 m) are divided into 16 x 23 km^2. To cover the area of investigation, a mass consistent finite difference system of the following equations has been developed.

$$\frac{\partial C_i}{\partial t} = \underbrace{\vec{v}_h \cdot \nabla_h C_i}_{I} - \underbrace{w\frac{\partial C_i}{\partial z}}_{II} - \underbrace{\frac{\partial (w' C_i')}{\partial z}}_{III} - \underbrace{\nabla_h \cdot (\vec{v}_h' C_i')}_{IV} + \underbrace{R_i}_{V} + \underbrace{Q_i}_{VI}$$

Processes to be considered in the model are:

I horizontal advection, $\vec{v}_h \cdot \nabla_h C_i$

II vertical advection, $w\frac{\partial C_i}{\partial z}$

III turbulent exchange vertically

IV turbulent exchange horizontally

V chemical reactions (sinks or sources)

VI emission intensities.

- Horizontal advection is calculated using consecutive horizontal windfields based on statistical interpolation of hourly wind observations at four stations.

- Vertical advection is based on requirement of air movements free of three dimensional divergence.

- Vertical exchange between layers is estimated using SODAR measurements of vertical fluctuations in the wind field (σ_w) at the levels separating the model layers (50 m, 100 m, and 200 m). Further, the statistical turbulence theory is used to describe the exchange rate using Venkatram (1984) for the description of the scale of turbulence and the Lagrangian time scale.

- For the horizontal exchange process close to the source the method suggested by Irwin (1983) has been applied.

7.2.2 <u>The boundary conditions</u>

Using upwind finite difference approximation for dispersion calculations, concentration values where air moves into the area (background concentrations) have to be measured. Accumulated concentrations in the grid system determine the flux out of the area at the downwind boundary.

Measurements from the existing stations have been applied to estimate background concentrations. The estimation is based on an optimizing process giving weight to measurements from stations that are only slightly influenced by local sources (near the upwind boundary) and from stations far from concentration gradients.

The concentration in the air entering the region (background concentration) is assumed to be constant or approximately constant in space both horizontally and vertically. Here it is denoted by the symbol β.

The background concentration is estimated at a given hour as

$$\hat{\beta} = \sum_{k=1}^{n} w_k \ (O_k - M_k).$$

Here n denotes the number of measuring stations, w_k for k=1, ..., n are weights attached to the stations, and O_k and M_k are observed and calculated concentrations based on data for emissions and dispersion at station k for k=1, ..., n.

Since the background concentration is an additive part of the concentration level in the area, differences between observed values O_k and calculated values M_k should convey information about the background concentration β. Ideally, for error-free data, the difference $O_k - M_k$ should equal β for all k=1 ... n.

The weights are introduced in order to give more weight to stations which are considered suited for estimating background concentrations.

The statistical model is based on defining and calculating variances V_k for each station k:

$$V_k = \sigma_{\varepsilon_k}^2 + M_k^2 \ \sigma_{Q_k}^2 + (1+\sigma_{Q_k}^2) \ ||\nabla M_k||^2 \ \sigma_{\Delta_k}^2$$

At station k, σ_{ε_k} denotes measurement noise, σ_{Q_k} uncertainty associated with the concentration level of the field, and σ_{Δ_k} spatial uncertainty in the position of the concentration field. Further, the quantity $||\nabla M_k||$ denotes the norm of the gradient vector of the calculated concentration field at station k.

The weights w_k are then chosen to minimize the total variance in the background predictor $\hat{\beta}$. It can be shown that optimal weights are inversely proportional to the V_k values i.e.,

$$w_k^* = V_k^{-1} / \sum_{i=1}^{n} V_i^{-1}.$$

The weights are here scaled in order to sum to 1. This makes the predictor $\hat{\beta}$ approximately unbiased as a predictor for the background concentration β.

This method is used to estimate background concentrations for the three components NO_x, SO_2, and suspended particles with a diameter less than 2.5 µm ($PM_{2.5}$). For NO_x and SO_2 values, the four stations Klyve, Nenset, Frednes, and Ås were used, while for $PM_{2.5}$ values, stations Klyve, Nenset, and Ås were used.

Data from station Georg Stangs gt. in Skien were not used in this estimation procedure, since concentrations were largely influenced by nearby industrial sources.

7.2.3 Correction of concentration distribution based on hourly measurements

The deviation between observed and calculated concentration values may be accounted for by the following groups of errors:

1 Errors as a result of input data on an hourly basis.

1.1 Sources outside the area
1.2 Emissions from single sources
1.3 Emissions from area sources
1.4 Horizontal wind field
1.5 Vertical exchange parameters

2 Errors as a result of dispersion model formulation

2.1 Subgrid distributions
2.2 Description of vertical exchange

These errors influence the calculated distributions in different ways. Errors as a result of sources outside the area are corrected for by adding a spatial homogeneous concentration value to all grid points in the area.

Errors that result from horizontal meandering are accounted for by the introduction of a spatial uncertainty in the results of dispersion calculations that cannot be corrected for by statistical interpolation procedures. Further, it is assumed that the main features of the concentration distribution based on dispersion calculations are preserved in the observed values. However, errors in emission intensity of the area sources and in the vertical exchange process influence the actual concentration values. This may be corrected for by a factor of proportionality. When the factor of proportionality varies in space, nonhomogeneous effects of the errors are taken into account.

The correction of the dispersion calculation is first based on the following equation:

$$\Delta c(x,y) = \sum_{k=1}^{n} W_k(x,y) \ln (O_k'/M_k')$$

Here n denotes the number of measuring stations, $W_k(x,y)$ is the weight attached to station k for gridpoint (x,y) and O_k' and M_k' are derived from observed and model calculated values for station k as follows:

$$O_k' = \max (O_k - \beta, 5)$$
$$M_k' = \max (M_k, 5)$$

The value M_k is here determined as the best fit concentration within 1 km distance from the station k (matching), where β is background concentration.

It is in order to prevent meaningless low or large values in the logarithmic difference, that the observed and model-calculated values are here replaced by modified values.

The weights are calculated based on an ordinary kriging procedure. The spatial correlation function is based on an exponential form with integral scale equal to 2 km.

The weights are computed independent of time.

The actual correction of the dispersion calculation is finally based on the following formula

$$\hat{M}(x,y) = M(x,y) \exp(\Delta c(x,y))$$

From this formula it follows that the updated values $\hat{M}(x,y)$ will be equal to the observed values at the measuring stations k=1 ... n. For gridpoints far away from the stations the multiplicative factor will be approximately the average of the individual ratios for each station. Thus, locally the corrected field will correspond to the observed concentrations, and a scaling of the concentration distribution will be preserved in the correction procedure.

Correction of the dispersion calculations is based on multiplication of concentration values with factors which are all non-negative and which vary about unity. Since the factors are all non-negative, the corrected field $\hat{M}(x,y)$ will also be non-negative.

Close to a station the adjusted concentration distribution will correspond to the observed value. Far from the stations, the geometric average ratio between observed and calculated values is applied as a correction factor. Thus, the local corrections will correspond to the observed concentrations, and the scaling of concentration distribution would be retained during the correction procedure.

This final correction method is used to correct the dispersion calculation for the components NO_x, SO_2, and $PM_{2.5}$. For NO_x and SO_2 the five stations Klyve, Georg Stangs gt., Nenset, Frednes, and Ås were used, while for $PM_{2.5}$ data for the three stations Klyve, Nenset and Ås were used.

7.3 ESTIMATED CONCENTRATIONS IN THE AIR ENTERING THE REGION (BACKGROUND CONCENTRATIONS)

Figure 7.2 shows estimated hourly variation in the background concentration for components SO_2 and $PM_{2.5}$. The figure shows fairly good agreement between concentrations of these components. Maxima in concentration values indicate episodes of long-range transport of pollution including SO_2 and particles simultaneously. The computations are based on separate series of measurements.

In the summer season, there were two predominant periods with high concentration of fine particles ($PM_{2.5}$) between 30 April-3 May 1988 and again between 25 May-28 May 1988. These two periods were characterized by high values of sulfate (SO_4^{2-}) at the stations Klyve and Ås. Measurements in the background area (station Birkenes) indicate that these concentrations mainly originate from sources outside the area also during the summer period.

7.4 RESULTS AND MODEL VALIDATION

Model evaluation has been performed using parameters recommended in U.S. EPA Guidelines (US EPA 1981, 1984). Also results of Willmott (1982) were taken into account.

The basis of the model evaluation is the comparison of observed and model-calculated hourly values of concentration at the measuring stations in the area.

For the components NO_x and SO_2 there are five measuring stations, Klyve, Georg Stangs gt., Nenset, Frednes, and Ås. For each station and for each period (winter: 3 January-15 March, summer: 18 April-24 June) we have computed several model evaluation parameters.

Figures 7.3 and 7.4 visually present results of the calculations for the entire area by km grid. Figure 7.3 shows the values for four components (O_3, suspended particles, NO_2 and

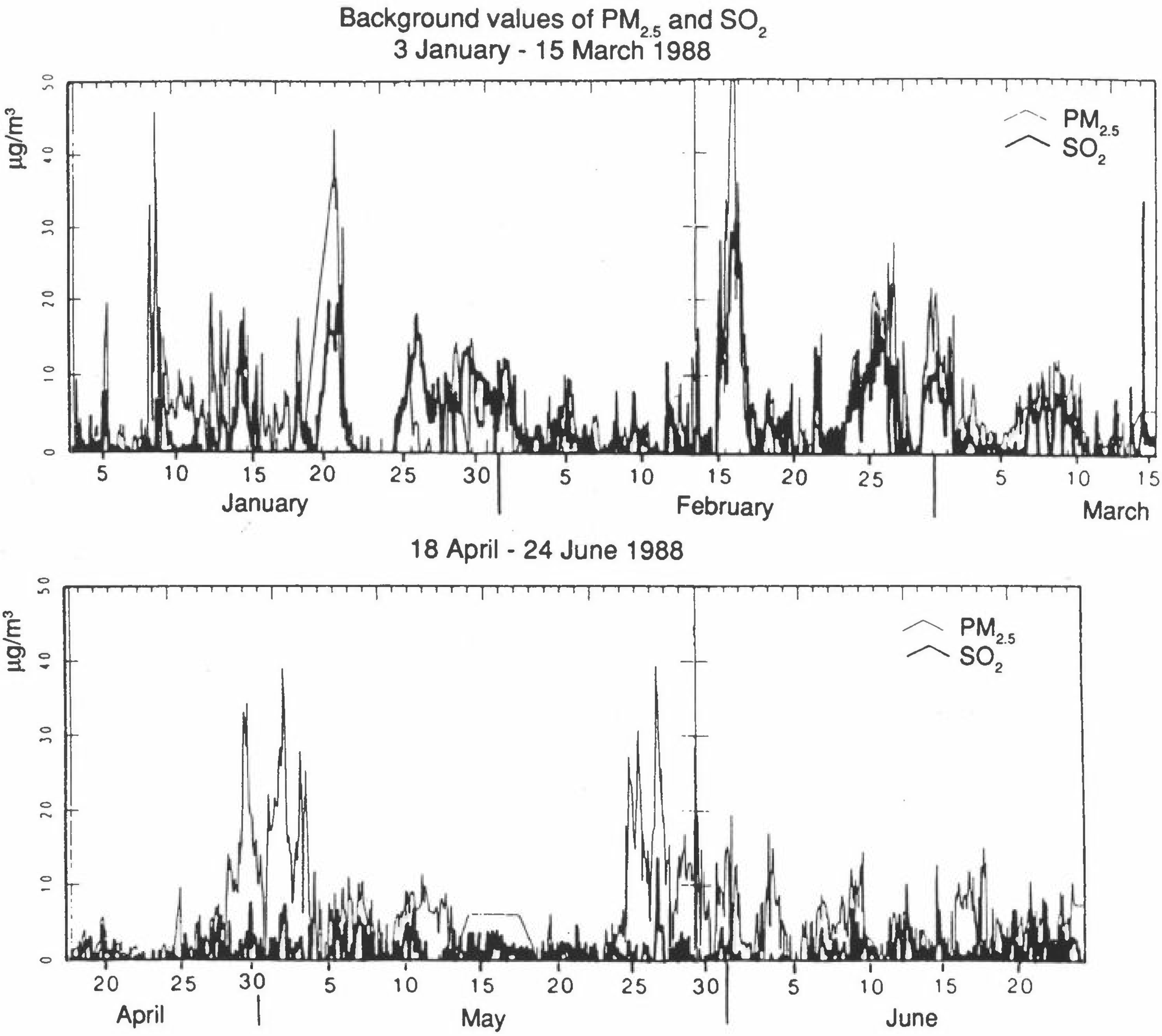


Figure 7.2: Hourly background concentrations of SO_2 and $PM_{2.5}$ in the air entering Grenland during the winter period 3 January-15 March 1988 (a) and during the summer period 18 April-24 June, 1988 (b).

SO_2) at 0100 9 March, 1988, and Figure 7.4 shows calculations for NO_x from 0600 to 1200, 8 January 1988 (every second hour).

7.4.1 Model validation for NO_x

Table 7.1 shows results of model validation for NO_x. For the five measuring stations, the mean calculated concentration of NO_x (P+B) is a result of adding the background concentration (B) to the model result (P). Then, the spatial uncertainty is taken into account by comparing the measured values to the closest concentration calculated within a range of one kilometer from the measuring stations. Through this matching procedure, the value P+B+M in Table 7.1 is obtained.

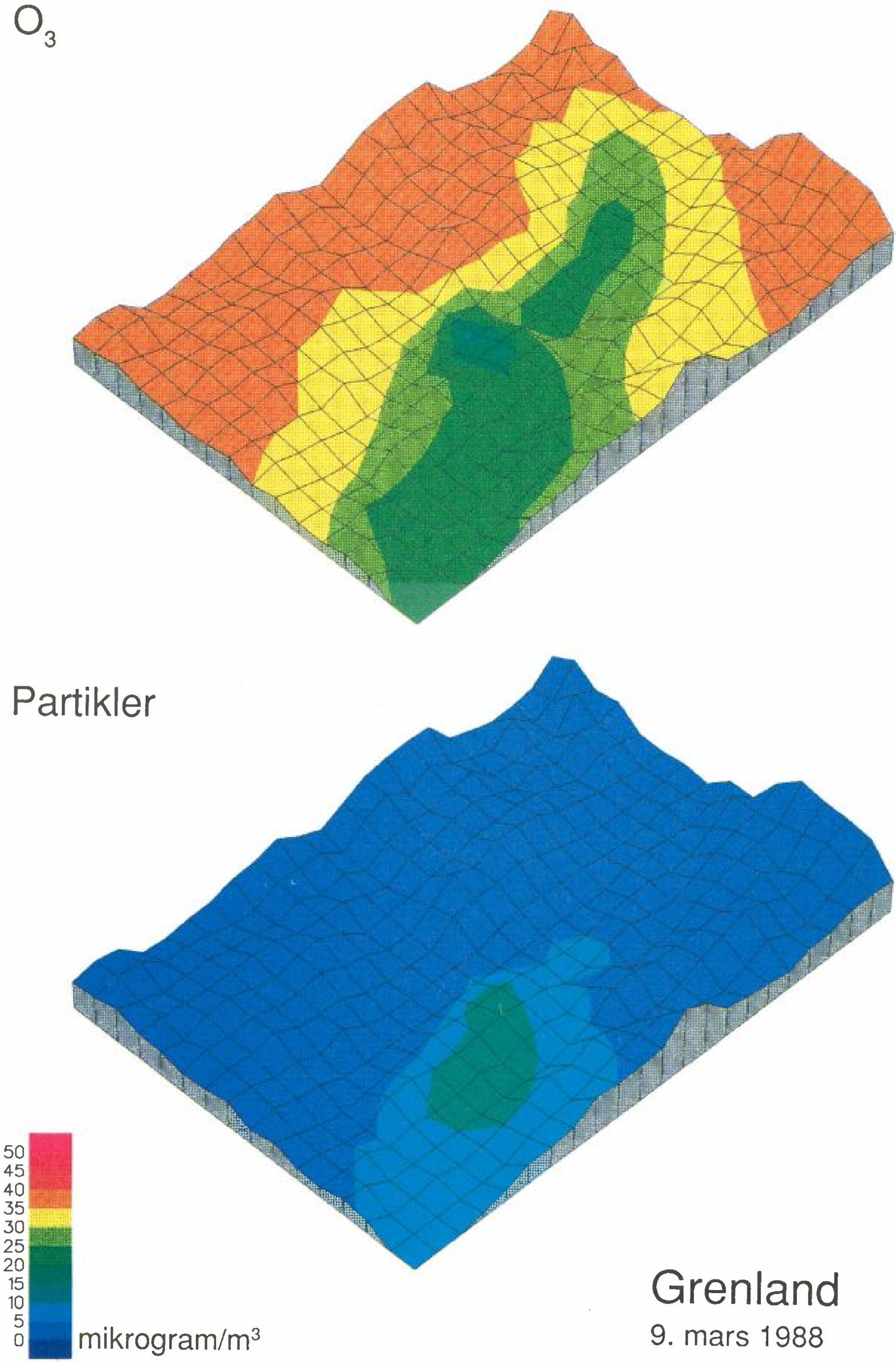
The model calculations are finally corrected by the measured concentrations. The correction is based on interpolation of the difference between the measured and calculated values, and is described in more detail in Grønskei et al. (1990).

Results in Table 7.1 show that the observed values of NO_x are in agreement with the average calculated values at station Klyve. At Ås, during situations with wind from the north, the calculated values are often higher than the observed ones.

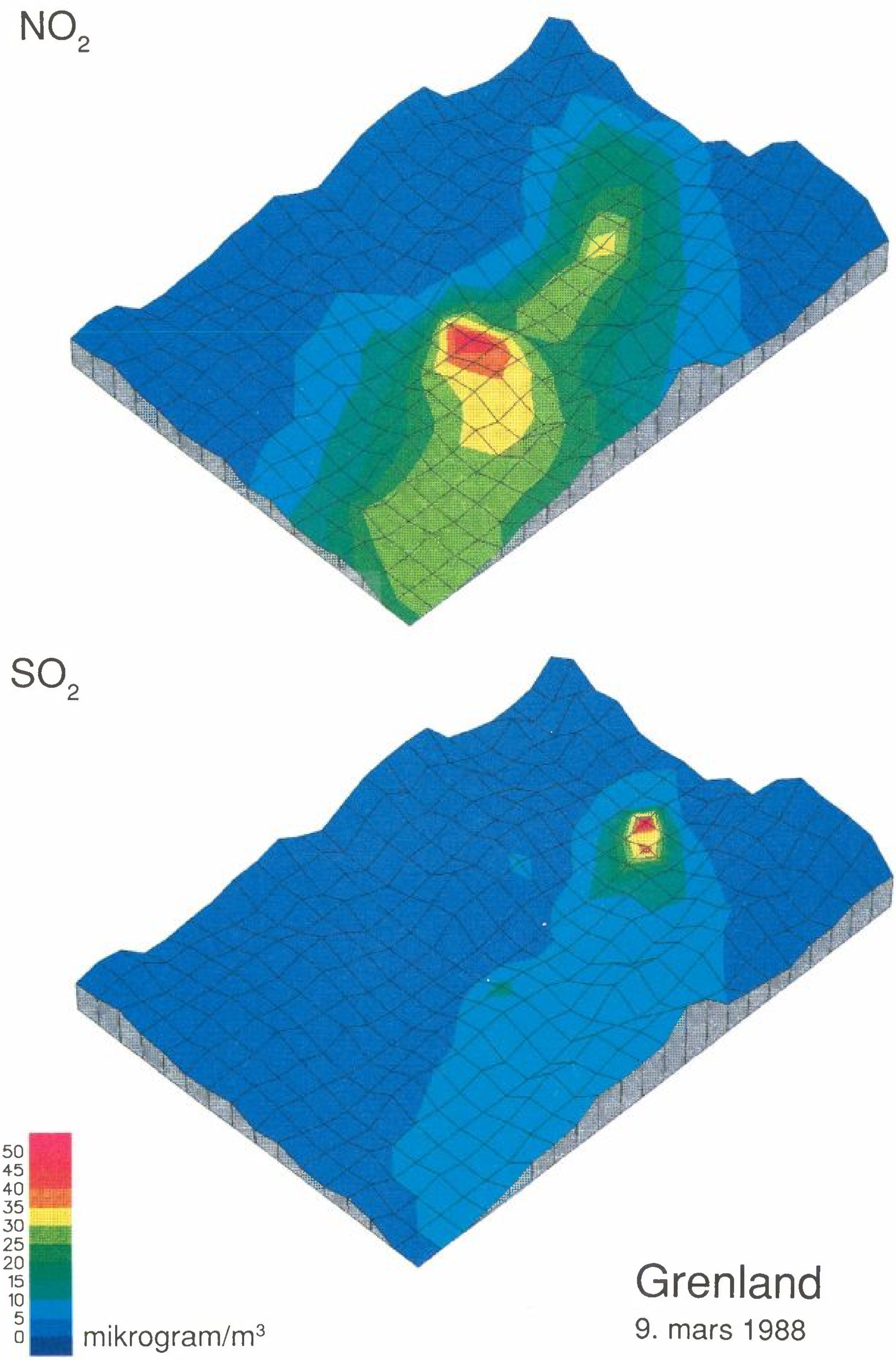
At the stations Nenset and Frednes, the observed values are often above those calculated. When the wind blows from nearby roads with high traffic, the observed concentrations become higher than calculated. This effect of subgrid concentration distribution is partly compensated for by taking into account a pollution contribution on the main roads. Dispersion calculations could be improved by considering the decay in pollution contribution with downwind distance from the road. In our calculations the hour to hour spatial average concentration

Figure 7.3: Estimated concentration of O_3, suspended particles, NO_2 and SO_2 at 0100 hrs 9 March 1988 for the entire investigation area. The concentrations are superimposed on a relief (3-D) map with the km grid system. For technical reasons the figure is printed in Norwegian.

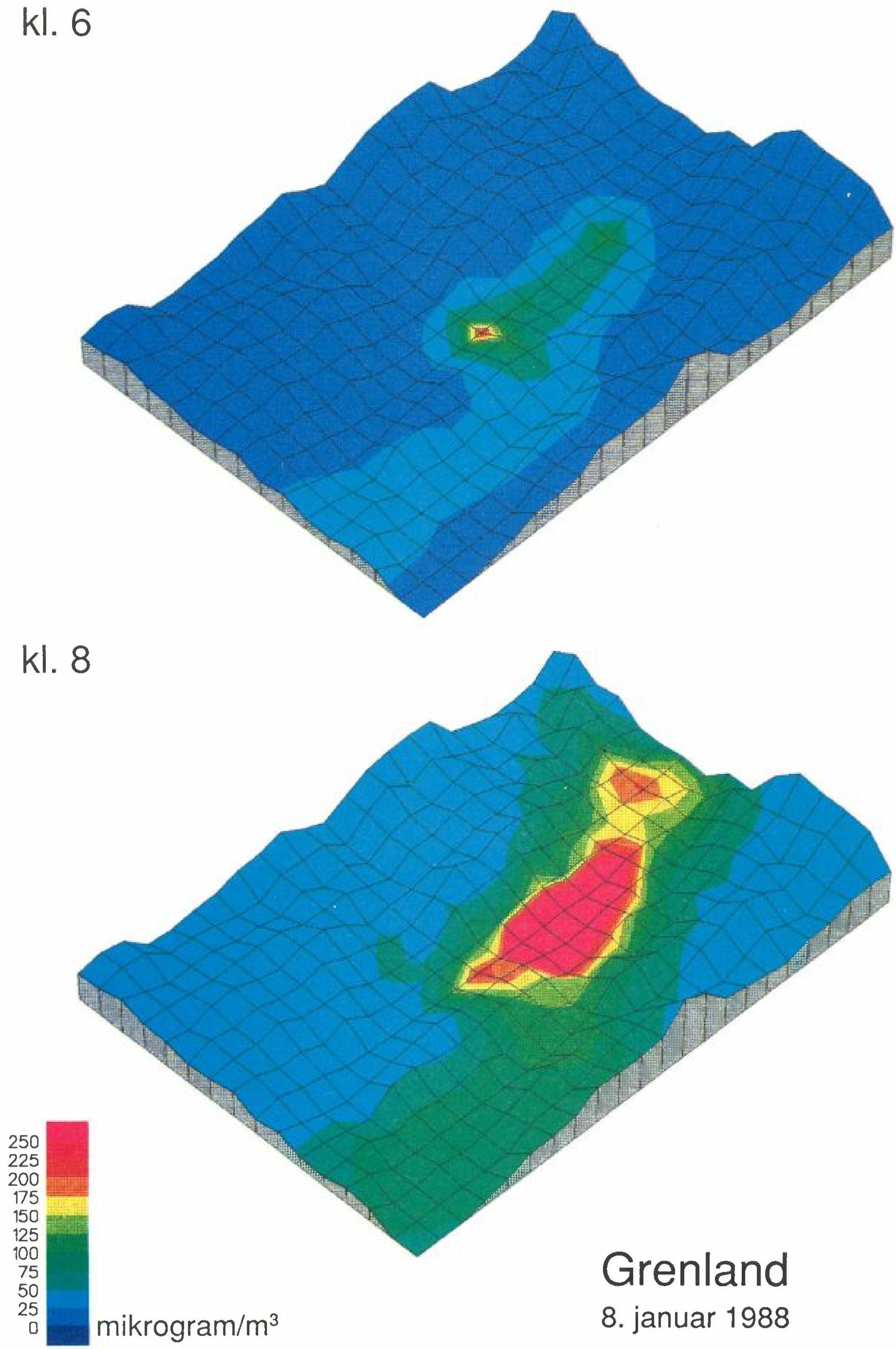
Figure 7.4: Estimated concentration of NO_x from 0600 to 1200, 8 January 1988 for the entire investigation area. The concentrations are superimposed on a relief (3-D) map with the km grid system. For technical reasons the figure is printed in Norwegian.



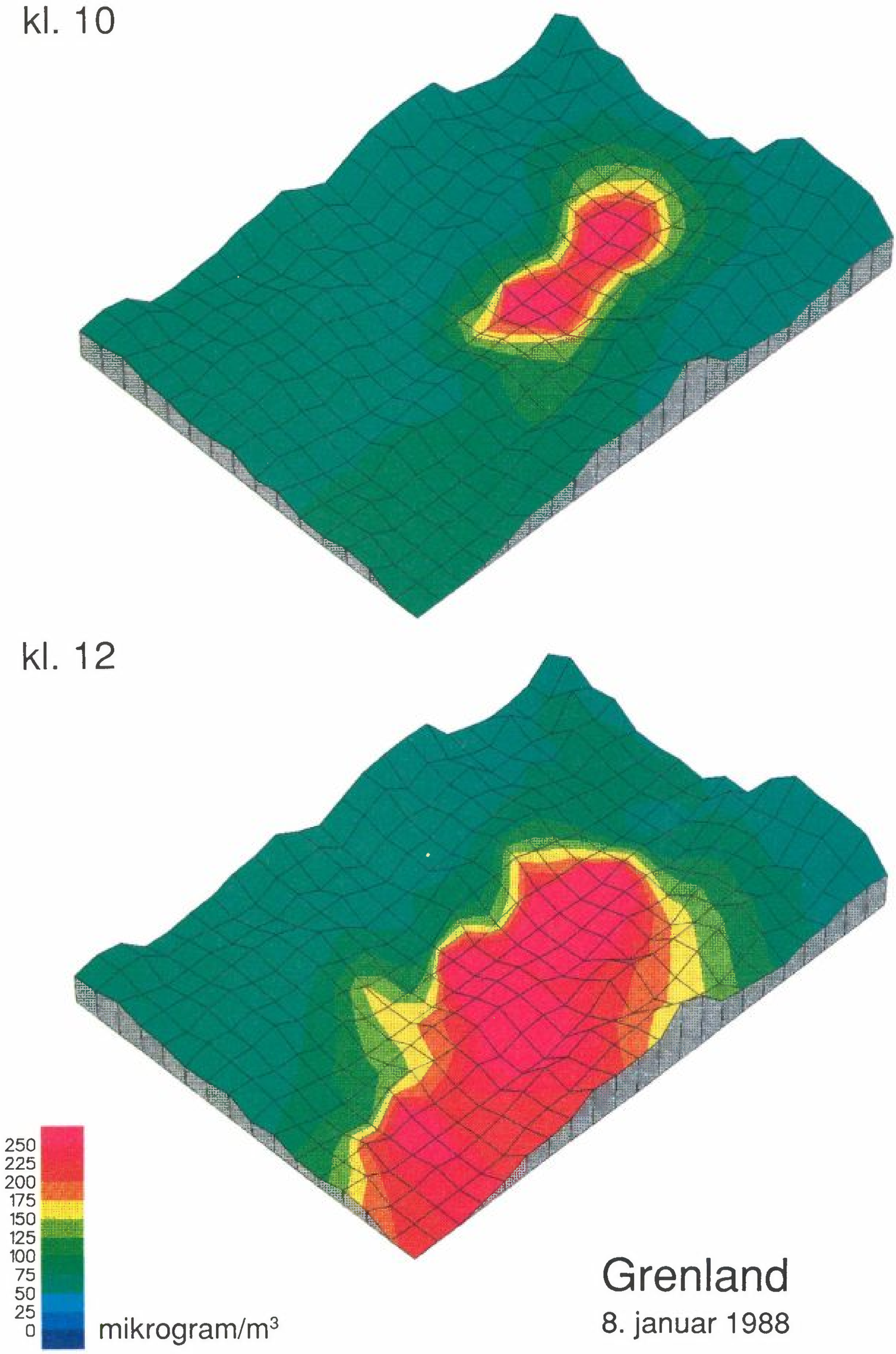
Figur 7.3.a: Konsentrasjonsfordeling av O_3 og partikler 9. mars 1988 kl 0100.



Figur 7.3.b: Konsentrasjonsfordeling av NO_2 og SO_2 9. mars 1988 kl 0100.



Figur 7.4: Konsentrasjonsfordeling av NO_x 8. januar 1988 kl 6, 8, 10, 12.



Figur 7.4: forts.

Table 7.1: Model validation for NO_x.
Period: 3 January-15 March 1988.

Station		Klyve			Georg Stangs street		
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	24.1	21.3	26.8	38.2	38.5	38.4
SDev	"	30.1	30.2	30.0	49.1	48.9	41.5
NMD	"		0.12	-0.11		-0.007	-0.003
RMSE	"		28.3	13.5		41.3	25.9
$RMSE_s$	"		13.4	4.1		17.6	13.8
$RMSE_u$	"		24.9	12.9		37.4	21.9
Corr	"		0.57	0.90		0.65	0.85
IA	"		0.74	0.95		0.79	0.91
Station		Nenset			Frednes		
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	61.9	40.6	44.1	73.4	44.1	57.5
SDev	"	89.9	51.0	29.4	95.5	57.7	64.9
NMD	"		0.34	0.29		0.40	0.22
RMSE	"		73.7	60.6		84.5	56.5
$RMSE_s$	"		61.9	53.0		69.7	44.1
$RMSE_u$	"		39.9	29.4		47.8	35.4
Corr	"		0.62	0.81		0.56	0.84
IA	"		0.69	0.80		0.67	0.87
Station		Ås					
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	24.4	29.6	33.8			
SDev	"	30.4	38.5	34.7			
NMD	"		-0.21	-0.38			
RMSE	"		38.6	26.3			
$RMSE_s$	"		15.7	10.8			
$RMSE_u$	"		35.2	24.0			
Corr	"		0.40	0.72			
IA	"		0.61	0.82			

O: Mean observed NO_x concentration.
P: Mean concentration value based on dispersion calculations.
P+M+B: Calculated concentration value based on contribution from NO_x concentration in the air entering the area, contribution from local sources and taking into account spatial uncertainties in the local pollution concentration.
NMD: Normalized mean difference.
RMSE: Root mean square error (systematic and unsystematic).
IA: Index of agreement.
Corr: Correlation coefficient.

value is considered within each square km. This subgrid error is not accounted for by the spatial uncertainty model. The index of agreement and correlation between hourly observed and calculated values of NO_x show good correspondence at all stations, better than for SO_2 and particles.

Results of dispersion calculation may be further used to describe the contribution of pollution from different groups of sources.

7.4.2 Model validation for particles ($PM_{2.5}$)

The mean value in the winter period is slightly overestimated at Klyve and Ås, and slightly underestimated at Georg Stangs gate. The standard deviation in the hourly fluctuations is seriously overestimated at the stations Klyve and Ås. The error is probably due to estimation of emission and dispersion of particles from the Herøya area. In general, the differences between the calculated and measured values seem acceptable when spatial uncertainty is taken into account.

Table 7.2 shows results of the validation of the model description of hourly concentration distribution for particles.

7.4.3 Model validation for SO_2

Table 7.3 shows results of model validation at the different stations.

Poor correlation between observed and calculated hourly fluctuations was found at all stations. This correlation was improved considerably, when hourly background concentrations were taken into account and further when allowance for spatial uncertainty was made.

The SO_2-calculation remained, however, uncertain. The emission intensities of some low level sources are poorly known in the Skien area. In the Porsgrunn area, SO_2 may react with other pollution components coming from the Herøya region.

Table 7.2: Model validation for particles ($PM_{2.5}$). Period: 3 January-15 March 1988.

Station		Klyve			Georg Stangs gate		
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	11.4	14.0	14.6	14.7	12.0	14.4
SDev	"	12.0	23.9	14.9	13.0	12.6	11.3
NMD	"		-0.225	-0.282		0.18	0.117
RMSE	"		23.0	10.4		14.9	7.9
$RMSE_s$	"		4.7	3.3		9.1	4.0
$RMSE_u$	"		22.5	9.8		11.9	6.8
Corr	"		0.34	0.75		0.34	0.80
IA	"		0.47	0.84		0.59	0.89
Station		Ås					
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	13.7	14.9	16.3			
SDev	"	11.4	23.7	14.4			
NMD	"		-0.04	-0.19			
RMSE	"		25.1	11.6			
$RMSE_s$	"		8.7	3.4			
$RMSE_u$	"		8.7	11.1			
Corr	"		0.12	0.64			
IA	"		0.33	0.78			

O: Mean observed $PM_{2.5}$ concentration.

P: Mean concentration value based on dispersion calculations.

P+M+B: Calculated concentration value based on contribution from PM 2.5 concentration in the air entering the area, contribution from local sources and taking into account spatial uncertainties in the local pollution concentration.

NMD: Normalized mean difference.

RMSE: Root mean square error (systematic and unsystematic).

IA: Index of agreement.

Corr: Correlation coefficient.

Table 7.3: Model validation for SO_2.
Period 3 January-15 March 1988.

Station		Klyve			Georg Stangs gate		
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	11.6	6.5	11.6	26.0	15.2	17.8
SDev	"	17.7	9.1	7.3	44.5	25.8	16.2
NMD	"		0.44	0.13		0.42	0.32
RMSE	"		20.1	15.7		51.0	40.0
$RMSE_s$	"		17.9	14.3		25.8	14.1
$RMSE_u$	"		9.1	6.5		25.8	14.1
Corr	"		0.057	0.47		0.07	0.50
IA	"		0.25	0.51		0.28	0.50
Station		Nenset			Frednes		
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	13.8	11.1	12.5	9.9	11.6	10.5
SDev	"	16.7	15.8	9.7	12.4	16.1	8.9
NMD	"		0.20	0.09		-0.17	-0.06
RMSE	"		22.2	14.4		18.3	8.9
$RMSE_s$	"		15.6	11.8		9.3	6.2
$RMSE_u$	"		15.8	8.3		15.8	6.4
Corr	"		0.08	0.52		0.20	0.69
IA	"		0.33	0.64		0.42	0.80
Station		Ås					
Parameter	Unit	O	P	P+B+M	O	P	P+B+M
Mean	$\mu g/m^3$	6.9	5.3	7.5			
SDev	"	7.3	9.2	7.0			
NMD	"		0.23	-0.09			
RMSE	"		11.7	5.2			
$RMSE_s$	"		7.3	2.3			
$RMSE_u$	"		9.2	4.8			
Corr	"		0.03	0.73			
IA	"		0.35	0.85			

O: Mean observed SO_2 concentration.
P: Mean concentration value based on dispersion calculations.
P+M+B: Calculated concentration value based on contribution from SO_2 concentration in the air entering the area, contribution from local sources and taking into account spatial uncertainties in the local pollution concentration.
NMD: Normalized mean difference.
RMSE: Root mean square error (systematic and unsystematic).
IA: Index of agreement.
Corr: Correlation coefficient.

7.4.4 Summary

To evaluate subgrid concentration variations, a list of concentrations along all segments of the main roads in the area is given for each hour. Further, positions of high concentrations downwind of the dominant point sources were registered.

The spatial distribution of hourly dispersion calculations based on local emissions is corrected by adding a background concentration value to all grid point values. This distribution is taken into account when the final corrections are made using the hourly measurements at the five stations.

The dispersion calculations of hourly mean values are performed in a square km grid and corrected using measurements at stations located outside the most polluted area. Therefore, it is likely that the hourly maximum concentrations occurring in the area of calculation are not detected. These maxima are likely to be found in the Skien area or close to the Herøya area. The areas close to roads with high traffic intensities may further be exposed to high vehicle exhaust pollution that is not reflected in the calculated values except on the roads themselves.

7.5 SULFATE, NITRATE AND OZONE CONCENTRATIONS AND CHEMICAL REACTIONS IN THE AIR IN GRENLAND

The area of investigation is characterized by emission of a complex mixture of pollution components. Some of them may interact producing secondary pollution components. Considering chemical reactions in the air downwind of the Herøya area, sulfates, nitrates and chlorides may develop as a part of the industrial haze formation. Sulfates and nitrates are also present in long-range transport episodes. In this study it was not feasible to include a detailed description of the local development of these secondary components.

- the location of the participants in the health investigation
- the location of the main sources to air pollution in the area
- discrimination of contribution from different groups of sources.

In addition to measuring the primary components, hourly measurements were performed to specify the hourly variation in the concentration of particles at three stations, and of the ozone concentration at two stations.

The SO_2-concentrations are of primary importance in the Skien area due to industrial emissions. Several groups of sources contribute to the air pollution of nitrogen oxides. The highest concentrations are observed along roads with high traffic intensity, and for short periods in locations downwind of point sources. The maxima downwind of point sources meander with variation in wind directions. In the Skien area and close to the Herøya area gradients of concentrations both in space and time may be of primary importance for the description of concentration exposure.

Data on hourly emission intensity of SO_2, NO_x, and fine fraction of particles have been collected for all groups of sources in the area. Hourly data on emissions and dispersion have further been used for dispersion calculations of hourly concentration values in km^2-grid system.

The primary components have many groups of sources. Further, the Herøya area should be considered separately since a large number of pollution components may originate here. Of these components, chlorine, ammonia, and nitrous aerosols should be mentioned. These components enter into complex chemical reaction with the primary components and may develop haze with different degrees of acidity. These reactions have not been considered in this project (Gram et al., 1990).

Existing measurements of 12 hour average concentrations were used as input to the interpolation procedure for developing spatial concentration distribution at ground level.

Ozone occurs in the area mainly as a result of advection from other areas (background concentration). The ozone oxidizes NO-pollution from local emissions to form NO_2:

$$(NO + O_3 \rightarrow NO_2 + O_2).$$

As a consequence the ozone concentration is reduced. Ozone was measured at two stations in the area, and the maximum observed value was considered to give a good estimate of background ozone concentration. The chemical reaction in the Grenland area is described in two steps:

1. Hourly NO_2-concentration is calculated assuming local emissions of NO to be transformed to NO_2 as long as ozone is present. Far from local sources the equation for photochemical balance was applied to determine the ratio between NO_2 and NO_x concentrations.

2. Observed NO_2 concentrations from four stations were used to correct the calculated NO_2 distribution.

7.6 APPLICATION OF HOURLY CONCENTRATIONS IN FURTHER EXPOSURE ESTIMATION

Hourly concentration values measured at 5 stations for NO_x, NO_2, and SO_2 are used as primary data for describing time variation in air quality throughout the area of investigation.

Selection of locations of measuring stations was based on

- avoidance of contribution from sources close to the measuring station

Calculated hourly concentrations of chlorine based on meteorological data and on monthly average emission data may be used as an indicator of areas influenced by the Herøya plumes.

Emission of chlorine contributes to the oxidation of SO_2 to sulfate and may also contribute to local development of ozone, normally of minor importance compared with background ozone values. Background values of ozone affect the chemical transformation of NO to NO_2, reducing the ozone concentration and increasing the NO_2 concentration. This is taken into account calculating hourly NO_2 values.

The hourly concentration distributions throughout the area have been determined by dispersion calculations, corrected by statistical interpolation to adjust the distribution locally to the measured concentration values at five stations.

Fluctuations in the concentration field as a result of hourly variations in emissions and dispersion or as a result of subgrid concentration distribution may cause errors in the calculated concentration field. The possibility of errors varies throughout the area. The maximum errors may be found in urban areas, in particular close to principal sources. The concentration variation in the nine neighbouring km^2-areas can be used as a measure of spatial uncertainty in the km^2-model. Further, the maximum street/road concentration and the mean puff concentration in each km^2, may be used as an expression of possible subgrid variations in concentration.

A clear conclusion on the applicability of data for exposure calculation may not be possible. However, the following remarks should be accounted for in the further use of concentration data:

- The total variability in the calculated and in the measured hourly concentrations is in agreement at all stations for nitrogen oxides, particles and sulfur dioxide.

- Observed signals in the time variation of concentrations are reproduced well by dispersion calculations for NO_x and reasonably well for particles.

- For SO_2 it is necessary to include a spatial uncertainty to reproduce observed signals on the different stations. In addition, some signals for SO_2 are not reproduced.

- The measured values at four stations are used to correct the calculated concentration distribution to obtain the distribution for exposure calculations. The method of correction is developed that preserves the structure of the pollution cloud determined by dispersion calculations and that corresponds with hourly observations at four stations.

- Pollution concentrations on a regional scale are advected through the area of investigation. This contribution is taken well into account by emphasizing measurements from stations influenced to a minor extent by local emissions.

- The dominant part of the sulfate and nitrate concentrations occurs as a result of long-range transport into the area and the spatial distribution is based on interpolation of measured values.

- The zones influenced by emissions from the Herøya area may experience elevated concentrations of sulfate, chloride and nitrate as a result of haze formation due to local emissions. On an hourly basis these areas are indicated by the calculated values of chlorine.

- The increased concentrations along the main roads resulting from exhaust emissions are taken into account by using hourly data on wind and traffic intensity.

To improve the description, priority should be given to subgrid modelling and improved emission data for the important sources.

The information derived from dispersion models (despite the recognized errors) should be used to extrapolate measured concentrations to areas beyond the measuring stations. We feel that this combination of modelling and measurements represents a large improvement to methods currently used in epidemiology when estimating exposure.

8 DESCRIPTION OF THE INDIVIDUAL AIR POLLUTION EXPOSURE ESTIMATES

J. Clench-Aas, A. Bartonova, A. Harstad, M. Johnsrud Aarnes

An individual's exposure to a contaminant is related to its concentration in the micro-environment that he/she is in at the moment. For example, the exposure is dependent on whether that geographical area is in proximity of heavy traffic or whether the individual is indoors or outdoors, travelling or shopping. Therefore, a micro-environment can be a city sidewalk, out in the woods, indoors at home, indoors at work, at a lunchroom, at work, in a restaurant or at the movies, etc. Without doubt the best method of measuring exposure is by the use of personal monitors, especially when people move from place to place. However, this is impractical when several compounds are being studied simultaneously. In addition, it is uncertain how much people change their routines when they have to carry some of the larger portable units. It can therefore be more practical to use computer models based upon data from diaries to estimate each individual's exposure to each pollutant for each prescribed time span. In this study, it was decided to use one hour as the unit of time. With this time resolution, it is possible to reflect major changes in micro-environments without requiring a diary that is impossible for people to fill out.

8.1 DESCRIPTION OF THE MODEL DESIGNED TO ESTIMATE INDIVIDUAL EXPOSURE

The major elements of an air concentration exposure model are:

- geographic location;
- proximity to traffic;
- being indoors or outdoors;
- shopping;
- travelling.

These elements are incorporated in a computer model that is briefly summarized in Figure 8.1 and Table 8.1.

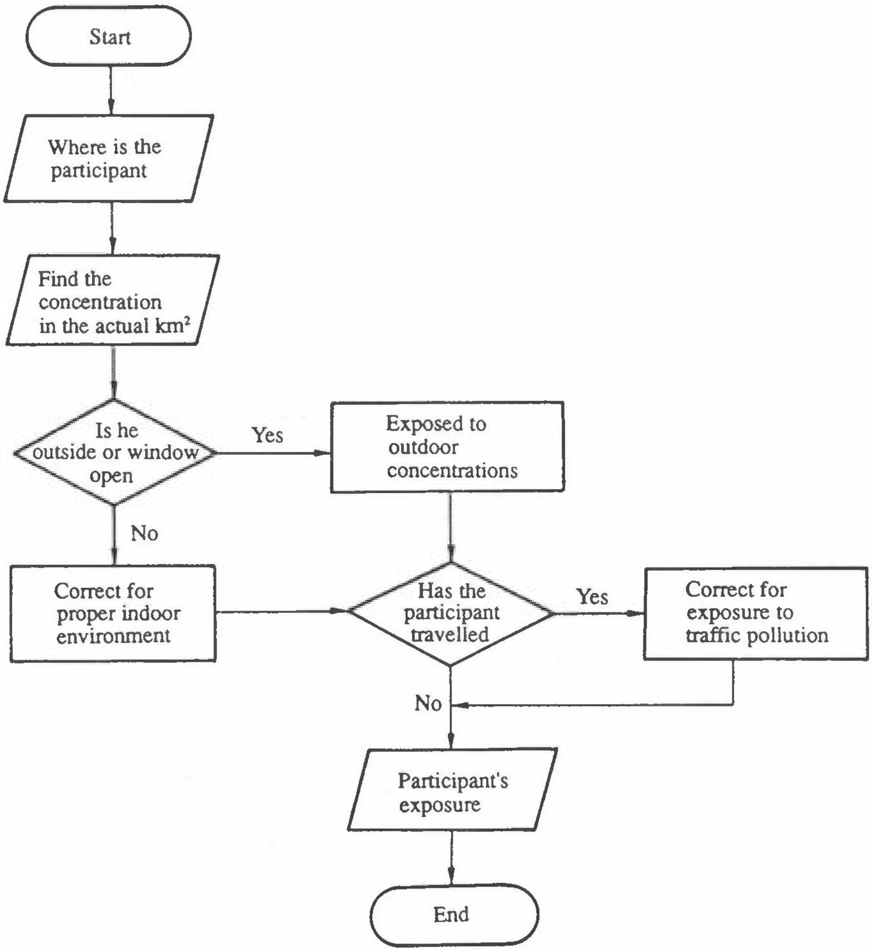


Figure 8.1: Overview of the program for estimation of each participants exposure, based on information from the diary.

Table 8.1: Factors included in calculating exposure to air pollution compounds and to meteorological parameters.

Compound	Outdoor value unchanged if window open	Outdoor value altered if window closed	Indoor Air Factor Accounted for: Season	Time of day	Home with asthmatic living there	Smoking in home	Factor to* Account for Extra Pollution from Traffic	Factor to Account for Active/ Passive Smoking
POLLUTANTS								
SO_2	Y	Y	N	N	N	N	N	N
NO_2	Y	Y	Y	Y	Y	N	Y	N
NO	Y	Y	Y	Y	Y	N	Y	N
O_3	Y	Y	N	N	N	N	Y**	N
Particles	Y	Y	Y	Y	N	Y	Y	Y
CO	Y	Y	N	N	N	N	Y	N
Cl_2	Y	Y					N	N
Nitrate	Y	Y	Y	Y	Y	N	N	N
Sulfate	Y	Y	Y	Y	Y	N	N	N
Pollen	Y	Y	NA	N	N	N	N	N
METEOROLOGICAL PARAMETERS								
Temperature	N	Y	N	N	N	N	N	N
Humidity	N	Y	N***	N	N	N	N	N

* Only for those who live in the central parts of the two towns.
**Value of ozone reduced to zero when NO_2 concentrations are high.
***Algorithm used differed according to ambient humidity.
NA = Not Applicable, Y = Yes, N = No.

Each person was asked to fill out a daily diary hour for hour as indicated in Figure 2.1. The entire Grenland area was divided into a one square kilometer grid system. Each address was coded to the nearest km^2, indicating at the same time proximity to a major road.

Each person was to indicate how many minutes he/she was shopping either in Skien or Porsgrunn (the two major towns in the area) or other places. Skien has a shopping area that is essentially free of traffic, whereas Porsgrunn is crossed by a major road. Therefore, in Skien, an average of the squares that represent the shopping area was used. For shopping in Porsgrunn, an average of the km^2 in downtown Porsgrunn were used, plus an additional factor for vehicular traffic.

One of the major pollution sources that contributes to exposure is traffic. Therefore, it is necessary to know when people are travelling and how much traffic they are encountering. The participants were asked to indicate how many minutes they were travelling in dense, medium or little traffic.

An example of the effect of geographic region is shown in Figure 8.2 where the estimated values for SO_2 and NO_2 in the Skien area as opposed to those values calculated in Porsgrunn, vary during the 24 hours. The date, 9 March, was chosen because ambient concentrations were higher that day. The effect of traffic emissions on NO_2 concentrations can be seen by comparing the values estimated in Porsgrunn with and without accounting for traffic.

The effect of changing wind directions can be seen on SO_2 concentrations. SO_2 is primarily emitted at the Union factory (paper mills) in Skien. At 0300 and 0800 hrs the wind is obviously blowing from the southwest up the valley leading to small puffs of SO_2 in Skien, but not in Porsgrunn. From 1800 to 1900 the wind is primarily from the north leading to low values in Skien and higher values in Porsgrunn.

Most people spend most of their time indoors. If, in addition windows and doors are closed, air quality indoors can be substantially different from outdoors. Based on simultaneous measurements made indoors and outdoors, a set of algorithms were developed to estimate concentrations indoors. Opening of windows for ventilation can influence indoor air quality.

Figure 8.3 demonstrates how time of day and smoking influence concentrations of particulates indoors. In some cases concentrations of particulates indoors can be higher than outdoors.

In order to get an indication of how the exposure model functions, the model was run for a fictitious person, living in Skien and working in Porsgrunn. Twentyfour hour averages of some compounds as modelled with the emissions based model for that day are shown in Figure 7.3. To simplify this discussion only the compounds SO_2, NO_2, O_3 and suspended particles (fine fraction) will be described in detail.

In Figure 8.4 three values are compared: those values for exposure estimated by the exposure model (dashed line), those values for the km^2 grid estimated by the dispersion model (see Chapter 7) (dotted line) and finally those values measured at the nearest measuring station (solid line). Measuring stations for some compounds were very near both Skien and Porsgrunn, therefore estimated km^2 and measured values are not usually that different. Hourly values of measured SO_2 varied substantially as compared to NO_2, O_3, and especially suspended particles. For SO_2 the estimated model values of exposure and km^2 grid are well related with the exception of when the individuals are indoors with the windows closed. The differences between estimated and measured values are rather marked and indicate how important wind direction is so close to the factory. The NO_2 values are lower indoors than outdoors, and exposure to traffic pollution is the largest cause for differences between the exposure and dispersion model estimated values. O_3 values are lower indoors than outdoors and the difference between measured and estimated values is rather large since the

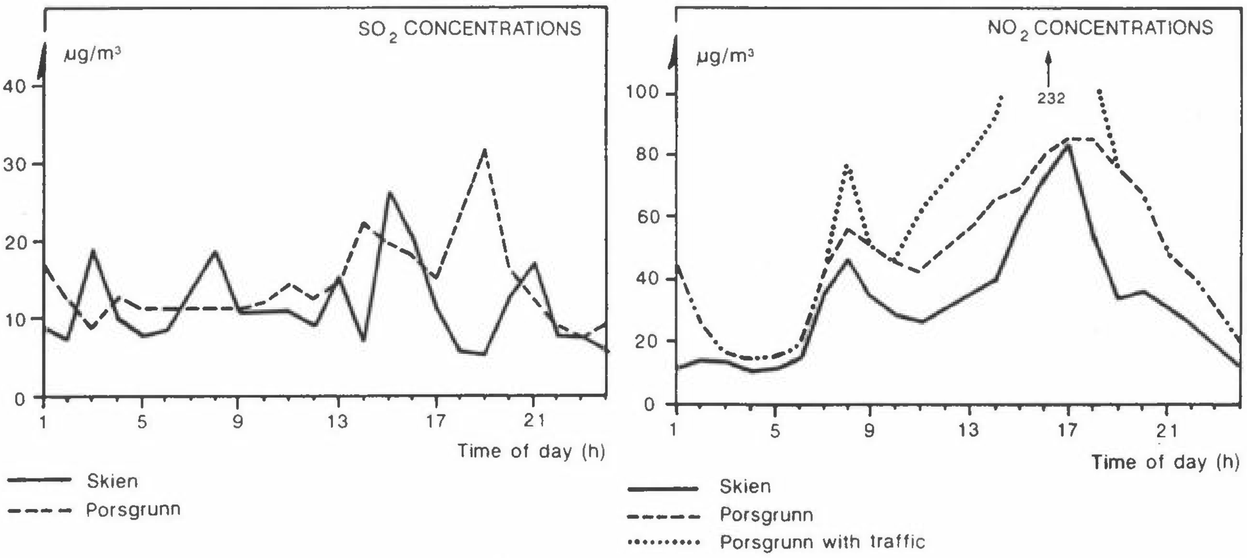


Figure 8.2: Estimated values for SO_2 and NO_2 on 9 March, 1988 in Skien and Porsgrunn, with or without additional pollution due to traffic.

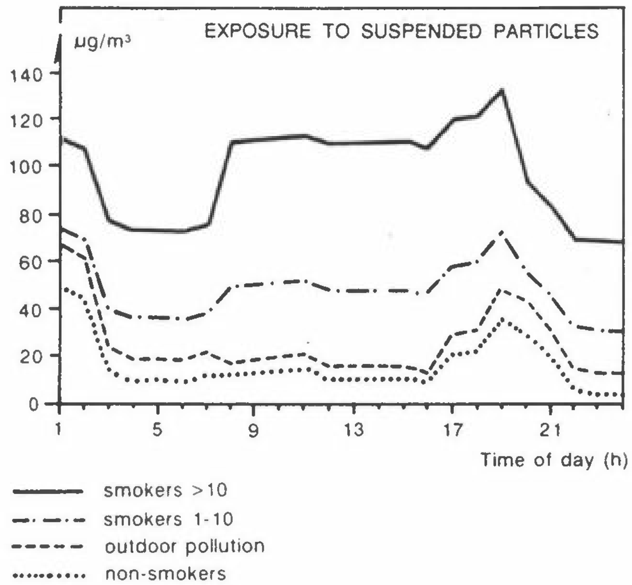


Figure 8.3: Effect of smoking on estimates of exposure to suspended particles indoors compared to estimated outdoor concentrations.

measuring station is far from sources of NO_2 (used for modifying O_3 values - see further discussion in Chapter 7). For suspended particles, the estimated values are heavily influenced by smoking and exposure to traffic pollution. The measured values have an averaging time of 12 hours.

8.2 DESCRIPTION OF TIME-USE BASED ON INFORMATION PROVIDED BY THE DIARY

Results of studies of the health effects of air pollution done in different countries where individual exposure has not been measured should be compared carefully. Even though pollution levels may be lower in one country, exposure may be higher due to cultural differences in ventilation of homes (e.g. sleeping with windows open) and amount of time spent outdoors. This section summarizes such features for the Norwegian population studied. Many of these parameters are features of the exposure assessment model.

There is a sharp contrast in time spent with window open, closed or outdoors between winter and summer (Table 8.2). Time spent travelling is stable in the two study periods. Even in the winter, people spend an average of 17% of their time in rooms with window open and 3% of their time outdoors. In the summer, time spent outdoors can be as high as 20%. Children are more outdoors than adults. Women are outdoors less than men, but have windows open more than men.

People were shopping 28% of study days. Twenty-five per cent of shopping days they were shopping less than 30 minutes, and they were shopping one hour or more on half of the shopping days. Women spend more time shopping than men. People spend more time shopping in Skien than in Porsgrunn or other places and they shop most on Thursdays, Fridays and Saturdays. They spend slightly more time shopping in summer than in winter.

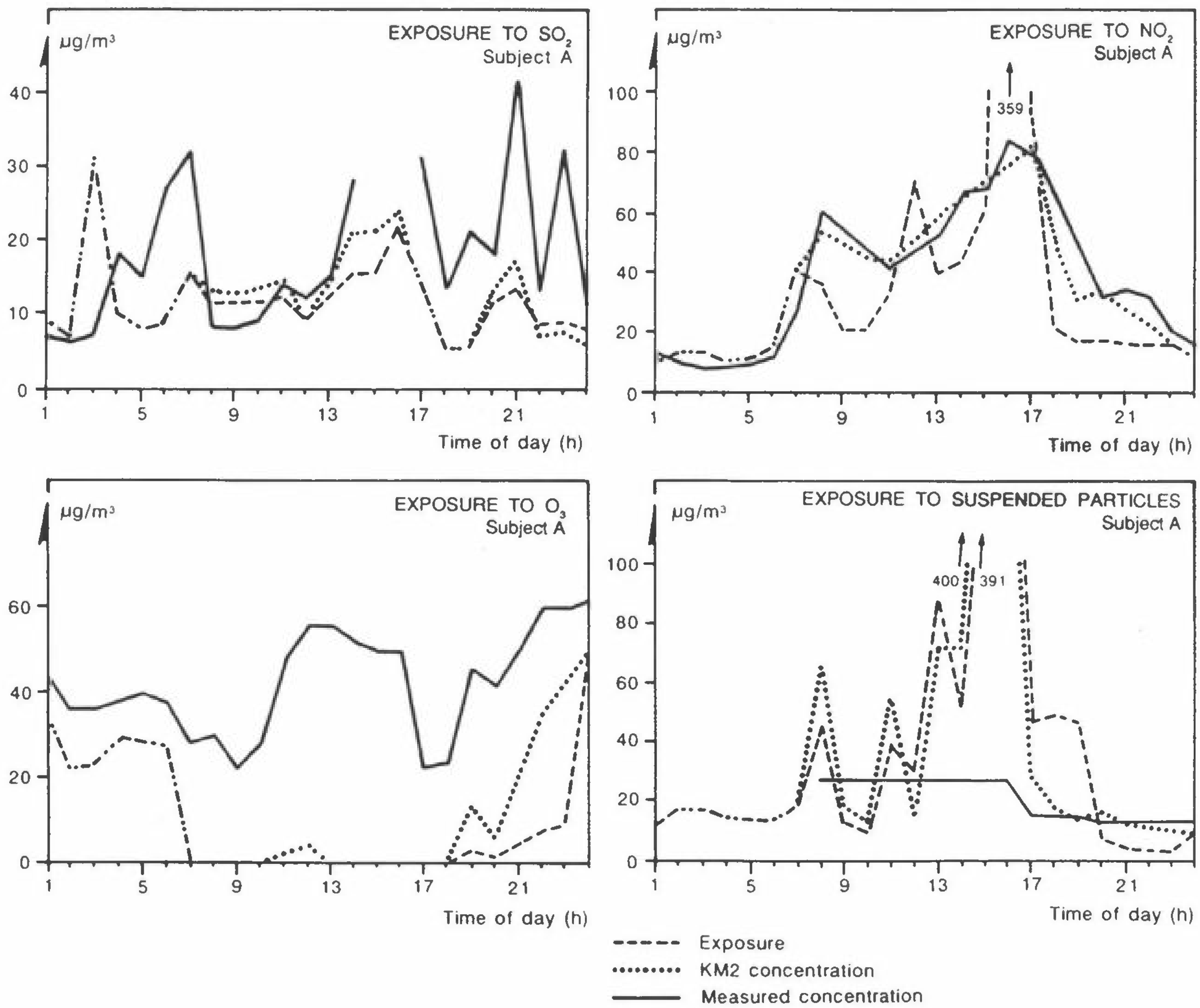


Figure 8.4: Comparison of exposure estimate, estimated value for km^2 and that value measured at the nearest air quality station for SO_2, NO_2, O_3 and suspended particles for a fictitious person living in Skien and working in Porsgrunn.

Generally smokers smoke the same number of cigarettes winter and summer and the same amount of time is spent smoking in both seasons. Individuals seem to be slightly less exposed to passive smoking in the summer. Women smoke fewer cigarettes than men and are exposed to passive smoking more than men. However, more women in the age group 30-40 years smoked (see Tables 8.3 and 8.4). The maximum number of cigarettes smoked in one day was 49.

Norwegians sleep more in winter (35% of the total time) than in summer (33.5%), whereas they exercise heavily only slightly

Table 8.2: A summary of information provided by the diary on time use, and presence in different micro-environments by the participants of the study.

	WINTER			SUMMER		
	Adult Women	Adult Men	Children	Adult Women	Adult Men	Children
TYPE OF LOCATION %						
Home	74.6	67.4	68.6	68.8	62.7	66.4
At work/school/kinderg.	9.7	17.4	12.4	8.7	15.2	10.4
Other places	15.7	15.2	19.0	22.5	22.1	23.2
Indoors window closed	76.5	76.3	81.2	45.5	44.0	54.9
Indoors window open	19.2	16.3	9.9	38.1	33.8	18.9
Outdoors	1.1	3.8	6.5	12.9	18.6	23.0
Travelling whole hour	3.2	3.6	2.4	3.6	3.6	3.2
NUMBER OF MINUTES TRAVELLING						
Dense traffic	3.91	6.91	6.87	6.09	7.96	6.16
Medium traffic	19.39	27.57	16.57	20.29	27.94	19.62
Light traffic	20.91	26.90	19.49	21.11	22.70	18.73
Total daily travelling	44.21	61.38	42.93	47.49	58.60	44.51
NUMBER OF MINUTES SHOPPING						
Shopping in Skien	13.01	10.48	5.30	14.67	9.15	8.78
Shopping in Porsgrunn	10.64	8.47	6.87	9.80	9.05	9.06
Shopping other	2.80	4.20	3.08	2.83	3.56	4.60
Total daily shopping	26.45	23.15	15.25	27.30	21.75	22.44
TYPE OF ACTIVITY %						
Sleeping	35.3	33.8	42.4	33.8	32.7	40.5
Daily activity	63.4	64.6	54.8	65.1	65.4	57.8
Hard work/training	1.2	1.5	2.8	1.0	2.0	1.7
WAKE UP %*						
6.00	0.9	3.3	0.7	0.9	4.2	0.1
7.00	12.4	25.7	4.1	15.1	26.6	2.2
8.00	26.6	28.6	46.2	29.3	30.5	39.7
9.00	24.8	17.7	24.7	27.0	19.5	32.2
10.00	18.0	11.8	12.2	14.9	11.0	15.1
11.00	6.3	4.0	6.7	5.0	2.7	5.6
12.00	2.4	1.5	2.2	1.7	1.1	2.3
ASLEEP %*						
19.00	0.1	0.1	0.3	0.3	0.0	0.1
20.00	0.2	0.2	13.1	0.2	0.1	4.2
21.00	1.4	2.3	37.0	0.6	1.1	30.8
22.00	11.8	16.7	20.0	7.1	13.8	23.5
23.00	35.9	38.8	17.7	34.6	39.1	23.8
24.00	33.6	28.2	7.6	42.8	35.7	14.2
1.00	5.2	3.7	0.5	5.3	3.8	0.1
2.00	2.3	2.0	0.6	2.3	1.4	0.8

* % are only given for selected hours and therefore do not add to 100.

Table 8.3: Mean number of cigarettes per day and week (where at least one cigarette was smoked), mean number of hours with at least one cigarette smoked, and mean number of passive smoking hours (all subjects included), per season, population group and gender.

Season	Persons smoked	Total cigarettes	Hours smoked	Cigarettes per hour	Indiv. sum cig./week		Hours passive smoking	
	Days	Mean	Mean	Mean	Mean	Person-weeks	Mean	Days
WINTER								
Population subgroups								
Adults based on random sample								
Women	1772	9.96	2.88	1.25	61.6	605	5.29	1974
Men	1187	11.09	3.99	1.32	67.5	437	4.64	1655
Adults with lung disease								
Women	118	5.10	1.98	1.14	29.2	72	5.88	395
Men	60	6.64	1.40	1.03	40.5	83	4.70	405
SUMMER								
Population subgroups								
Adults based on random sample								
Women	1297	9.55	2.91	1.21	58.4	500	4.60	1323
Men	998	11.87	4.58	1.30	71.3	368	4.21	980
Adults with lung disease								
Women	75	6.88	2.81	1.14	40.5	54	4.99	283
Men	24	7.11	1.42	1.01	43.7	77	4.99	330

Table 8.4: Mean number of cigarettes smoked per day for adult smokers by sex and age group.

Age group	Women			Men		
	Mean No. cigarettes	No. of days	% of smokers in age group	Mean No. cigarettes	No. of days	% of smokers in age group
20-29	9.6	1081	61	5.9	302	35
30-39	9.2	2760	68	12.4	871	50
40-49	10.3	1289	42	12.6	1402	45
50-59	9.5	1030	46	11.5	1239	53
60-69	8.6	551	50	8.2	1291	48
70-79	1.7	39		4.1	103	

* Smokers = people who smoked at least once.

more in the summer. They sleep more on Sundays. Children sleep more than adults, women sleep more than men. Table 8.2 shows at what hour people go to sleep or wake up in winter and summer. Men wake up earlier than women, and adults generally wake up earlier in the summer than winter. Children wake up later in summer. Women go to sleep later than men. In summer, all groups go to sleep later, but for children the difference between summer and winter is larger than for adults.

People in general travelled 78% of the study days. Thirty-six per cent of the days with travel they travelled less than 30 minutes. On 32% of days with travel they travelled over 1 hour. Essentially people spend the same amount of time in traffic in winter and summer, and the same amount of time in each of the three categories light, medium or dense traffic (see Table 8.2). Generally, people in Grenland spend 5 to 10 minutes per day in dense traffic, and 20 to 30 minutes in light or medium traffic.

8.3 DESCRIPTION OF ESTIMATED EXPOSURE TO DIFFERENT AIR POLLUTION COMPONENTS IN GRENLAND

Based on information reported in the diary and summarized in the previous section, each participant's exposure to each component was estimated hour for hour. These estimated concentrations can be described as a function of various parameters.

8.3.1 Exposure to pollution at different days of the investigation

Figure 8.5 shows the mean temperature and relative humidity that the participants were exposed to during the investigation. Temperatures rose during the period, with considerable fluctuation during the mild winter months. Figures 8.6 and 8.7 describe mean air pollution concentrations by day of study. The two coldest periods that occurred that winter, were only accompanied by increases in sulfates and suspended particles. As reported in paragraph 8.5, the individual pollution components seem rather independent of each other.

8.3.2 Exposure to pollution at different times of day and season

Changes in temperature and humidity during day and night are especially noticeable in the summer, and affect some of the contaminants giving them marked circadian (24-hour) variations. Human activities that tend to occur at routine times during the day, e.g. driving to work, working, etc. also can affect exposure to contaminants.

Figure 8.8 and 8.9 show changes in exposure to the gaseous and particulate air contaminants as a function of season and time of day. NO and to a lesser degree NO_2 show the typical peaks associated with exposure to traffic pollution. These peaks are especially noticeable in the afternoon rush hour and are slightly higher during the winter than the summer. Exposure to NO is higher in the winter than in the summer and exposure to NO_2 slightly lower in the winter. Exposure to SO_2 is only slightly higher in the winter than in the summer and does not vary markedly with time of day. Exposure to O_3 is, as expected, much higher in the summer than in the winter and shows a pronounced circadian variation in the summer. Exposure to suspended particles shows a marked circadian variation in the winter but not in the summer. Exposure to nitrates and sulfates is lower in the winter than in the summer.

8.3.3 Exposure to pollution in different population subgroups

There were only slight, probably non-significant, differences in exposure between the two sexes. However, exposure to all parameters were either equal or slightly higher in men, with the exception of suspended particles. Men were exposed to slightly higher concentrations of the nitrous oxide components and this is especially so in younger men, possibly indicating more exposure to traffic pollution. Both older men and women

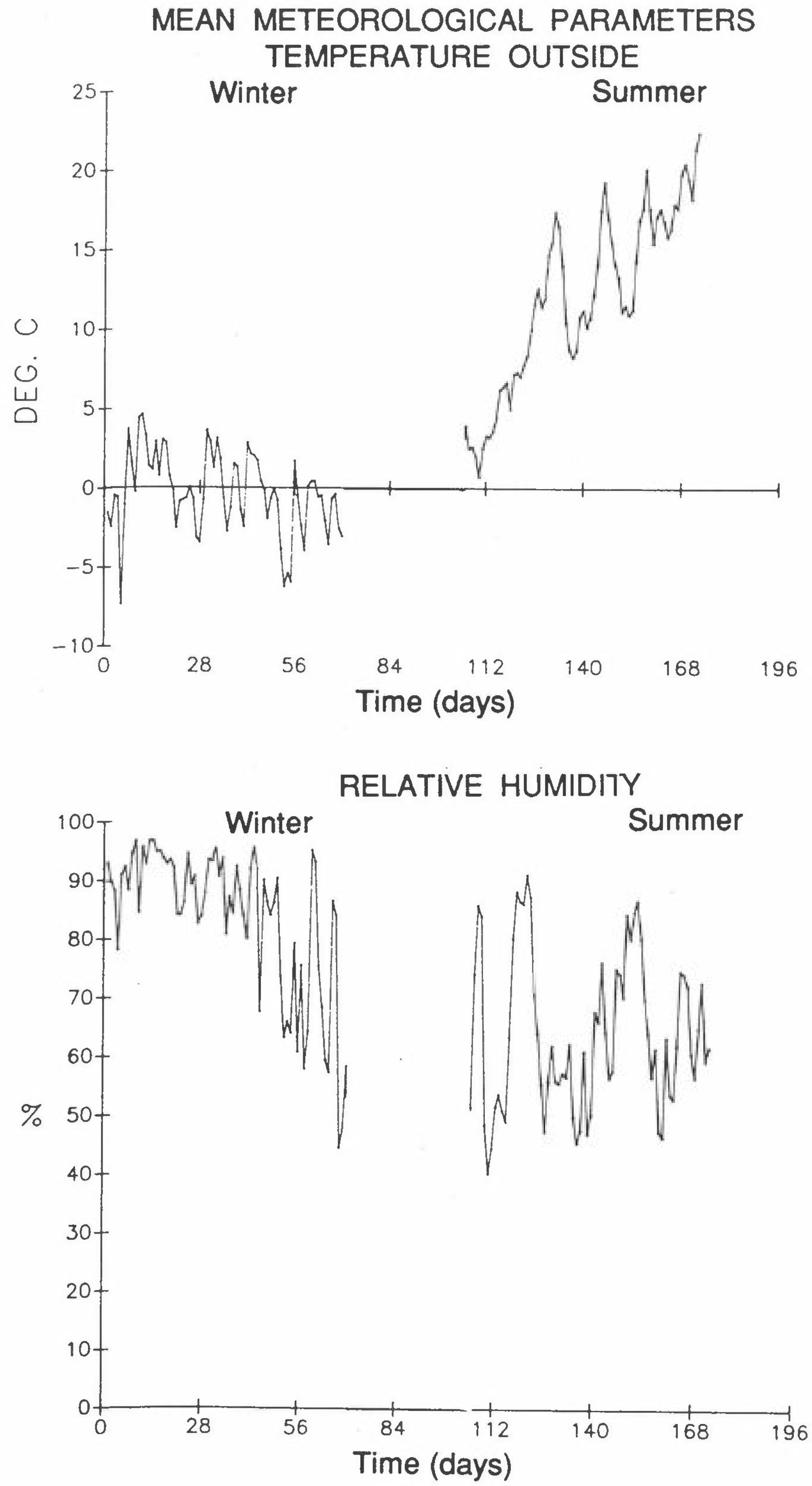


Figure 8.5: Daily averages of temperature and humidity during the investigation. Temperatures measured at Ås, from 2 January to 11 March, and from 18 April to 24 June, 1988. Day 1 = 2 January, 1988.

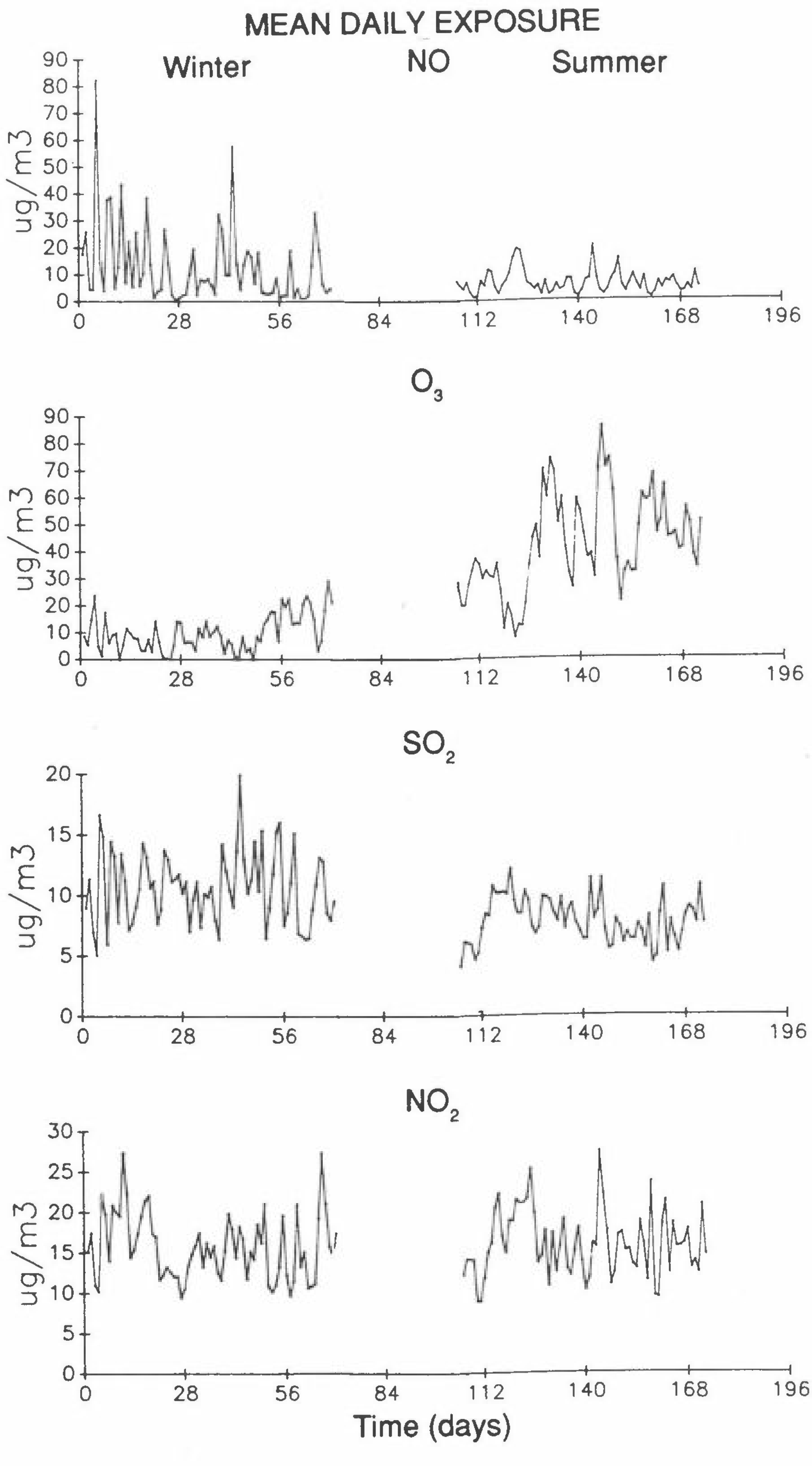


Figure 8.6: Concentrations of mean daily exposure of the entire study population to the gaseous contaminants NO, NO_2, O_3 and SO_2 as a function of day of study. Day 1 = 2 January, 1988.

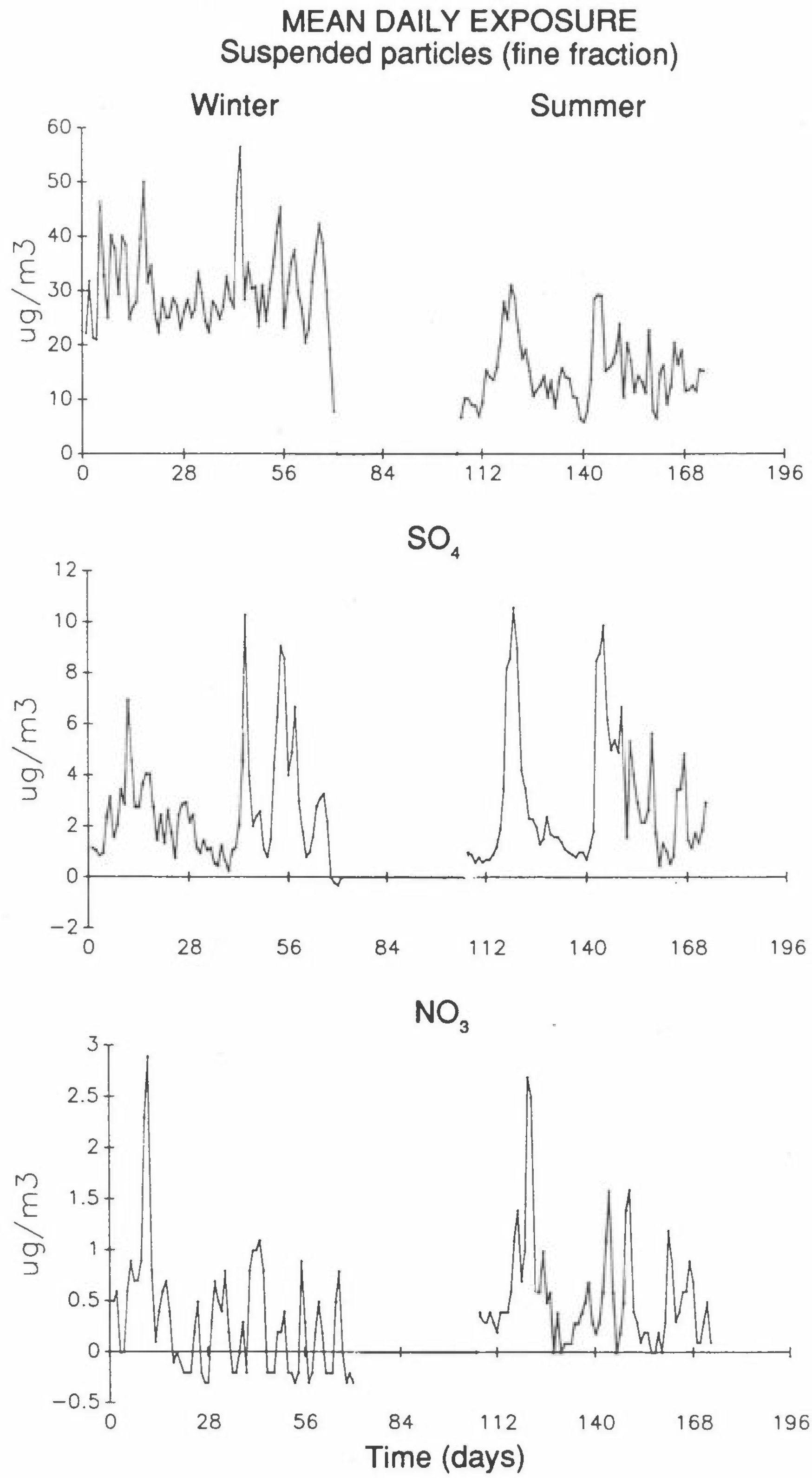


Figure 8.7: Concentrations of mean daily exposure of the entire study population to the particulate contaminants, suspended particles (fine fraction), nitrates and sulfates. Day 1 = 2 January, 1988.

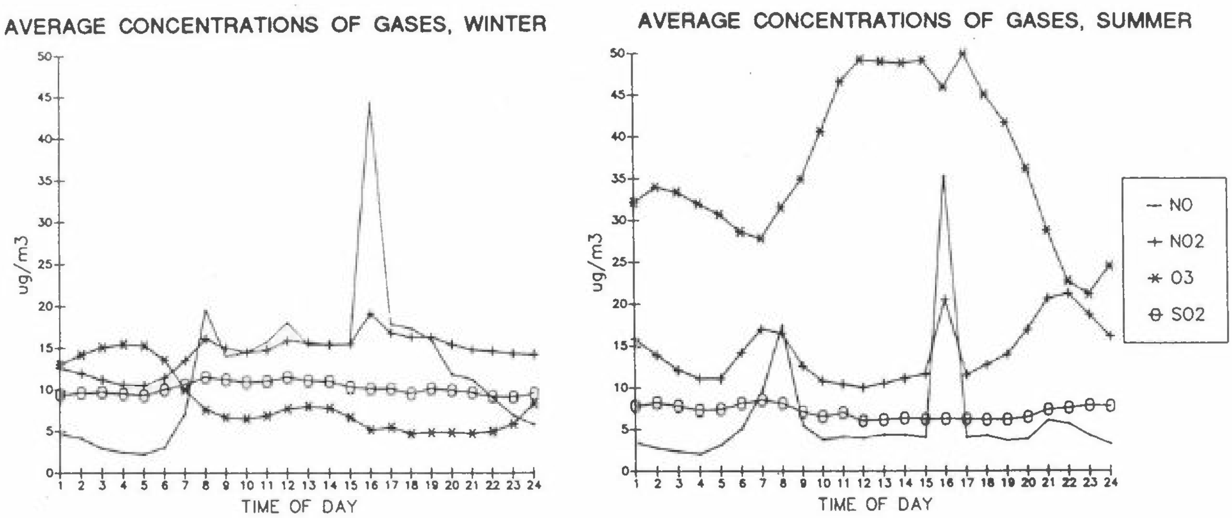


Figure 8.8: Variations in concentration of exposure to the gaseous contaminants, NO, NO_2, O_3 and SO_2 as a function of time of day and season.

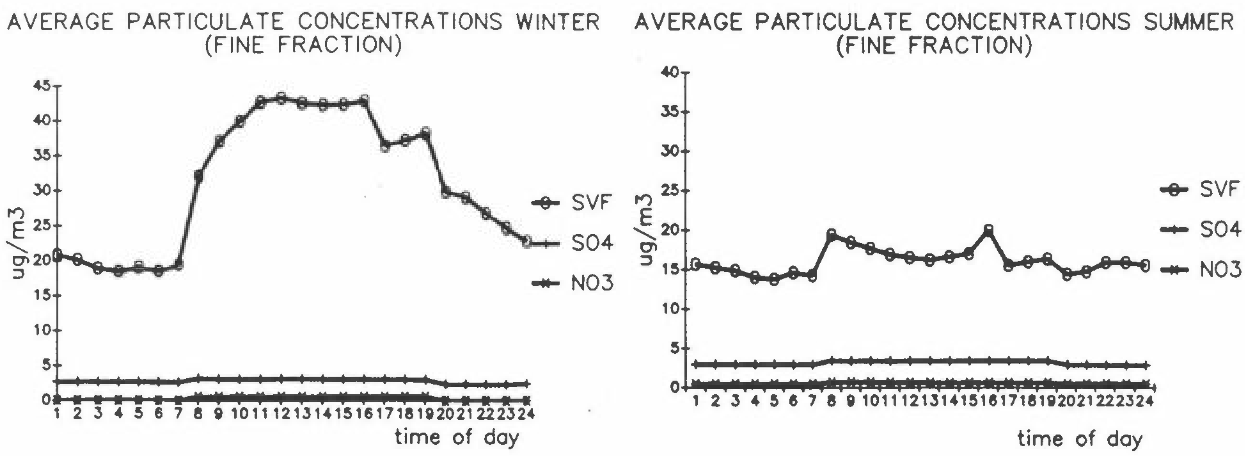


Figure 8.9: Variations in concentration of exposure to the particulate contaminants; suspended particles, sulfate and nitrate as a function of time of day and season.

have higher exposure to ozone, possibly indicating more time spent outdoors. The higher exposure to suspended particles in women is especially evident in younger women, although younger men are also exposed to higher concentrations than older men.

This may indicate higher exposure to tobacco smoke in the young as opposed to the elderly, and in women as opposed to men.

Non-smokers are slightly more exposed in the winter than in the summer to particles. The difference between winter and summer is slightly more noticeable in occasional smokers, and even more marked in daily smokers. There is a mean difference of 32 $\mu g/m^3$ exposure to suspended particles in the winter, between non-smokers and those who smoke every day; whereas that difference is only 10 $\mu g/m^3$ in the summer. This is a direct reflection of time spent outdoors, or with window open in the summer as opposed to the winter.

8.3.4 Exposure to pollution in different micro-environments

Travelling led to higher exposure to the nitrous oxides, and indoor values of some pollutants are less than values outdoors or indoors with window open. However, the difference between individual exposure when the participants are indoors and when they are outdoors does not purely reflect the mathematical algorhythms used. This difference is modified by such factors as geographic location and time of day.

8.4 COMPARISON OF ESTIMATED HOURLY, 8-HOUR AND 24-HOUR EXPOSURE TO FIXED SITE OUTDOOR CONCENTRATIONS

An interesting way to summarize the information presented on exposure estimates is to examine how often air quality guidelines for ambient concentrations are exceeded by the exposure estimates. In Chapter 4, Table 4.2, this information was provided for each outdoor air quality measuring station and for the components SO_2, NO_2, O_3 and suspended particles. Proposed Norwegian and WHO air quality guidelines were used (SFT, 1982; WHO, 1987).

Tables 8.5 and 8.6 compare exposure estimates with ambient air quality guidelines. These guidelines, however, are not defined in relation to personal exposure. Therefore, conclusions based on comparisons between personal exposure and air quality guidelines are limited.

For SO_2 it can be seen that for a total of 23 hours in the winter (19 individuals) and for 80 hours in the summer (48 individuals) the air quality guidelines were exceeded as opposed to a maximum of 6 hours in Skien (both G. Stangs gt. and Skien brannstasjon) in the winter and none in the summer for measurements made at the air quality stations. For the 24 hour measurement the results are different. There were only two days in the summer (2 individuals) where the exposure estimate exceeded the air 24 hour quality guidelines, whereas none occurred in the winter. There was a maximum of 2 days in the winter for the measuring stations.

No measured values of NO_2 ever exceeded either the 1 hour or 24 hour air quality guidelines either in winter or summer at any station. However, the 1 hour limit was exceeded 18 times (15 individuals) in the winter and 135 times (63 individuals) in the summer, and the daily limit twice in the winter (1 individual), based on exposure estimates.

Neither measured values nor estimated exposure of ozone ever exceeded the guidelines in the winter. However, in the summer, measurements at Ås exceeded the 1 hour guideline 406 times and the 8 hour limit 35 times. This can be compared to 33 592 times (8%) (328 individuals) the exposure estimate exceeded the 1 hour limit, and 411 times (173 individuals) the estimate exceeded the 8 hour limit (24 hour means used here).

No values of suspended particles ever exceeded air quality guidelines at any of the air quality measuring stations. However, 2 061 times (129 individuals) the daily limit was exceeded by the exposure estimate in the winter and 13 times (7 individuals) in the summer (Table 8.5).

Table 8.5: Number of days individual exposure to SO_2, NO_2, O_3 and suspended particles exceeded the 24 hour air quality guideline (AQG) by season and population subgroup. Number of individuals in parenthesis.

SEASON	No. person days	SO_2 mean per day	NO_2 mean per day	O_3 mean per 8-hr	SP mean per day	Number of partici-pants
		Days over AQG	Days over AQG	Days over AQG	Days over AQG	
WINTER						
<u>Population subgroup</u>						
Randomly selected study p.	15362				1920 (113)	290
Children with lung disease	855		2 (1)		27 (3)	16
Adults with lung disease	3114				114 (13)	59
SUMMER						
<u>Population subgroup</u>						
Randomly selected study p.	13712	2 (2)		304 (136)	10 (6)	260
Children with lung disease	756			13 (5)	3 (1)	14
Adults with lung disease	2872			94 (32)		54
Air Quality Guidelines		100 Norway	100 Norway	100 WHO	70 WHO	

Table 8.6: Number of hours individual exposure to SO_2, NO_2, O_3 and suspended particles exceeded the 1 hour air quality guideline by season and population sub-group. Number of individuals in parenthesis.

SEASON	No. person days	SO_2 over 1 hour	NO_2 over 1 hour	O_3 over 1 hour	Number of partici-pants
		Hours over AQG	Hours over AQG	Hours over AQG	
WINTER					
<u>Population subgroup</u>					
Randomly selected study p.	15362	18 (14)	17 (14)		290
Children with lung disease	855	1 (1)			16
Adults with lung disease	3114	4 (4)	1 (1)		59
SUMMER					
<u>Population subgroup</u>					
Randomly selected study p.	13712	69 (41)	107 (50)	25778 (260)	260
Children with lung disease	756	1 (1)	2 (2)	1661 (14)	14
Adults with lung disease	2872	10 (6)	26 (11)	6153 (54)	54
Air Quality Guidelines		350 WHO	200 Norway	100 Norway	

8.5 STATISTICAL PROPERTIES OF THE EXPOSURE ESTIMATES AND THEIR POSSIBLE INTERDEPENDENCE

One aim of this investigation was to correlate reporting of symptoms of health effects in all individuals with exposure to a set of air pollutants. It is therefore of interest to see how the exposure estimates for each contaminant correlate with each other. Prior to the investigation it was felt that unique geographical features of the region should result in a relatively independent distribution of the contaminants that should allow distinguishing between the effects of each component.

Interrelations between exposure estimates for individual components are generally stronger in summer than in winter but often of the same general dimensions. Important exceptions are relative humidity and sulfates (slight negative correlation in the winter, yet a stronger positive correlation in the summer); O_3 shows negative correlations with all compounds other than sulfates in the winter, whereas it is positively correlated with all compounds other than CO and Cl_x in the summer.

Correlations that exceed 0.25 are indicated in Table 8.7.

Another method of examining air pollution interactions is by categorizing air pollutants as a function of presumed health effects. We chose to use suggested air quality guidelines where available (see Table 11.1). The pollutant concentrations were divided into three categories:

- above air quality guideline values (category 2),
- between 30% of the guidelines and the guideline values (category 1),
- and below 30% of suggested guideline values (category 0).

For each hour a new variable was created, that accounted for the simultaneous occurrence of different concentrations of each compound (categorized). The frequency distribution of this new variable allows investigating the simultaneous occurrence of high concentrations of several compounds.

The results for winter and summer separately are shown in Table 8.8. for those occurrences over 0.5% of time.

It was originally felt that because of the geographical setting of the air pollution sources in this area it would be possible to study the relative effects of the pollutants since they would vary independently of each other. Table 8.8 reinforces this concept. In Grenland, the geographic placement of the principle sources were, together with local meteorological situations, modelled over short-time periods (1 hour). The most important sources in the area are industrial and high pollution concentrations are only expected sporadically (problems in operation of the plants). It is evident that high exposure mainly occurs for one compound at a time.

The results (partially presented in Tables 8.7 and 8.8) seem to indicate that the individual compounds vary independently of each other. Variations in lifestyle (time spent outdoors, keeping windows open) etc. were large enough between seasons and population groups to indicate that these factors should be accounted for when investigating the effects of air pollution on health.

Table 8.7: Mean weighted Pearson correlation coefficients for the log-transformed air pollution data for winter, (over the diagonal) and summer, (under the diagonal) (only values over .25 listed).

	SO_2	NO_x	NO_2	O_3	Susp. Part-F	Cl_x	SO_4	NO_3	CO	Outdoor temp.	Rel. Hum.
SO_2	●	.78	.79		.62		.44	.38			
NO_x	.67	●	.99	.28	.71		.53	.43	.91		
NO_2	.67	.89	●	.31	.71		.53	.43	.73		
O_3				●	.35		.31		-.35	.43	-.40
Susp. * Part-F	.58	.57	.56		●	.29	.60	.45	.60		
Cl_x						●					
SO_4	.44	.35	.37		.35		●	.62			.33
NO_3		.40	.35		.26		.43	●			
CO		.83	.68		.47				●		
Outdoor Temp.								.33		●	-.53
Rel. Hum.				-.39				.28		.26	●

S U M M E R

W I N T E R

*See glossary (Chapt. 15).

8.6 APPLICATION OF EXPOSURE ESTIMATES IN ASSESSING THE HEALTH EFFECTS OF AIR POLLUTION

Participants exposure is summarized in Table 8.9. The table shows percentiles of exposure estimates and maximum estimated exposure for winter and summer.

The diary method used in this investigation has its limitations but seems the preferred method of investigation of short-term health effects. It allows measuring more individuals over a

Table 8.8: Per cent of occurrences of different classification of air pollutants. Classifications in parenthesis are based on air quality guidelines, if nothing else indicated between 30 and 100%, and (2) = over hourly air quality guideline values.

WINTER VALUES		
Composition of pollutant compounds	Number of registered hours	Per cent
All compounds at low levels	169 388	35.3
Acid aerosols	10 596	2.2
Clx	6 060	1.3
Clx + aero	7 547	1.6
Clx(2) + aero	3 595	.7
Pr-f	85 875	17.9
Pr-f + aero	17 641	3.7
Pr-f + clx	3 847	.8
Pr-f + clx + aero	9 147	1.9
Pr-f + clx(2) +aero	4 614	1.0
Pr-f+clx(2)+aero(2)	2 204	.5
Pr-f(2)	57 786	12.0
Pr-f(2) + aero	8 781	1.8
Pr-f(2) + clx	2 457	.5
Pr-f(2) + clx + aero	4 853	1.0
Pr-f(2)+clx(2)+aero	2 935	.6
Pr-f(2)+clx(2)+aer(2)	2 853	.6
O_3	31 237	6.5
O_3 + aero	2 731	.6
O_3 + Pr-f + aero	2 737	.6
Missing	35 281	7.4
Total	479 928	100.0

SUMMER VALUES		
Composition of pollutant compounds	Number of registered hours	Per cent
All compounds at low levels	115 529	26.0
Acid aerosols	15 453	3.5
Pr-f	36 516	8.2
Pr-f + aero	22 936	5.2
Pr-f(2)	2 129	.5
Pr-f(2) + aero	3 578	.8
O_3	109 071	24.5
O_3 + aero	8 874	2.0
O_3 + Pr-f	9 036	2.0
O_3 + Pr-f + aero	13 936	3.1
O_3(2)	25 668	5.8
O_3(2) + aero	2 825	.6
O_3(2) + Pr-f + aero	3 976	.9
Missing	61 384	13.8
Total	444 960	100.0

* Pr-f = Suspended particles - fine fraction

Table 8.9: Percentiles of the calculated exposure to air pollutants for study population and adults with pre-existing lung disease.

Randomly selected study population	Hours registered	10% quantile	Median	90% quantile	95% quantile	Maximum
Winter						
Sulfur dioxide (µg/m^3)	354735	5	9	18	22	900
Nitrogen oxides (µg/m^3)	354735	8	17	55	85	3065
Nitrogen dioxide (µg/m^3)	354735	8	14	23	33	334
Nitrogen monoxide (µg/m^3)	354735	0	3	31	61	2731
Ozone (µg/m^3)	354735	0	4	28	41	93
Carbon monoxide (mg/m^3)	354735	0	0	0	0	31
Particles (fine fr.) (µg/m^3)	354735	2	17	101	108	581
Sulfate (µg/m^3)	354735	0	2	6	8	17
Nitrate (µg/m^3)	354735	0	0	1	2	8
Chlorine (µg/m^3)	354735	0	0	3	7	297
Summer						
Sulfur dioxide (µg/m^3)	304697	2	7	13	19	1414
Nitrogen oxides (µg/m^3)	304697	6	16	40	55	2313
Nitrogen dioxide (µg/m^3)	304697	6	14	30	39	325
Nitrogen monoxide (µg/m^3)	304697	0	2	9	17	2033
Ozone (µg/m^3)	304697	5	24	97	112	185
Carbon monoxide (mg/m^3)	304697	0	0	0	0	23
Particles (fine fr.) (µg/m^3)	304697	2	11	44	53	614
Sulfate (µg/m^3)	304697	1	2	8	10	15
Nitrate (µg/m^3)	304697	0	0	1	2	9
Chlorine (µg/m^3)	304697	0	0	1	1	55
Birch pollen (pollen/m^3)	325387	0	0	17	47	833
Grass pollen (pollen/m^3)	324534	0	0	5	19	2185

Adults and children with pre-existing lung disease	Hours registered	10% quantile	Median	90% quantile	95% quantile	Maximum
Winter						
Sulfur dioxide (µg/m^3)	89912	5	9	17	22	446
Nitrogen oxides (µg/m^3)	89912	8	16	52	79	1912
Nitrogen dioxide (µg/m^3)	89912	7	13	25	33	214
Nitrogen monoxide (µg/m^3)	89912	0	2	26	54	1698
Ozone (µg/m^3)	89912	0	5	31	42	91
Carbon monoxide (mg/m^3)	89912	0	0	0	0	36
Particles (fine fr.) (µg/m^3)	89912	0	13	58	89	485
Sulfate (µg/m^3)	89912	1	2	6	9	16
Nitrate (µg/m^3)	89912	0	0	1	2	8
Chlorine (µg/m^3)	89912	0	0	3	6	269
Summer						
Sulfur dioxide (µg/m^3)	78900	1	6	13	18	1414
Nitrogen oxides (µg/m^3)	78900	4	14	39	54	2518
Nitrogen dioxide (µg/m^3)	78900	4	12	31	40	324
Nitrogen monoxide (µg/m^3)	78900	0	2	8	15	2218
Ozone (µg/m^3)	78900	6	27	100	114	184
Carbon monoxide (mg/m^3)	78900	0	0	0	0	25
Particles (fine fr.) (µg/m^3)	78900	1	10	31	47	424
Sulfate (µg/m^3)	78894	1	2	8	10	14
Nitrate (µg/m^3)	78894	0	0	1	2	8
Chlorine (µg/m^3)	78900	0	0	1	1	55
Birch pollen (pollen/m^3)	85856	0	0	14	43	833
Grass pollen (pollen/m^3)	84892	0	0	5	24	2185

greater time period, and over shorter time intervals and estimates more pollution compounds than an ideal method (portable pollution measuring equipment) could possibly do. It allows relating concentrations of pollution concentrations measured at fixed site stations to individual differences in exposure due to lifestyle.

9 DESCRIPTION OF SELF-REPORTED HEALTH DATA REPORTED BY THE PARTICIPANTS

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The American Thoracic Society (1985) has described in detail what can be considered an adverse respiratory health effect. The symptoms span a range from less severe such as annoying smell, irritation of the throat, nose, eyes to more serious health effects such as asthma attack, cancer and death. Research needs surrounding these health effects are connected both to the seriousness of the disease state or symptom, and the number of people affected. Therefore, research concerning less severe disease conditions or symptoms is necessary, simply because so many more people are likely to be affected.

The health effects of air pollution will be investigated using different models (see Chapter 11) where the symptoms of health effects are the dependent variables and will be studied as a function of a set of independent variables including the estimates of air pollution exposure.

Prior to data analysis, these points should be considered:

- what criteria should be used in defining subgroups,
- what confounding factors should be considered in future analysis,
- what patterns are evident in health symptom reporting,
- which if any of these symptoms can be combined in the analysis.

The following sections describe the study populations as a function of several parameters. The reported differences are in most cases based on univariate analyses. The results of these univariate tests are summarized in Table 9.8. It is obvious that a multivariate model for each health symptom can be constructed. This may be done in a later phase of the analysis.

9.1 FREQUENCIES AND DURATION OF RESPONSES IN THE STUDY POPULATION AND POPULATION WITH PRE-EXISTING LUNG DISEASE

In this study, each individual was asked to report in a diary the presence or absence of a set of health symptoms (Fig. 2.1). Table 9.1 gives an overview of the mean number of health effect symptoms that was reported by the participants. The table shows that in both seasons of investigation, the number of symptoms reported by an individual is smaller in the randomly selected study population than in the population with pre-existing lung disease. The mean number of symptoms is in both participant groups smaller in the summer period than in the winter period. More symptoms are registered when data from both seasons are pooled, which indicates that different types of symptoms are reported in winter and in summer.

Each health effect symptom can be described by the number of participants that reported the symptom at least once in the study, or in a given per cent of the study period. This indicates the size of the population that is affected.

As shown in Figure 9.1, the two adult groups in the study do not differ considerably in the percentage of participants that report a given symptom, with the exception of symptoms connected to lower airways, eye irritation, sneezing/running nose and feeling feverish.

The symptoms of health effects can be described with respect to the number and duration of reported episodes. Here the number of episodes of each symptom and their duration measure severity of each individual's response. The duration of episodes is closely related to the type of symptom. Some symptoms tend to

Table 9.1: Overview of number of types of health effect symptoms reported per participant.

	Winter[1]			Summer[2]			Both seasons		
	SP*	LSA*	LSC*	SP	LSA	LSC	SP	LSA	LSC
Number of registered participants	291	59	16	260	54	14	292	60	16
Average number of reported symptoms	5.8	7.2	7.2	4.2	6.4	5.4	7.0	8.8	8.8
Per cent of participants with number of reported types of symptoms:									
0	8.9	1.7	6.3	20.4	5.6	7.1	7.2	0	0
1- 3	22.0	23.9	6.3	31.2	18.5	14.3	17.1	10.0	0
4- 7	34.1	23.9	50.0	30.0	40.7	57.1	29.1	28.3	43.8
8-11	26.2	40.9	25.0	13.8	22.2	14.3	29.8	38.3	31.3
12-16	8.9	10.3	12.5	4.6	13.1	7.1	16.1	20.0	25.0
17	0	0	0	0	0	0	0.7	3.3	0

*SP : Randomly selected study population
LSA: Adults with pre-existing lung disease
LSC: Children with pre-existing lung disease

1) Winter = 4.1.1988-15.3.1988
2) Summer = 15.4.1988-24.6.1988

last longer (muscle pains), others are usually short-termed (bothersome smell).

For each participant in the study and for each symptom, a mean duration of the episode and the number of these symptoms can be calculated. This is displayed in Figure 9.2, that gives cumulative frequency (per cent) of:

- The mean duration of episodes of symptom reporting ("lper" in the graph)
- The number of response episodes ("nper" in the graph).

Each participant is represented by his/her mean value of "lper" and "nper". The participants who did not experience a given symptom are also included in the graphs, so that each graph provides both information on per cent of population affected

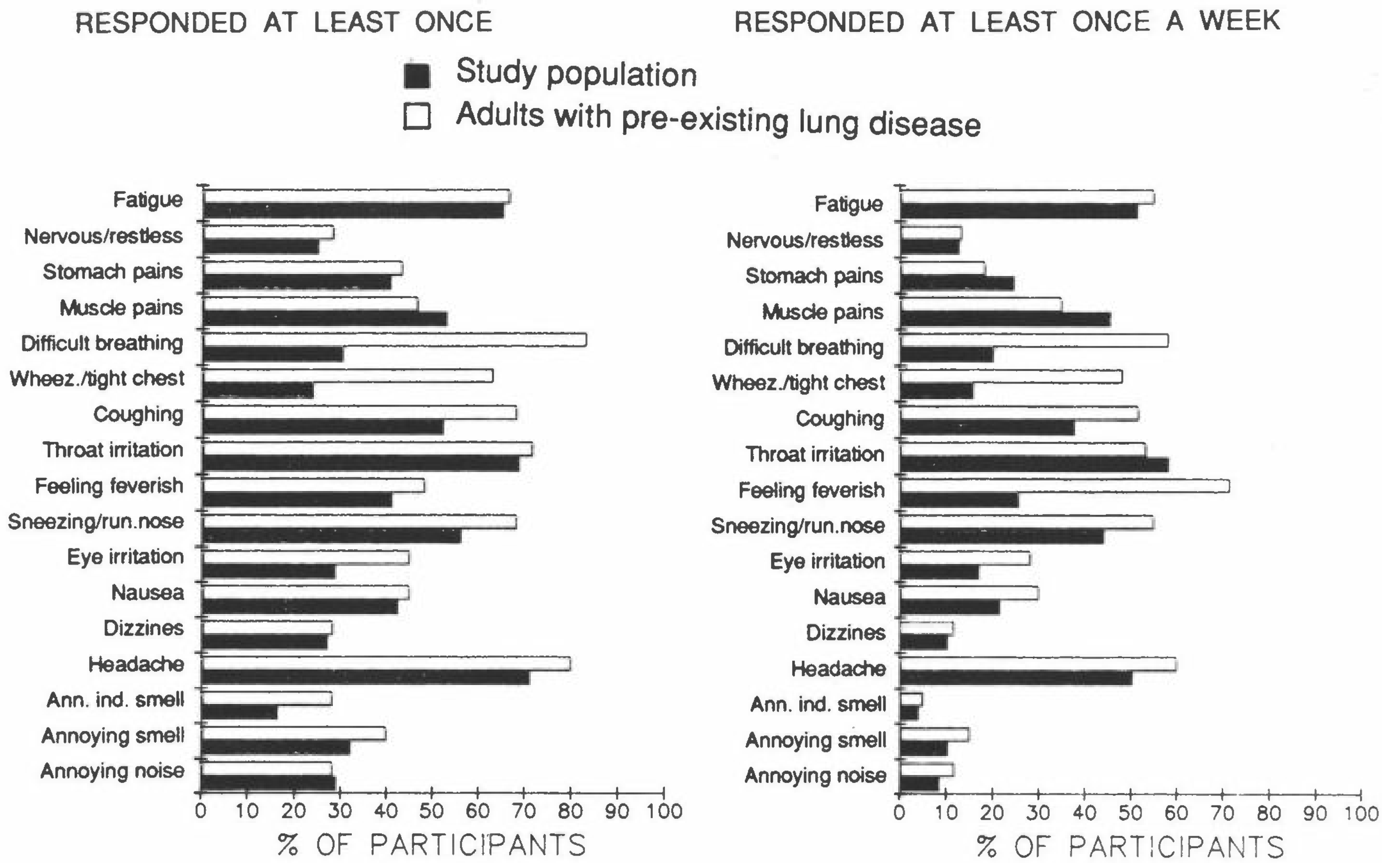

Figure 9.1: Percentage of adult participants from the randomly selected study population and from the group with pre-existing lung disease reporting a set of health symptoms a) at least once and b) in the mean at least once a week (0.6% of the total number of registered hours).

and on per cent of individuals with different numbers of responses, and different durations of symptom episodes. Number of episodes and episode duration varies for each health symptom, with shortest and fewest episodes of annoying industrial smell, (steepest slope of the curve and more than 70% of participants without response); longest episodes of irritated throat (flat slope of the LPER curve), and most episodes of headache (flat shape of the NPER curve).

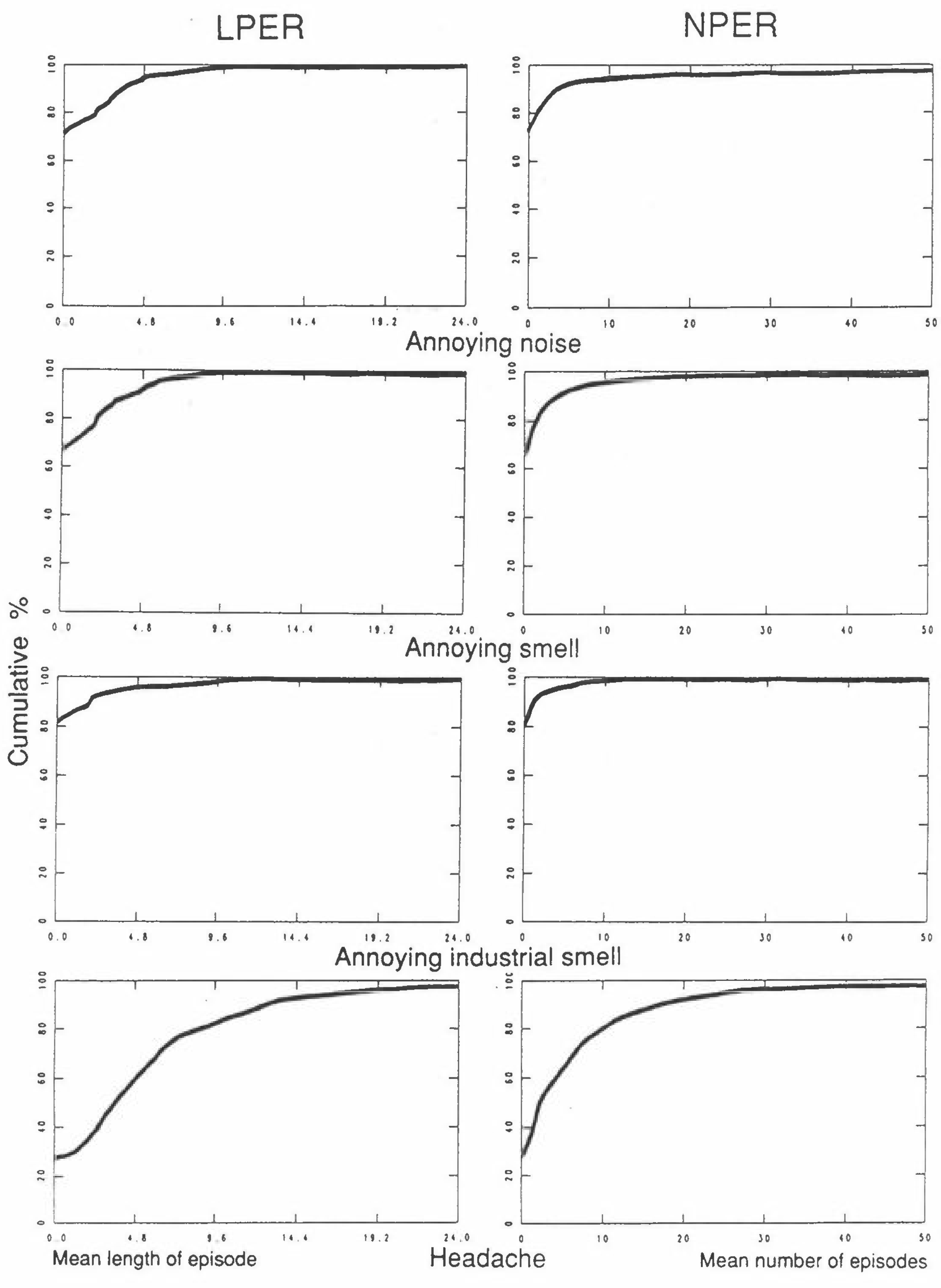

Figure 9.2: The cumulative frequency of the mean duration of episodes (LPER) and mean number of episodes (NPER) for each symptom. Participants with no symptom periods for a given symptom are included in the graph as zero.

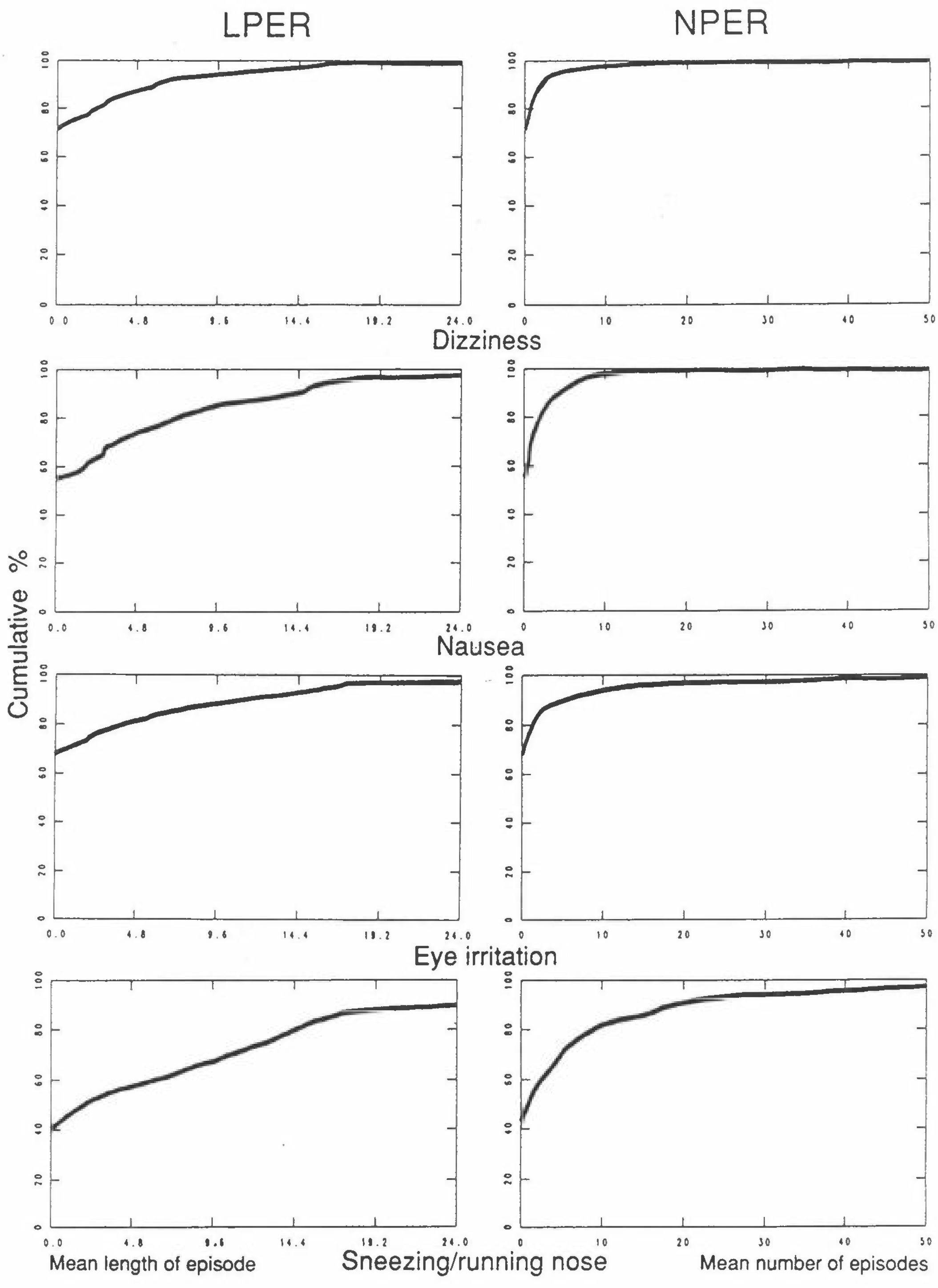

Figure 9.2: Cont.

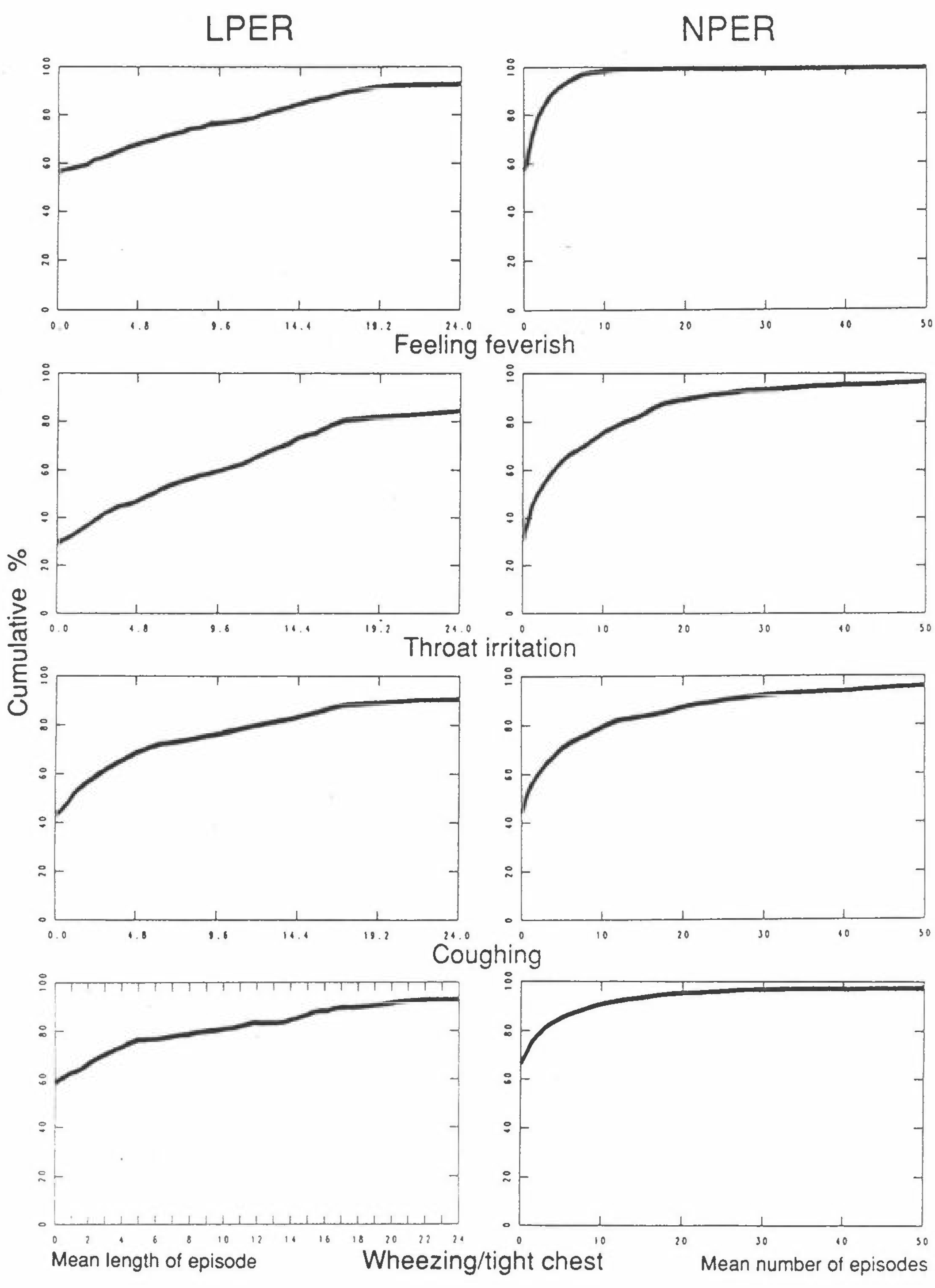

Figure 9.2: Cont.

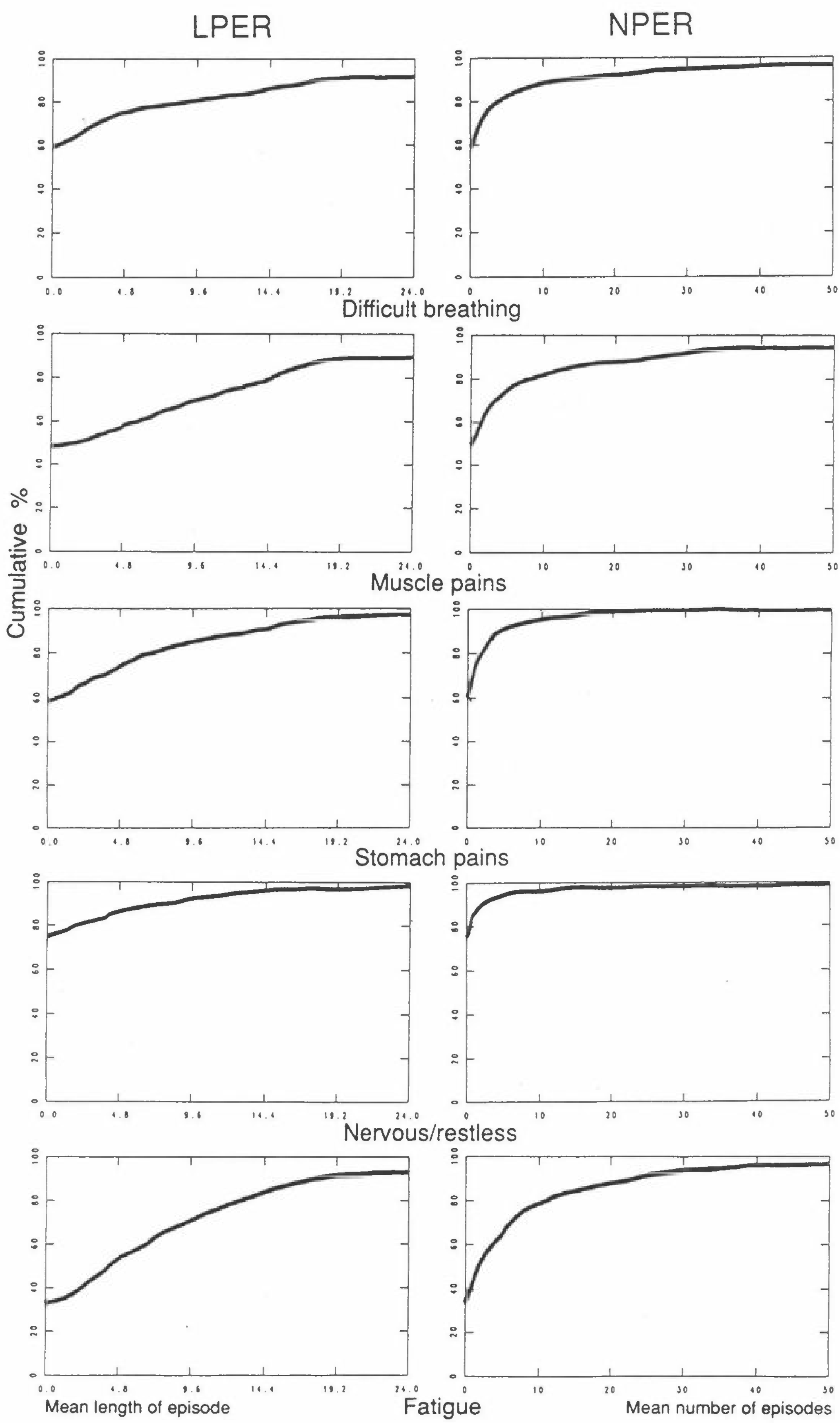

Figure 9.2: Cont.

More than 50% of the participants in the study reported at least once fatigue, coughing, having muscle pains, irritated throat and nose, and headaches. When looking at the amount of hours with response, more than 50% of the population complained of fatigue or having an irritated throat or headache on an average corresponding to at least one hour a week (0.6% of the time). The study group consisting of those with pre-existing lung disease had higher percentages of individuals experiencing difficult breathing, tight chest or feeling feverish.

Response rates measured in Grenland differ little from those reported in international literature (e.g. Gulsvik, 1979; Quackenboss, Lebowitz and Hayes, 1989; Viegi et al., 1988). Throat irritation may be a possible exception, since there seems to be a higher percentage of those affected in our investigation than reported elsewhere (Robertson and Lebowitz, 1984).

The two population groups (the randomly selected study population and the participants with pre-existing lung disease) were selected using totally different methods and criteria, and their reported response rates are apparently different. It is therefore sensible to study these separately.

9.2 FREQUENCIES AND DURATION OF RESPONSES BY VARIOUS FACTORS

In trying to categorize individuals into population groups there are several approaches that can be taken. First is to look at biological factors. Second is to use lifestyle parameters and third is to account for physical surroundings.

9.2.1 Population characterization based on biological factors

The biological factors considered are gender, age and health. Women report more symptom types than men and a higher percentage of women than men report most types of symptoms. Women report longer periods of dizziness, nausea, headache and muscle pains than men. Men with pre-existing lung disease report more often wheezing and tight chest than both women with pre-existing lung disease or men from the randomly selected study population. Participants with pre-existing lung disease report both more types of symptoms, and more episodes with longer duration. Some of this information is summarized in Tables 9.2 and 9.3.

Table 9.1: Per cent of individuals in each group reporting a symptom at least once (number of individuals in a group is given in parentheses under the group description).

	Randomly selected study population				Adults with pre-existing lung disease				Children with pre-existing lung disease			
	Women		Men		Women		Men		Girls		Boys	
	Winter (153)	Summer (140)	Winter (138)	Summer (120)	Winter (25)	Summer (22)	Winter (34)	Summer (32)	Winter (7)	Summer (5)	Winter (9)	Summer (9)
Annoying noise	20.9	15.0	29.7	15.8	20.0	22.7	29.4	18.8			11.1	
Annoying smell	29.4	21.4	22.5	16.7	44.0	27.3	32.4	18.8	57.1	20.0	11.1	
Annoying industrial smell	11.1	10.7	13.8	8.3	20.0	18.2	17.6	18.8		20.0	11.1	
Headache	77.8	62.9	51.4	33.3	84.0	72.7	67.6	37.5	71.4	60.0	55.5	44.4
Dizziness	26.8	17.8	14.5	8.3	36.0	31.8	14.7	6.3	85.7	40.0	11.1	22.2
Nausea	43.1	27.9	25.4	9.2	56.0	31.8	29.4	12.5	42.9	40.0	44.4	33.3
Eye irritation	26.1	19.3	18.1	11.7	44.0	50.0	14.7	21.9	14.3		44.4	22.2
Sneezing/ Running nose	47.7	48.6	38.4	30.1	64.0	72.7	41.2	50.0	14.3	80.0	66.7	55.5
Feeling feverish	37.3	25.0	22.4	17.5	40.0	40.9	26.5	28.1	42.9	60.0	44.4	44.4
Throat irritation	68.0	47.1	55.1	35.0	72.0	72.7	47.1	46.9	100.0	60.0	44.4	44.4
Coughing	43.8	36.4	36.2	25.0	52.0	63.6	44.1	56.3	57.1	80.0	66.7	66.7
Wheezing/ tight chest	17.0	16.4	17.4	12.5	60.0	45.5	52.9	56.3	100.0	80.0	77.8	55.5
Difficult breathing	26.1	17.9	23.2	12.5	80.0	59.1	58.8	65.6	57.1	80.0	55.5	33.3
Muscle pains (neck/back)	58.8	46.4	32.6	26.7	60.0	50.0	26.5	25.0	42.9		22.2	
Stomach pains	45.1	27.9	23.2	11.7	48.0	50.0	26.5	21.9	57.1	20.0	22.2	
Nervous/restless	28.8	18.6	13.8	5.0	32.0	18.2	14.7	15.7	14.3			
Fatigue	67.3	55.7	48.6	30.8	76.0	54.5	47.1	43.8	85.7	60.0	33.3	33.3

Table 9.2: Mean relative frequency of reporting for each symptom as a function of group, gender and season (mean of individuals rel. frequencies, i.e. individual's number of hours reported divided by individual's number of hours registered in the study).

	Randomly selected study population				Adults with pre-existing lung disease				Children with pre-existing lung disease			
	Women		Men		Women		Men		Girls		Boys	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Annoying noise	.005	.005	.009	.005	.056	.054	.013	.006			.000	
Annoying smell	.010	.003	.004	.002	.003	.001	.010	.006	.003	.002	.000	
Annoying industrial smell	.009	.001	.001	.001	.003	.001	.010	.006		.000	.002	
Headache	.027	.022	.018	.009	.035	.030	.023	.008	.029	.009	.005	.003
Dizziness	.007	.003	.002	.000	.006	.004	.002	.004	.010	.003	.001	.001
Nausea	.008	.003	.004	.001	.014	.008	.008	.001	.006	.004	.010	.005
Eye irritation	.012	.007	.005	.004	.011	.010	.024	.025	.001		.006	.004
Sneezing/ Running nose	.031	.029	.026	.026	.038	.029	.030	.030	.000	.031	.131	.099
Feeling feverish	.010	.007	.005	.005	.010	.017	.005	.009	.007	.005	.004	.008
Throat irritation	.048	.059	.054	.038	.020	.036	.037	.046	.077	.041	.020	.018
Coughing	.023	.027	.035	.030	.037	.048	.053	.058	.040	.022	.017	.040
Wheezing/ tight chest	.011	.007	.014	.014	.015	.031	.107	.114	.032	.032	.048	.024
Difficult breathing	.017	.009	.031	.013	.070	.074	.153	.136	.004	.016	.017	.023
Muscle pains (neck/back)	.085	.065	.051	.039	.093	.113	.013	.023	.008		.001	
Stomach pains	.010	.006	.012	.007	.006	.009	.033	.027	.011	.004	.002	
Nervous/restless	.011	.009	.003	.003	.011	.007	.004	.006	.001			
Fatigue	.047	.029	.028	.019	.046	.049	.035	.040	.051	.017	.009	.006

Table 9.2 gives percentages of each group who reported a given symptom. Table 9.3 describes mean relative frequencies of symptom reporting (i.e. hours with a symptom divided by total hours in the study) based on individual relative frequencies.

Certain tendencies in the tables can be pointed out: male children have relatively more often episodes with running nose. Wheezing/tight chest and difficult breathing are mostly reported by men in the group with pre-existing lung disease and more often in summer. Muscle pains, headache and fatigue tend to be reported more by women, with fatigue being more often reported in winter in all groups. As for the mean length of reporting periods, the main differences seem to be between the symptoms, not between the population groups.

Age in the adult groups (characterized as over and under 50) does not seem to affect the number of periods with symptoms or their duration. The older age group tends generally to have fewer symptoms.

Those individuals who have been sick at least once have as expected more episodes with symptoms than those who did not report sickness.

9.2.2 Population characterization based on lifestyle factors

The two primary factors in this study connected to lifestyle are smoking and alcohol consumption. These factors differ between the two study groups: the group with pre-existing lung disease reports less often alcohol consumption. The percentage of smokers in this group is lower than in the study population and smokers with pre-existing lung disease smoke fewer cigarettes and less often. Smoking does not affect total number of different symptoms each individual reports. Relatively more smokers reported dizziness and irritated throat than non-smokers. More smokers from the randomly selected study population were reporting symptoms in the lower airways.

Reporting of health symptoms on days with and days without alcohol consumption does not seem to differ. However, more of those who consume alcohol at least once a week, report being irritated by noise, headache, sore throat and coughing than those who did not report alcohol consumption. Those who reported alcohol consumption, reported more periods with annoying industrial smell, and felt tired for longer periods of time than persons who did not report consuming alcohol.

9.2.3 Population characterization based on factors concerning physical surroundings

Individuals were grouped according to their workplace (see Table 9.4). The registered hours during the investigation were grouped according to whether or not the participants were indoors (see Fig. 11.3).

Those individuals who work outside their homes do not report more health symptoms than those who work at home, but the types of symptoms are different in the two groups. Those not working outside their homes are more often bothered by difficult breathing and nervousness, yet less bothered by running nose (the episodes are shorter as well). They tend also to experience more and longer episodes of annoying noise.

Those individuals working in what can be called jobs with possible work exposure to air pollutants do not report more types of symptoms than other participants. More of them report annoying noise. Those that do report symptoms, have longer duration for episodes of symptoms associated with the lung (coughing and wheezing). They have fewer but longer periods of running nose and nausea. This group is characterized by fewer number of participants with episodes of headache, dizziness, eye irritation, stomach pains and nervousness. This may be an indication that being able to work in an exposed setting, pre-selects a healthier population.

Table 9.4: Overview of the work situation of adult participants.

	Study population		Adults with pre-existing lung disease	
	Women	Men	Women	Men
Number of participants	153	138	25	34
No risk for additional work exposure	59%	59%	52%	32%
Work outside home	68%	90%	68%	71%

The participants stayed indoors most of the time. The mean number of registered hours per participant are: 721 hours indoors with window closed, 347 hours indoors with window open, 112 hours outdoors and 140 hours per participant partly or whole used for travel or shopping. Symptom episodes usually start indoors. The length of episodes of most symptoms is independent of where the response was first registered (indoors or outdoors) with the exception of sneezing/running nose, coughing, difficult breathing and stomach pains. With these symptoms the registered periods are twice or three times longer if the first hour of registered reporting was indoors. A possible explanation can be these symptoms are associated with sickness, where one usually stays indoors. Per cent hours with response is about equal in all the four micro-environments (compare to Figure 11.3).

9.3 DAILY AND SEASONAL VARIATIONS IN THE RESPONSES

In searching for a possible relationship between air pollution exposure and health symptom reporting on an hourly basis, it is necessary to first determine patterns in health reporting that are independent of air pollution.

Figure 9.3 shows variations in response rates in the different groups of participants for all types of symptoms for all study days. Day 1 here was Monday, 4 January 1988 for all participants. There is appreciable difference in the symptom reporting from day to day.

Response rates seems to be reduced on weekends, and increased mid-week.

Most of the participants reported more types of symptoms in winter (see Table 9.1). More participants report also a given symptom in winter than in summer (see Table 9.2), but this depends on which participant group they are from, on their gender, and on the symptom. There is little difference between seasons in number of reporting episodes for each person.

The situation for sneezing/running nose and for wheezing/tight chest is shown in Figure 9.4. Sneezing/running nose is reported by a greater percentage of adults with pre-existing lung disease than in the study population, and by more women than men irrespective of the population group ("delt"). Adults with pre-existing lung disease report more episodes, especially in the winter, and women report relatively more episodes than men ("nper"). The duration of episodes reported by participants in the randomly selected study population are longer than those reported by participants with pre-existing lung disease, with longer episodes reported in summer ("lper"). Adults with pre-existing lung disease (both men and women) constitute the largest group reporting the wheezing/tight chest. Men, however, report more and longer episodes of symptoms ("nper" and "lper") than women.

Diagrams of the response rates where day one is each participants own first day of registering, indicate neither an adaptive increase nor decrease in the reporting of symptoms. The figure is not shown here.

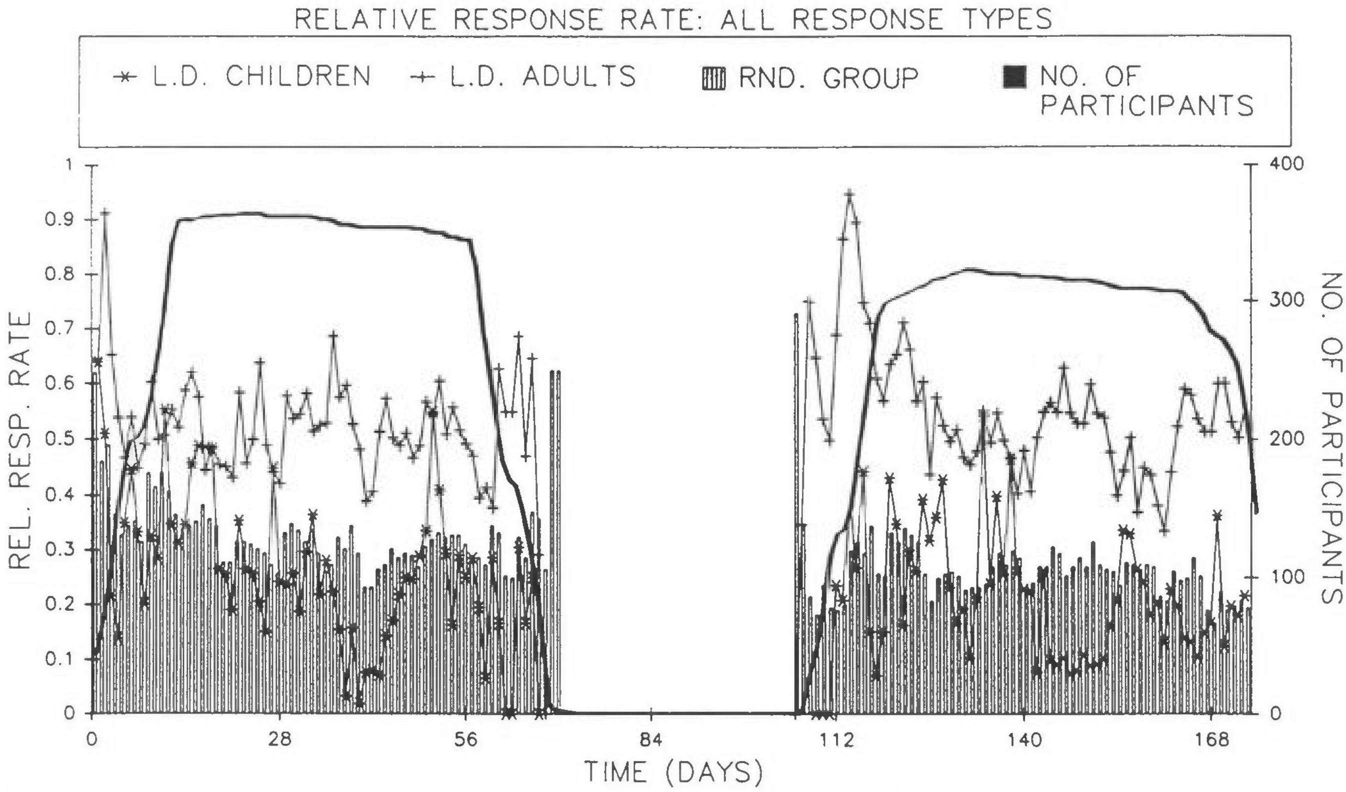

Figure 9.3: Daily variations in the response rate of all symptoms during the study (day 1 = 4 January 1988). Study population is depicted as columns. Adults with pre-existing lung disease (+) and children with pre-existing lung disease (*) are depicted as thin lines with corresponding symbols, number of participants reporting as a thick line. This last information is necessary to judge properly the fluctuations of the relative response rate (for each day, total number of hours reported in each group divided by total number of hours registered for that day and group).

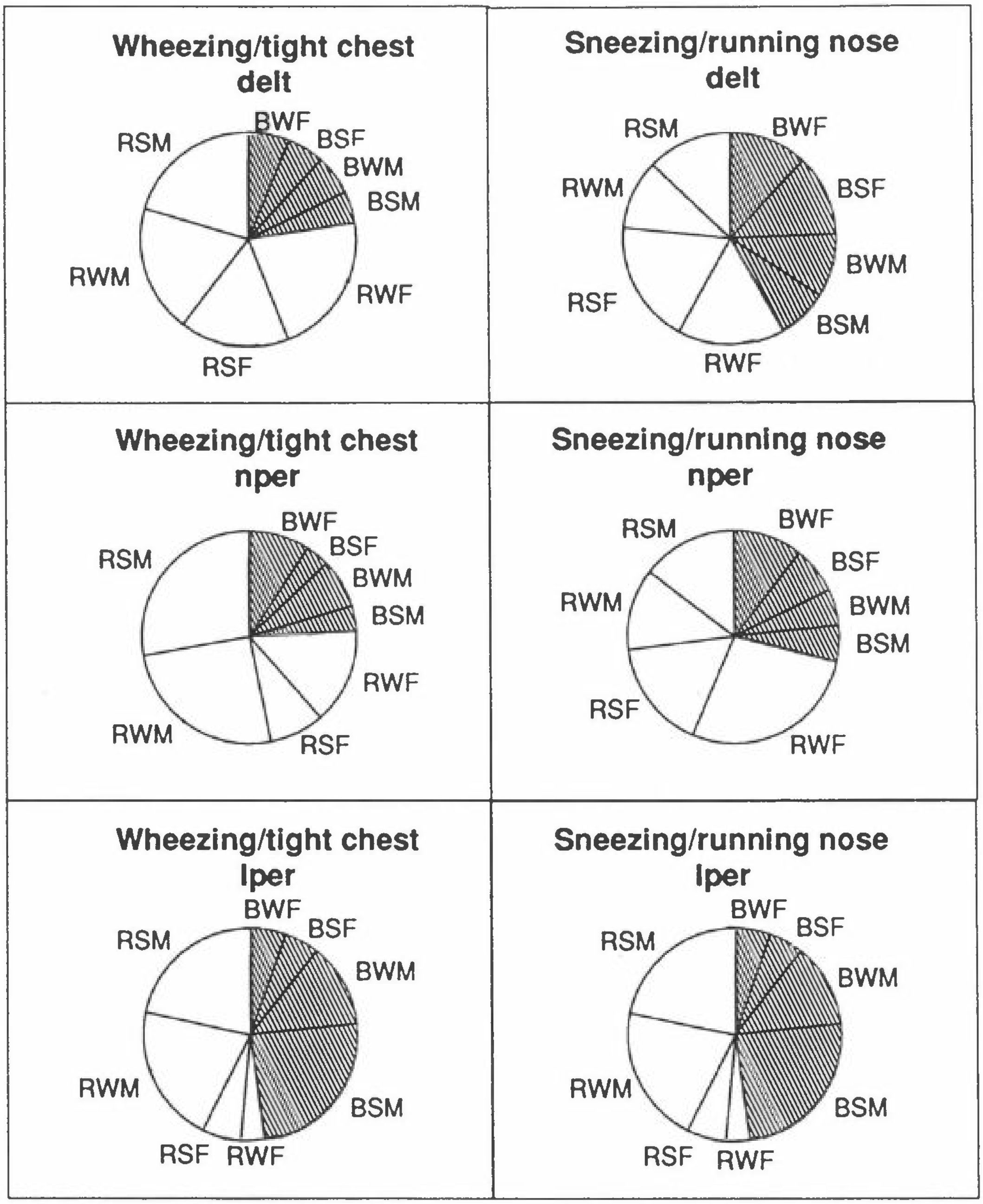

Figure 9.4: Relative number of participants with symptom ("delt"), relative number of episodes with symptom ("nper") and relative duration of reporting episode ("lper") for sneezing/running nose and wheezing/ tight chest in the study population and in the population with pre-existing lung disease. The participant populations are weighted to compensate for unequal number of participants. Diagrams are divided by participant groups (B=Randomly selected study population, R=adults with pre-existing lung disease), season (W=Winter, S=Summer) and gender (F=Female, M=Male). The group description shows which group is represented by the part of the circle, e.g. BWM represents women from the randomly selected study population in winter.

9.4 ONSET OF RESPONSES BY TIME OF DAY AND ACTIVITY

Examining the relationship between episodes of each health symptom and time of day, revealed a pattern with maximum reporting in the morning. Figure 9.5 shows this for all symptoms cumulated, but the pattern is repeated for most individual symptoms as well. Although this phenomenon is well described for some types of symptoms, such as morning cough, it is less described for the other health symptoms.

It was also noted by examining the duration of responses that the mean symptom duration is longest at night possibly indicating that individuals who do report at night tend to indicate the symptom for the entire night.

9.5 FREQUENCIES AND DURATION OF REPORTING OF SICKNESS, FEVER, ALCOHOL USE, AND USE OF MEDICATION

Each individual, in addition to filling out the symptom list on an hourly basis, filled out a set of health parameters on a daily basis (see Figure 2.2) that provided information on the use of medication, whether or not the individual was sick, consumed alcohol, etc. These data may be used both as separate response variables and as explanatory factors for the variation in the hourly reported symptoms.

The relationship between being sick and individual's general feeling of well-being on a daily basis (daily form) was studied. This parameter can be used in the final model of the effects of air pollution as a better indicator for illness than a direct question about being sick, since being sick was associated with possibly having stayed at home (see Figure 2.2). Generally, those who were sick reported lower well-being on days with sickness. But there were cases where individuals indicated being sick and yet said they were in good shape (highest well-being).

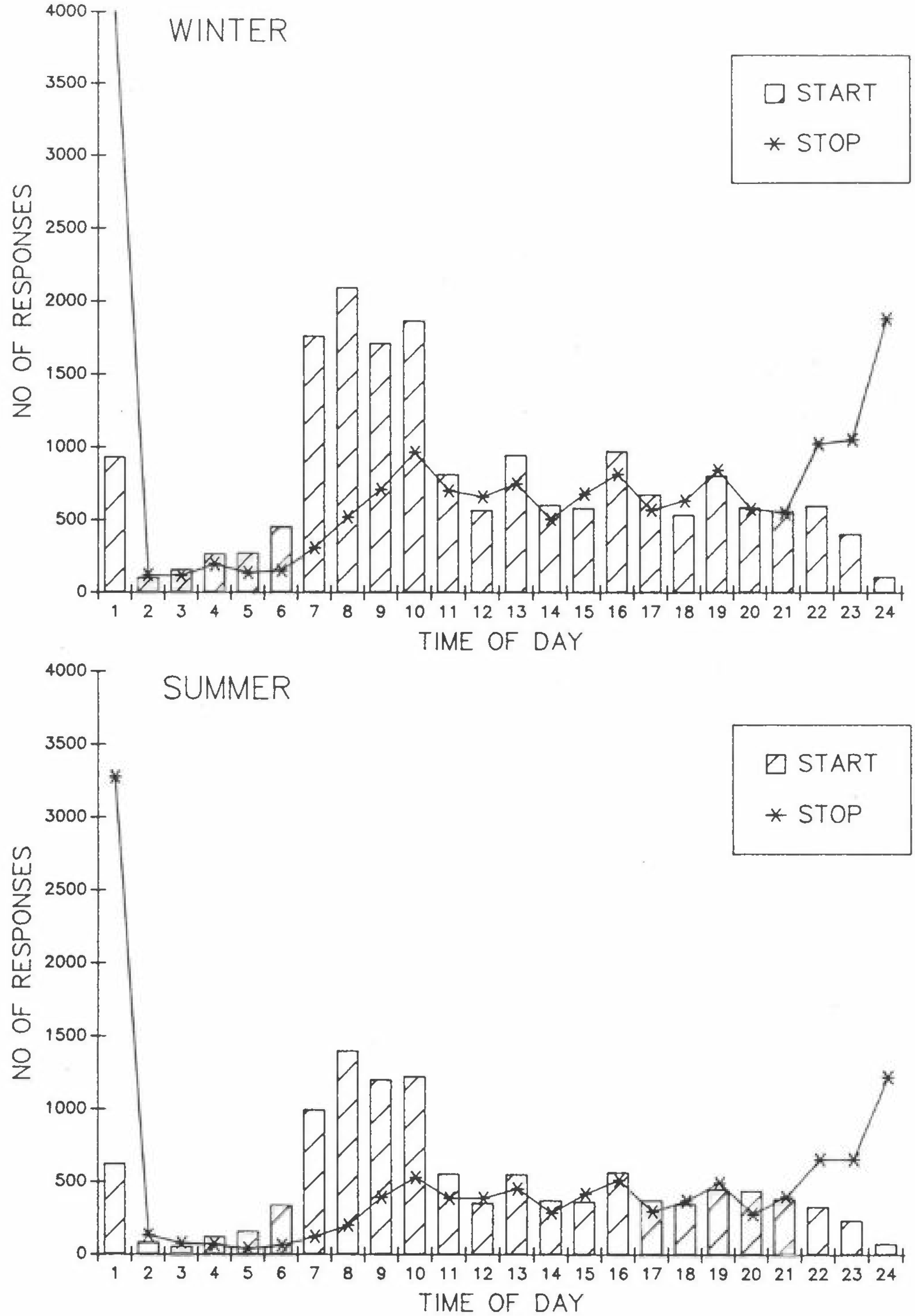

Figure 9.5: Variations in number of responses of all symptoms cumulated, as a function of time of day and season. Hour of start of the response is the first hour of response period, hour of stop is the first hour the response was not reported after a response period.

Reduced daily form is reported more often by the elderly, by those with pre-existing lung disease, by men and in winter. Men and women were sick approximately the same amount of time.

The use of medication (in addition to that taken regularly) was recorded daily. Most individuals took a pain killer during the measuring period. There were obvious differences in use of medication between those having pre-existing lung disease and the study population. The lung disease group took anti-asthmatic medication more often in addition to antibiotics and typical cold medication. There was not a noticeable difference in medication use between men and women with the exception of pain killers, psycholeptic preparations, muscle relaxants and anti-inflammatory or anti-rheumatic medication which were more used by women. More people under 50 years took medication (with the exception of medications used in heart disease).

Alcohol is primarily consumed during the weekends, with no statistical differences between men and women in alcohol consumption, but adults with pre-existing lung disease reported consumption less often.

9.6 ASSOCIATIONS BETWEEN RESPONSES

The first step in looking into the possibility of combining several health symptoms into a new variable is to investigate their interrelationships. For each individual and each pair of symptoms an association is described as per cent of hours the two symptoms were reported simultaneously out of all hours when at least one of those symptoms occurred. This excludes the hours when none of the symptoms was present. A measure of strength of a given association can be simply that the association is larger than zero (at least one hour of simultaneous occurrence), or larger than a given percentage.

More than 30% of participants had associations greater than zero between feeling feverish and sneezing, throat irritation and sneezing, and headache and feeling feverish, in other words between those symptoms typically associated with colds or influenza. Other associations seemed less easily explained. There did not seem to be any clearly defined group of individuals that had any special associations between symptoms.

Tables 9.6 and 9.7 give percentages of each adult participant population (divided by gender) with an association between two symptoms greater than 10%. The symptom coding is given in Table 9.5. Children are not presented.

Table 9.5: Coding of symptoms as used in Tables 9.6 and 9.7.

12 annoying noise	21 throat irritation
13 annoying smell	22 coughing
14 annoying industrial smell	23 wheezing/tight chest
15 headache	24 difficult breathing
16 dizziness	25 muscle pains (neck/back)
17 nausea	26 stomach pains
18 eye irritation	27 nervous/restless
19 sneezing/running nose	28 fatigue
20 feeling feverish	

Table 9.6: Per cent of the randomly selected study population with an association between pairs of symptoms over 10%. Percentage for women under diagonal (total=153 women), percentage for men over diagonal (total=138 men). Symptoms coded according to Table 9.5.

		Men																
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	12		1	1	-	-	-	1	-	2	1	1	1	2	1	2	1	10
	13	3		1	-	1	1	1	-	1	1	1	-	1	-	1	-	-
	14	3	2		-	1	-	1	-	-	-	-	-	-	-	-	-	-
	15	1	1	1		11	6	11	12	12	7	2	5	10	4	4	10	2
	16	1	1	1	7		2	1	2	2	-	1	-	1	1	2	1	1
W	17	1	1	2	5	5		3	7	4	2	1	3	1	5	7	8	2
o	18	1	-	1	7	-	2		5	2	6	3	3	4	1	1	3	-
m	19	-	1	-	14	3	5	7		23	21	7	7	7	1	-	12	-
e	20	1	1	2	11	2	3	4	18		8	5	7	4	4	1	9	4
n	21	1	-	1	8	2	3	5	20	11		8	9	9	1	1	5	2
	22	-	1	-	4	1	-	3	6	3	13		12	8	-	1	10	3
	23	-	1	1	5	4	1	7	7	4	9	14		7	1	1	2	3
	24	-	1	1	10	2	2	3	6	5	9	5	6		3	1	8	1
	25	-	-	-	5	2	11	3	5	3	5	1	4	1		2	11	1
	26	-	-	1	5	4	5	1	1	2	1	1	1	3	1		5	1
	27	-	1	2	13	4	8	5	8	7	12	10	3	4	12	3		-
	28	10	1	-	4	1	1	-	1	3	1	-	1	1	2	1	-	

Table 9.7: Per cent of the adult population with pre-existing lung disease with an association between pairs of symptoms over 10%. Percentage for women under diagonal (total=25 women), percentage for men over diagonal (total=34 men). Symptoms coded according to Table 9.5.

		Men																
		12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	12		3	6	-	-	-	-	-	-	3	-	-	-	-	-	-	-
	13	4		9	-	-	-	3	-	-	6	-	-	-	-	-	-	-
	14	-	-		-	-	-	-	-	-	6	-	-	-	-	-	-	-
	15	-	-	-		9	6	6	9	9	6	3	6	6	6	3	-	6
	16	-	-	-	3		9	3	-	3	-	3	-	3	3	3	-	3
W	17	-	-	-	16	-		3	-	-	6	-	-	3	-	9	-	6
o	18	-	-	-	-	-	-		9	3	9	6	3	3	-	-	-	6
m	19	-	4	-	20	-	-	12		3	12	12	6	9	3	3	3	3
e	20	-	-	-	12	4	8	4	8		3	3	6	6	3	-	-	6
n	21	-	-	-	16	4	-	8	12	12		26	6	9	3	-	-	3
	22	-	-	-	12	-	8	4	12	12	16		12	15	6	-	-	-
	23	-	-	4	4	-	4	4	8	4	4	12		29	3	-	-	-
	24	-	1	-	1	-	-	12	4	8	2	16	16		3	-	-	3
	25	-	-	-	8	-	4	-	-	-	-	-	-	-		-	-	3
	26	-	-	-	-	-	4	-	-	-	-	-	-	-	-		-	-
	27	-	-	-	4	4	-	-	-	4	4	4	-	-	4	-		-
	28	-	-	-	20	-	12	8	8	16	12	16	-	8	4	4	4	

9.7 CONCLUSIONS

Most of the findings reported in this chapter are summarized in Table 9.8. The table is to be considered as a descriptive tool rather then an analytical one. The three characteristics of each symptom (number of participants who responded at least once, (referred to as "delt"); mean duration of episodes of symptoms for those who responded (referred to as "LPER"); and mean number of episodes for those who responded (referred to as "NPER") are treated separately. For each type of symptom and tested parameter (f.ex. participant group, season, gender, etc.) a cell of the table indicates a result of a t-test for each of the three characteristics. The univariate test level was set at 10%. Each test compares one group to a reference group. The group functioning as a reference is given in the table heading, together with the number of participants in the reference group. In a cell, a "+" sign indicates a significant increase with respect to the reference category, and a "-" sign a decrease.

Table 9.8: Statistically significant differences between subgroups. Univariate significance level is 10%. Factors defining groups were dichotomized (yes/no), reference category and number of participants (N) are indicated. Sign "+" indicates increase in characteristics (delt, LPER of NPER) from reference to tested category, sign "-" indicates decrease. Line "delt" summarizes results for number of participants who reported a symptom at least once, LPER summarizes results for mean length of episode with response (only individuals who reported given symptoms included), and NPER indicates results for mean number of episodes of symptoms (only individuals with reported symptom are included).

Factor	Participant group	Season	Gender	Age	Smoking	Work exposure possible	Working at home only	Cons. alcohol	At least one sick day
Reference category	Randomly selected study population	Winter	Women	Under 50 yrs	Non-smokers	No	No	No	No
(N)	(292)	all indiv.	(187)	(240)	(185)	(317)	(276)	(113)	(221)
SYMPTOM									
Annoying noise									
delt		-				+		+	
LPER	+						+		
NPER							+		
Annoying smell									
delt		-	-						+
LPER									
NPER				-		+			
Annoying ind. smell									
delt									
LPER									
NPER						+		+	
Headache									
delt		-	-			-		+	+
LPER			-						
NPER			-			-			
Dizziness									
delt		-	-		+	-			+
LPER				-					
NPER									

Table 9.8 Cont.

Factor	Participant group	Season	Gender	Age	Smoking	Work exposure possible	Working at home only	Cons. alcohol	At least one sick day
Reference category	Randomly selected study population	Winter	Women	Under 50 yrs	Non-smokers	No	No	No	No
(N)	(292)	all indiv.	(187)	(240)	(185)	(317)	(276)	(113)	(221)
SYMPTOM									
Nausea									
delt		-	-						+
LPER			+			+			
NPER	+		-			-			
Eye irritation									
delt	+		-			-			
LPER									-
NPER							+		
Sneezing/running nose									
delt	+		-				-		+
LPER		+	+		-	+	-		
NPER	+			-	-	-			
Feeling feverish									
delt		-	-						+
LPER									+
NPER									
Throat irritation									
delt		-	-		+			+	+
LPER	-	+			+				
NPER									
Coughing									
delt	+		-					+	+
LPER		+				+			
NPER									
Wheezing/tight chest									
delt	+								+
LPER			+		-	+			
NPER									
Difficult breathing									
delt	+	-					+		+
LPER					-				
NPER	+		+						

Table 9.8 Cont.

Factor	Participant group	Season	Gender	Age	Smoking	Work exposure possible	Working at home only	Cons. alcohol	At least one sick day
Reference category	Randomly selected study population	Winter	Women	Under 50 yrs	Non-smokers	No	No	No	No
(N)	(292)	all indiv.	(187)	(240)	(185)	(317)	(276)	(113)	(221)
SYMPTOM									
Muscle pains									
delt		-	-					+	+
LPER									
NPER									
Stomach pains									
delt		-	-			-		+	+
LPER			+						
NPER									
Nervous/restless									
delt		-	-			-	+	+	
LPER									
NPER									
Fatigue									
delt		-	-						+
LPER								+	
NPER									+

For illustration of Table 9.8, let us take as an example a result for nausea, when the participants are stratified by gender. A minus sign in the "delt" line indicates that less men report nausea than women in the whole population (reference category being the 187 women). A plus sign in the "LPER" line indicates that for those who have nausea, men tend to have longer periods then women. Finally, of those who respond, men report fewer periods ("NPER") than women.

The initial phase of the investigation described in this chapter led to the following suggestions concerning further analysis of health effects of air pollution:

1. The two study groups, and subsequently men and women should be studied separately.

2. The categorization of the population into subgroups by smoking, alcohol consumption or age should be done carefully, and on a symptom by symptom basis.

3. Obvious confounding factors to be accounted for are: gender, smoking and alcohol consumption and possible work exposure to the studied compounds.

4. Variations due to the day of the week are possibly too small to warrant taking into account.

5. Since individual's daily well-being was scaled from 1 to 5, as opposed to a yes/no scaling for sickness, it seems a preferable variable to use. It probably characterizes well the period surrounding a sickness.

6. Use of each medication type should be considered as an independent health effect symptom.

10 DESCRIPTION OF OBJECTIVE HEALTH DATA FOR THE PARTICIPANTS

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10.1 CLINICAL EXAMINATION

Everyone who volunteered to participate as a subject in the project was requested to join a comprehensive physical examination in November/December 1987. The study period started the first Monday of January 1988. A preliminary examination, comprizing a comprehensive clinical examination, was carried out to characterize the participants. Each participant was assigned an identity number that followed him/her throughout the investigation. These numbers were also used to anonymize the recorded data.

In the preliminary examination, data were recorded with respect to age, height, weight, blood pressure (measured while seated with cuff on right arm), armpit temperature (recorded with electronic thermometer), heart-rate, respiration rate, psychological evaluation, skin status, throat status, eyes, chest/ lung condition, heart condition, general neurological examination (including mental status and upper arm, knee, and heel reflexes). As a comprehensive questionnaire was planned with respect to anamnestic information, the subjects were asked only about coughing and any expectorate as well as smoking habits. Attention was also paid to possible specific symptoms of illness or any other condition judged to be of significance for the outcome of the study.

The preliminary screening process also comprised full spirometry with Forced Vital Capacity (FVC), Forced Expiratory Volume at one second ($FEV_{1.0}$), and Peak Expiratory Flow (PEF). Blood samples were drawn and analysed with respect to hemoglobin (Hb), sedimentation rate (SR) and carbon monoxide (COHb). A serum sample was frozen at -20 °C. Urine samples were obtained and examined with a three point test strip for albumin, sugar, and blood. An additional urine sample was frozen. One half hour was used for the physical examination. This examination was well received by the participants, and some claimed that this was the reason why they agreed to participate in the study. One might wonder if some of them (12) speculated in this, since they did not turn up for the start of the project, but only went through the screening. The project's physicians were available for the participiants on a 24-hour basis throughout the project, and they also administered treatment where this was necessary. Otherwise there were few findings of significance to note in the examinations. The various parameters for each group are described in Chapter 3.

10.2 SPIROMETRY

10.2.1 Test description

Spirometric lung function measurements were central both in the preliminary examinations and the biweekly check-ups. FVC and $FEV_{1.0}$ were measured and recorded on a Vitalograph (model S), and PEF measurements were carried out by means of a peak flow meter of the Mini-Wright type. The PEF instrument was identical to the apparatus that the subjects had at home and which they used four times a day. During the preliminary examination process everybody were given a thorough briefing on the technique and use of the Mini-Wright peak flow meter by trained personnel. The same personnel monitored the later biweekly spirometry tests. The tests were repeated three times at each time of day and the highest value was recorded.

- FVC - Forced Vital Capacity - the volume of air a person is able to expel from full inspiration to full expiration, recorded as so-called BTPS values, i.e. calculated with respect to body temperature and degree of humidity.

- $FEV_{1.0}$ - Forced Expiratory Volume - an expression of resistance in the airways, recorded as the volume of air expelled during the first second from full inspiration of the lungs.

- PEF - Peak Expiratory Flow - also an expression of resistance in the airways, registered as the maximum volume of air expelled, measured in litres per minute.

The analysis below is based on the spirometric values obtained at the biweekly examinations.

10.2.2 Statistical analysis

a. Variation in and between individuals

For each of the three spirometric tests the recordings will show interindividual variation. This will be due to differences based on gender, height, age, and lung performance.In addition, over time the recordings for any individual will also vary. This may in part be due to ambiguous test results, and has therefore a bearing upon the validity of the readings. It may also indicate actual changes in lung function. This latter aspect can only be evaluated when it is possible to relate the changes in lung function to alterations in air pollutant levels.

As an initial analysis in this section, two main variations will be treated separately so as to produce separate estimates relative to the variation in and between individuals. For this purpose a standard variation component model is used, and this model is analysed by means of the "one way" SPSS procedure. It is important to note that the number of measurements the various individuals have undergone, vary a great deal (from 1 to 11). In this analysis no attention has been paid to the time the tests were carried out (i.e. if the time lapse between them has been large or small).

The variation components are designated $S^2{}_{in}$ and $S^2{}_{between}$ where the former records the variation from time to time for an "average" individual, while the latter records the variations between individuals. The standard deviations - which are the square roots of these figures - are recorded below.

An average for each group is also indicated. These have been computed first by calculating the average recordings of every individual to arrive at the average for all the individuals.

Randomly selected study population (312 individuals):

PEF (l/min)	average = 525	S_{in} = 24.3	$S_{between}$ = 104.5
FVC (ml)	average = 4163	S_{in} = 224	$S_{between}$ = 1050
$FEV_{1.0}$ (ml)	average = 3391	S_{in} = 200	$S_{between}$ = 898

Adults with pre-existing lung disease (66 individuals):

PEF (l/min)	average = 449	S_{in} = 37.0	$S_{between}$ = 111.1
FVC (ml)	average = 3975	S_{in} = 332	$S_{between}$ = 1156
$FEV_{1.0}$ (ml)	average = 2730	S_{in} = 356	$S_{between}$ = 1052

Children with pre-existing lung disease (18 individuals):

PEF (l/min)	average = 345	S_{in} = 37.1	$S_{between}$ = 104.5
FVC (ml)	average = 2766	S_{in} = 296	$S_{between}$ = 1155
$FEV_{1.0}$ (ml)	average = 2101	S_{in} = 305	$S_{between}$ = 882

Commentary:

The variation in recordings for adults with pre-existing lung disease is from 50 to 80 per cent higher than for those without lung disease. The variation between individuals with pre-existing lung disease is somewhat greater than is the case noted for healthy individuals, although it is not much greater. The variation from time to time for children with lung disease is almost as great as is the case for adults with lung disease.

b. Analysis of individual averages

A more detailed analysis has been performed of the variations in spirometric values between individuals in order to determine the degree to which such variations can be explained by gender, age, height, or smoking habits. Also a comparison has been made between those with pre-existing lung disease and those who do not have such disease. For every individual and for every one of the three spirometric tests, recordings have been considered to be derived from the full number of tests carried out on this individual. Only adults will be considered.

First of all, multiple regression analyses were performed, since they can provide a general insight into the effects involved. Initially, simple and unweighted analyses have been carried out. As background data are lacking for some individuals, because of incomplete anamnestic information, these individuals were excluded from the analyses. In all the analyses, the average value of PEF, FVC or $FEV_{1.0}$ are treated as dependent variables, while the independent variables were:

- gender (1 = male, 2 = female)
- age in years
- age in years, to the second power
- height in centimeters
- smoking (number of cigarettes smoked per day)
- lung status (0 = healthy, 1 = lung disease)

The square of the age was included in order to evaluate any non-linear reduction in spirometric values with advancing age.

Results of the regression analysis are presented below in Table 10.1.

In Table 10.1 the coefficients have been established for the variables together with the associated test values (t-value). If the absolute value of t is greater than 2.0, then the p-value is below 5 per cent, and if the value is greater than 2.6, the p-value is below 1 per cent.

Table 10.1: Results of the regression analysis for all spirometric values.

VARIABLE	PEF		FVC		$FEV_{1.0}$	
	Coeff	t	Coeff	t	Coeff	t
Constant	116	0.81	-3974	-3.28	-2068	-1.76
Gender	-101	-8.73	- 617	-6.25	- 396	-4.13
Age	4.62	2.39	20.8	1.27	- 2.25	-0.14
Age squared	- 0.075	-3.77	- 0.57	-3.40	- 0.36	-2.17
Height	3.12	4.40	56.1	9.36	41.0	7.03
Smoking	- 2.03	-3.39	- 16.2	-3.20	- 17.7	-3.59
Lung status	- 92.6	-8.68	- 368	-4.07	- 676	-7.69
Explained variation		61%		70%		65%

Comments:

Two thirds of the variations can be explained as being due to background variables. Recordings for males were significantly higher than those for females, also when values were adjusted for height. For instance, males have, on average, a PEF value which is approximately 100 l/min higher than that of females. Age is also important, but it is especially the second power component which dominates. The correlations between height as well as smoking are very clear and as expected. Individuals with pre-existing lung disease recorded significantly lower values than those who are healthy; e.g. the PEF value is on average 90 l/min lower.

Figures 10.1 and 10.2 present illustrations of such correlations. Only PEF values are represented.

A noticeable reduction in lung function is seen from age 50 and beyond (Fig. 10.1). The second order element in the regression equation reveals that the reduction is not linear with age, but that it only starts at a certain age.

A very clear correlation with height is also seen (Fig. 10.2), and it is evident that the correlation is very close to being linear.

A comparison has also been made for the FVC and $FEV_{1.0}$ values recorded in the present investigation with the values developed from the Gulsvik equation (1985) for the study population. This group should be comparable whith the individuals Gulsvik used as basis for deriving this equation. The correlation index (CORR) is given from the equation:

CORR = (Grenland/Gulsvik) X 100%

This resulted in the following:

FVC : the mean value was 98.0% and standard deviation 13.5%

$FEV_{1.0}$: the mean value was 94.3% and standard deviation 15.1%

The low quartile for FVC was 89.4% and the high 107.2%. For the $FEV_{1.0}$ the low quartile was 85.6% and the high 105.1%. The correlation is also shown in the histograms below (Figures 10.3.1-10.3.4).

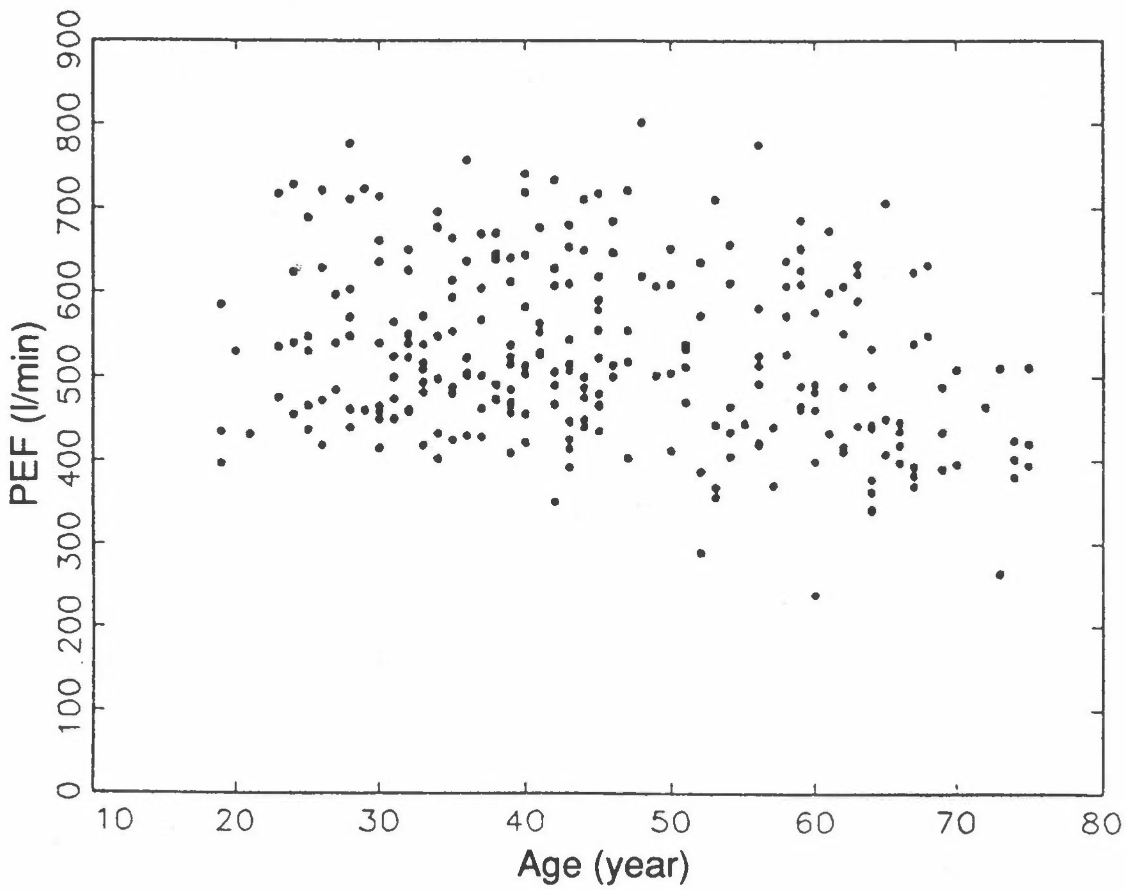


Figure 10.1: Spread chart of peak expiratory flow (PEF) against age for the randomly selected study population (N=265).

10.3 BLOOD TESTS

At every second biweekly check-up blood samples were taken. Hemoglobin (Hb), sedimentation rate (SR) and carboxyhemoglobin (COHb) were analysed directly. A volume of thirty ml blood was centrifuged, serum siphoned off with a pipette and frozen down.

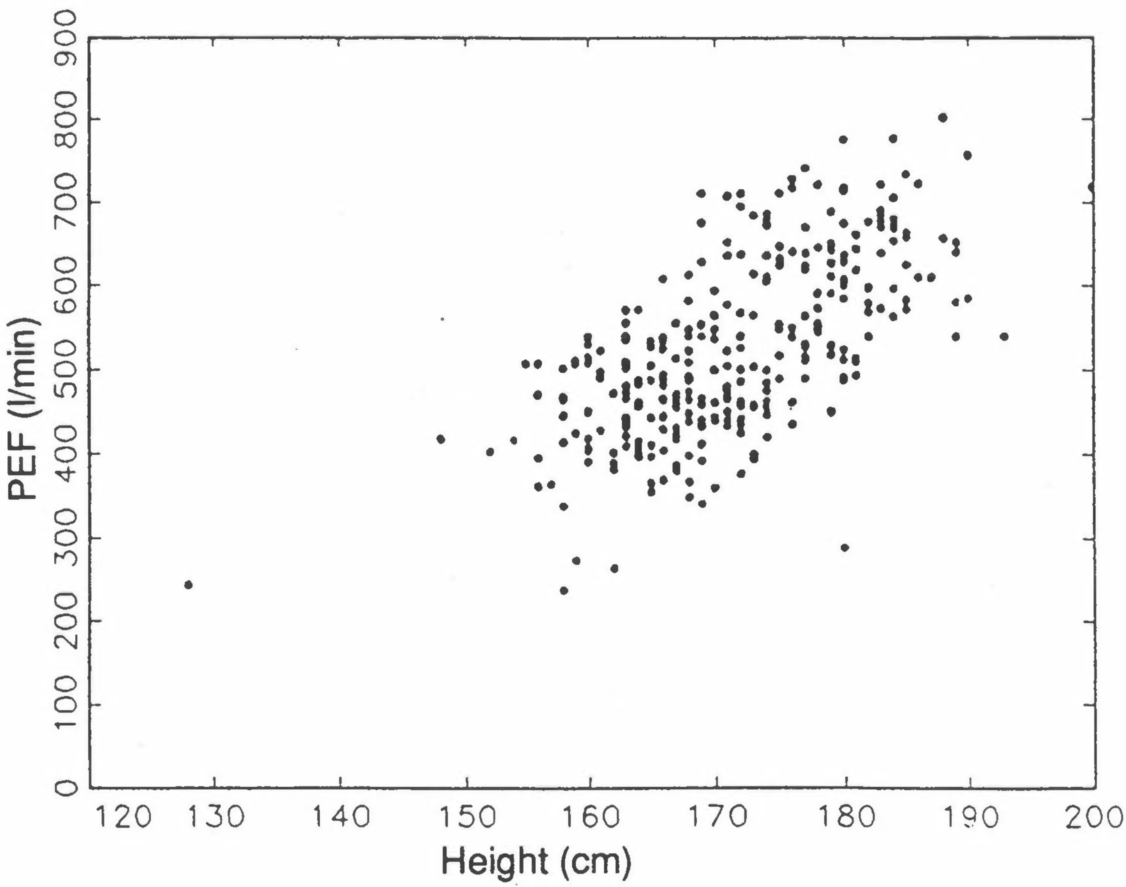


Figure 10.2: Spread chart of peak expiratory flow (PEF) against height for the randomly selected study population (N=309).

10.3.1 Carboxyhemoglobin

In this analysis COHb was studied in relation to information about smoking recorded on the status praesens forms. As for spirometry, the number of tests varied somewhat between individuals. As previously, the average values of the actual tests were analysed.

As in the case of spirometry, the variations in and between individuals were first studied giving the following results:

Randomly selected study population (312 individuals):

COHb (%) average = 2.50 S_{in} = 0.72 $S_{between}$ = 1.85

Adults with pre-existing lung disease (66 individuals):

COHb (%) average = 1.73 S_{in} = 0.49 $S_{between}$ = 1.09

Children with pre-existing lung disease (18 individuals):

COHb (%) average = 1.08 S_{in} = 0.43 $S_{between}$ = 0.47

There is a significant variation between individuals. This is especially noticeable among adults, and can most likely be attributed to the fact that this group includes smokers.

Further, analysis was performed on the average COHb values (computed on basis of all tests) for every individual. An analysis of average COHb against background variables revealed that only smoking had any significant effect. Neither age, gender, nor marital status added much. Therefore, only the influence of smoking will be considered in the following.

Non-smokers of all ages, altogether 233 individuals, had an average COHb value of 1.18 per cent. The correlation between smoking and COHb value was found to be 0.77. These values cannot be compared with those from other Norwegian investigations due to differences in methodology.

The calculated correlation is obvious, as smokers also have a higher COHb value than non-smokers. Among those who report smoking little, there are also some individuals with higher COHb values. This may at least partly be due to underreporting of smoking. Some participants quit smoking during the study. This will, due to the use of mean values, result in a too high COHb value for someone registered as a non-smoker (0 cigarettes per day).

To describe the calculated correlation between COHb-values and tobacco use as being linear may seem rather dubious. Nevertheless, a linear regression was performed to include all individuals, which resulted in the following:

$$COHb (\%) = 1.45 + 0.216*(\text{number of cigarettes})$$

However, such a line will be turned upwards because of a few extreme COHb values for individuals with low reported levels of cigarette smoking. For this reason the 1.45 per cent figure is higher than the number for non-smokers (1.18 per cent) listed above. Smoking explains 60 per cent of the COHb variation. If the other background variables are included, the explained variation is not much increased.

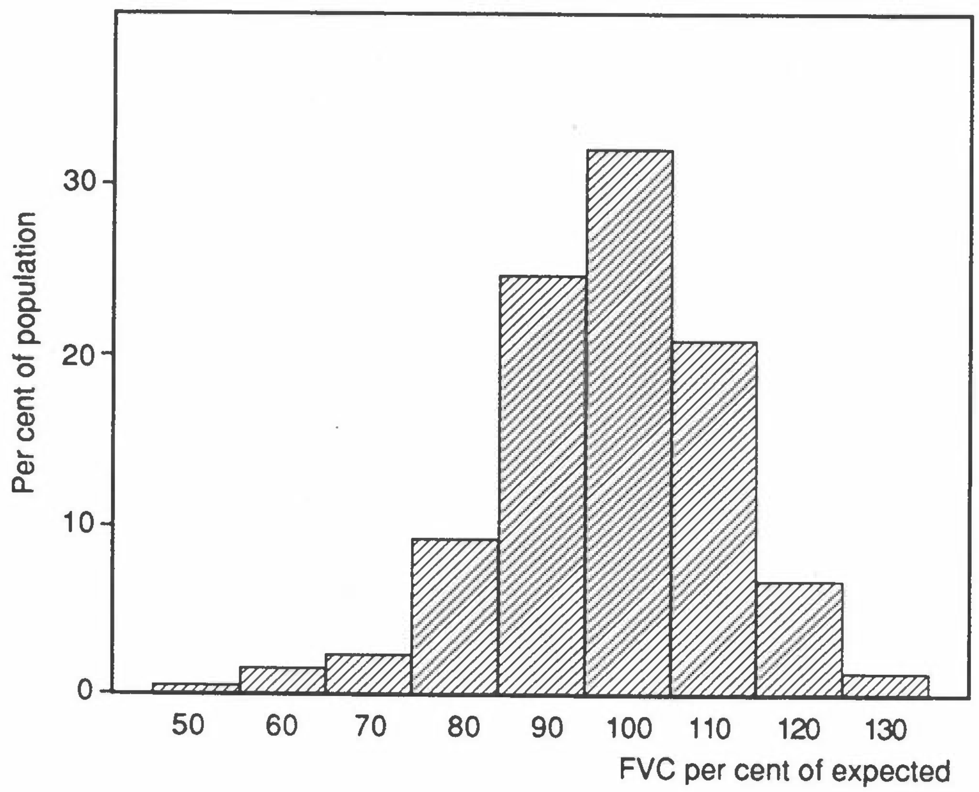


Figure 10.3.1: Forced vital capacity (FVC) in the randomly selected study population (N=309) compared to Norwegian Standards (Gulsvik, 1985).

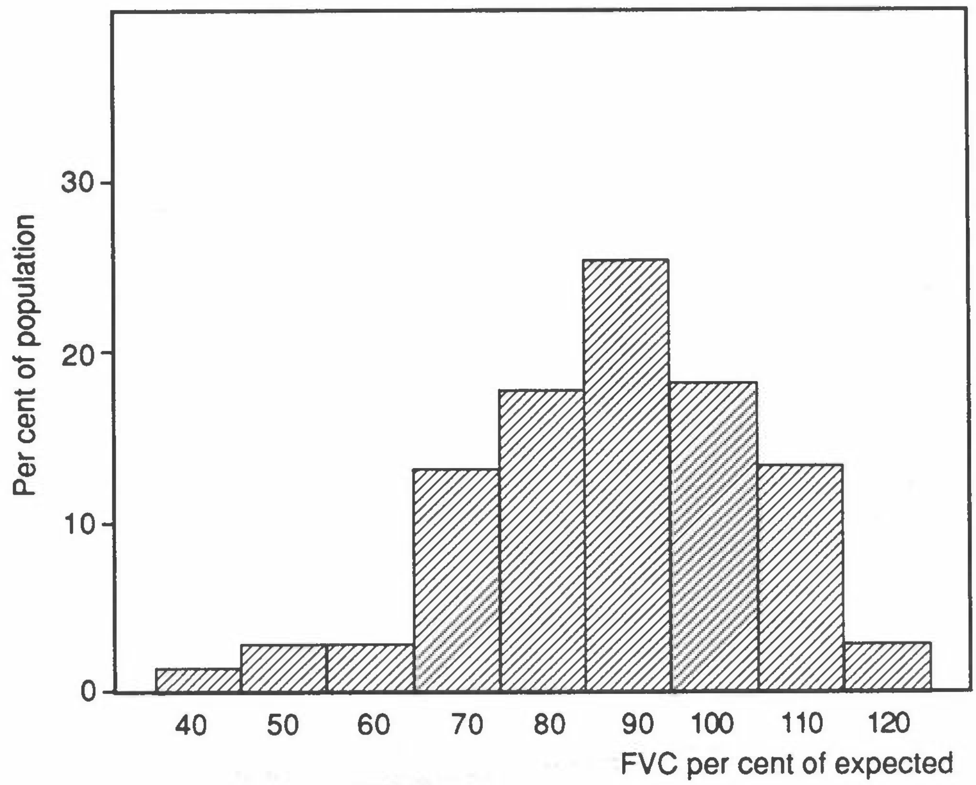


Figure 10.3.2: Forced vital capacity (FVC) in adults with pre-existing lung disease (N=66) compared to Norwegian Standards (Gulsvik, 1985).

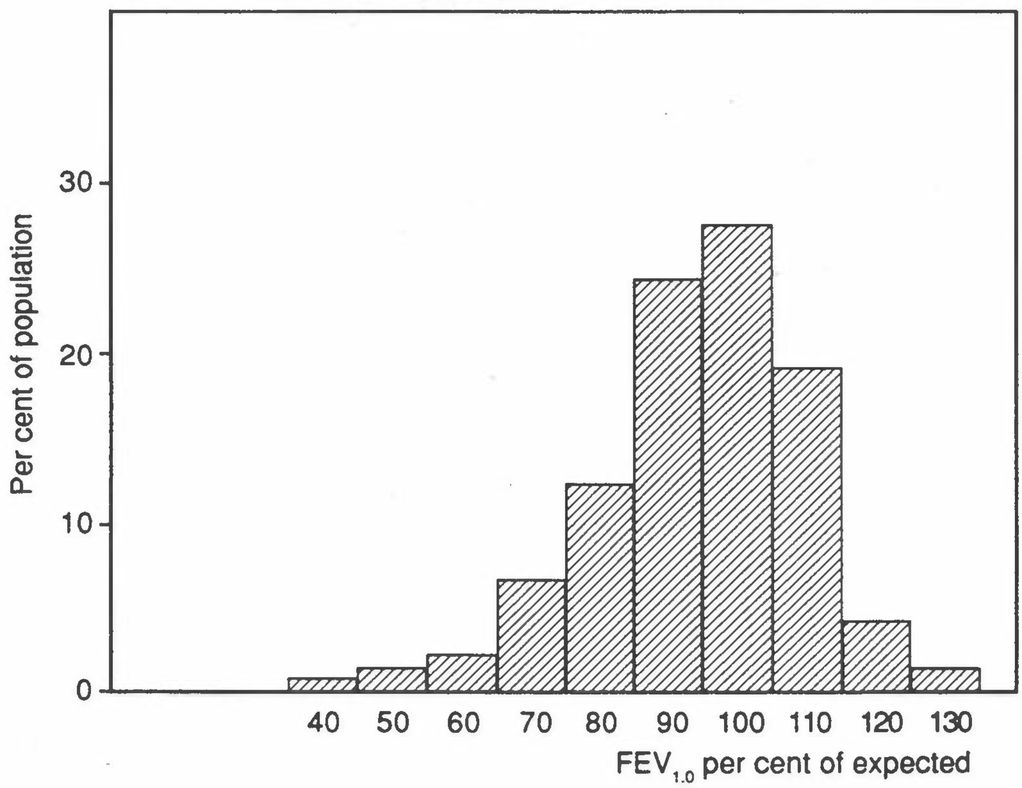


Figure 10.3.3: Forced expiratory volume ($FEV_{1.0}$) in the randomly selected study population (N=309) compared to Norwegian Standards (Gulsvik, 1985).

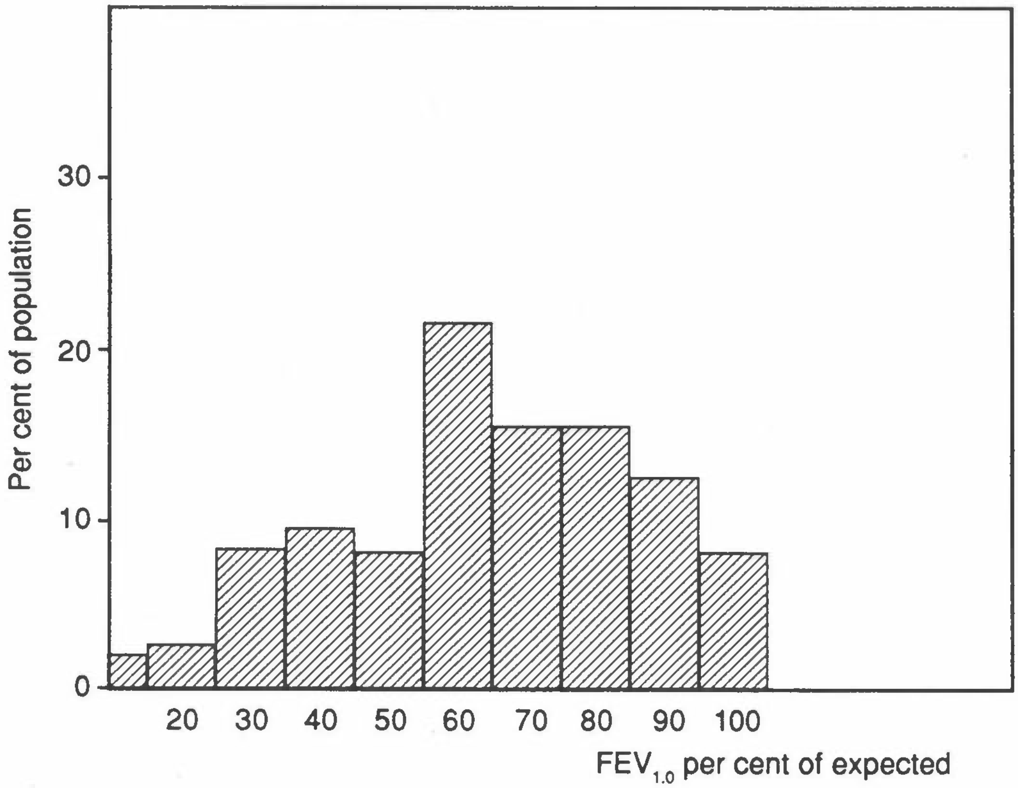


Figure 10.3.4: Forced expiratory volume ($FEV_{1.0}$) in adults with pre-existing lung disease (N=66) compared to Norwegian Standards (Gulsvik, 1985).

10.3.1.1 Analysis of COHb against daily smoking information obtained from the diary form

In the previous section COHb has been analyzed against information on smoking from the status praesens forms. It should also be of interest to compare COHb levels with information derived from the diary form, since information from the latter possibly is more reliable than information recorded at the preliminary examination. In all, there are relevant data for 368 individuals. Among these are 148 smokers and 220 non-smokers. The average COHb value was found to be 1.13 per cent (previously 1.18 per cent). The correlation between smoking and COHb value is now 0.83 (previously 0.77).

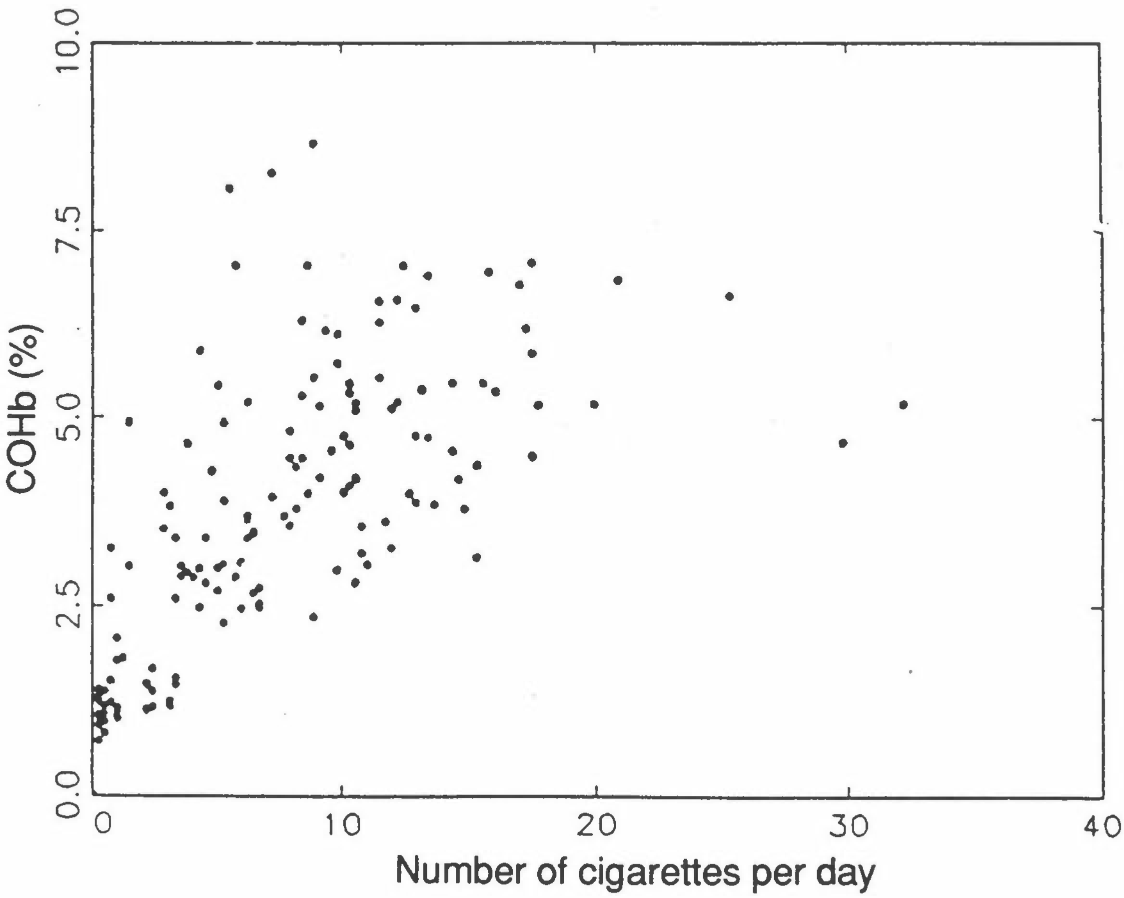


Figure 10.4: Carboxyhemoglobin (COHb)-values for the 148 smokers in the Grenland project (number of cigarettes per day ascertained from the diary).

Figure 10.4 shows the relationship between COHb values and the number of cigarettes smoked. The results correspond reasonably well with the previous data based on the status praesens forms. The increase in COHb with cigarette consumption is even steeper here, this is due to the lower reporting of cigarettes smoked in the diaries compared to that from the status praesens form.

10.3.2 Sedimentation rate (SR)

During the project 2297 sedimentation reactions were recorded and only 87 were registered as pathological (above 30 mm/h). These were obtained from 55 individuals of whom 14 belonged to the adult group with pre-existing lung disease. The average SR was 10.1 mm/h. The causes for the pathological sedimentation

10.4 URINE TESTS

During the course of the project, a total of 3344 urine samples were analyzed by means of test strips. The tests covered hemoglobin (blood in the urine), protein (albumin) and glucose (sugar).

With respect to protein 97.4 per cent of all tests were negative and traces were found in only 2.2 per cent. Of the grand total of 3344, only 11 samples were clearly positive for protein. These were all followed up clinically.

With respect to glucose 96.7 per cent of the tests showed no sign of sugar in the urine and only 2.1 per cent showed traces of it. Slightly more than 1 per cent tested positive for glucose and these were followed up.

Concerning blood in the urine, 88.2 per cent of the tests were negative. Of the close to 12 per cent that to varying degrees registered positive, nothing was done in the cases where it was reason to believe that it was caused by menstrual bleeding. These constituted the greater part, and only a few needed to be followed up clinically. In addition to the strip test, urine samples were frozen down (20 ml, and for the winter period an additional 4.5 ml) for later use (nicotine/cotinine measurements).

10.5 MICROBIOLOGICAL TESTS

At the beginning and the end of the study throat swab samples were obtained from all participants, and these were analyzed with respect to the presence of Hemophilus influenza bacteria and meningococci. Of a total of 651 samples, 363 were positive for Hemophilus influenza, but few were pathological. Hemophilus influenza was classified by the participating laboratory as belonging to the normal bacterial flora of the throat.

reactions were to a large extent known (rheumatoid arthritis, etc.), some were also due to acute infections (pneumonia, etc.).

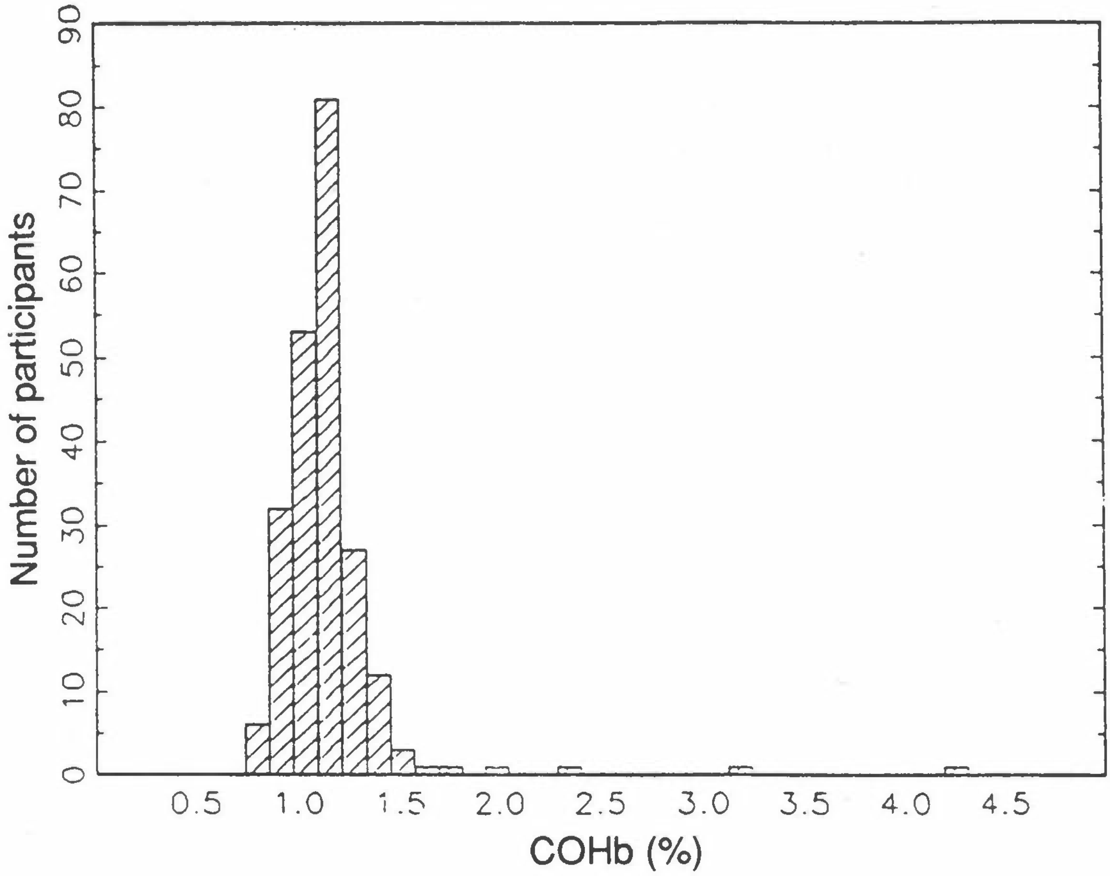


Figure 10.5: Carboxyhemoglobin (COHb)-values for the 220 non-smokers in the Grenland project (smoking status ascertained from the diary).

10.3.3 Hemoglobin (Hb)

Hemoglobin was measured a total of 2336 times during the project. The mean value was 13.5 g/100 ml with a standard deviation (SD) of 1.2 g/100 ml, so that 2 SD were within the normal values.

In all, 40 samples with meningococci were found. In a further separate study (to be reported elsewhere), the bacterial strain was "finger-printed", and no pathological strains were found among the subjects in the Grenland project.

10.6 DAILY MEASUREMENTS OF PEF

As a part of the daily reporting of health symptoms, the participants in the project were to measure peak expiratory flow (PEF) four times every day. The intention of the PEF measurements was to determine if - and in such cases to what extent - air pollution would influence lung function. In this section, it is discussed whether the present data are suitable for such an evaluation. A description is therefore given of how the reporting of the PEF measurements was performed. Further, a description is given of the variation in PEF measurements over the day, over the days of the week and throughout the study period. In addition, the daily PEF measurements have been compared to the PEF measurements at the bi-weekly health examinations. All in all, the follow-up on PEF measurements seems to be satisfactory and the data should allow for detection of moderate changes in PEF values caused by exposures when these are determined without considerable error.

The participants in the study were given PEF meters of the type Mini-Wright. The results were to be reported in columns on the backside of the diary. At each measurement the participants were instructed to make three expirations. In the winter period only the maximal measurement was to be reported, while in the summer period all three results were to be given.

10.6.1 Follow-up over the day

The participants were asked to make the meaurements evenly distributed throughout the day. It was suggested that the first measurements should be made around 8 a.m., the second around 12 a.m., the third around 4 p.m. and the fourth around 8 p.m. In Figure 10.6 is shown how the measurements were actually distri-

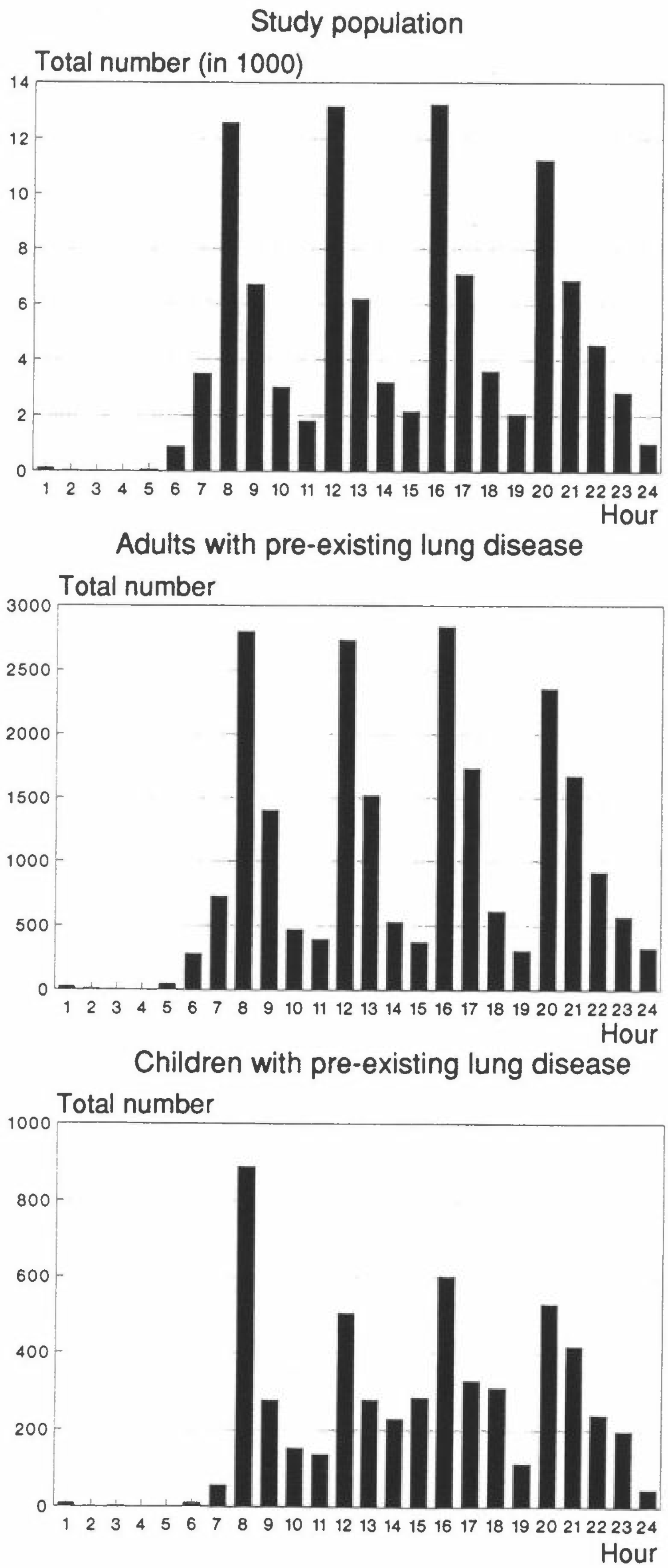


Figure 10.6: Number of PEF measurements per hour for the randomly selected study population, for adults with pre-existing lung disease and for children with pre-existing lung disease.

buted throughout the day in the randomly selected study population, among the adults and children with pre-existing lung disease, respectively. It is evident that the adults, both in the study population and among those with lung disease, managed to follow the scheme quite well. The children also in most instances managed to follow the scheme, but in this group a greater variation around the suggested timepoints for measurements is displayed. For all groups the greatest variation around suggested timepoints occurred at the last measurement of the day.

10.6.2 Variation in PEF over the day

It is well known that lung function varies over the day (Clark and Hetzel, 1977). It is lower in the morning, especially just after awakening, and in the evening. It is thus a requirement for consistency in the recorded data that such a variation can be found. In Figure 10.7.1 a first simple attempt to show this variation is given. The figure shows deviations from the total mean of all PEF measurements at each hour throughout the day in the three groups. However, the expected variation is not evident.

The results from the next analysis are shown in Figure 10.7.2. These results are derived from a two-way analysis of variance (without interaction), with the factors individual and hour. The figure shows the deviations at each hour compared to the mean after adjusting for differences between individuals. It is now evident that a clear variation over the day appears in all three groups of participants.

The reason for it being necessary to adjust for individual values in this analysis, is based on at least two aspects. One is that the variation between individuals is large compared to the variation over the day. Thus, the daily variation may easily disappear in the individual variation. In this respect

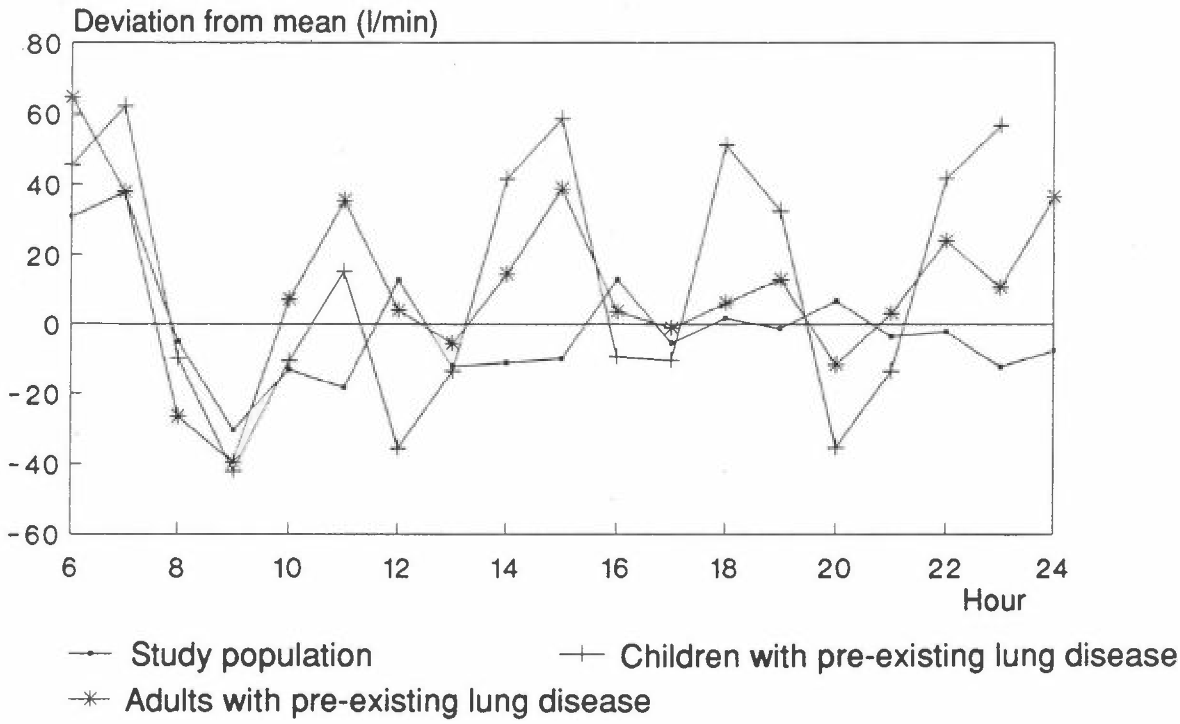


Figure 10.7.1: Deviation from mean PEF values during the day, uncorrected for individual differences.

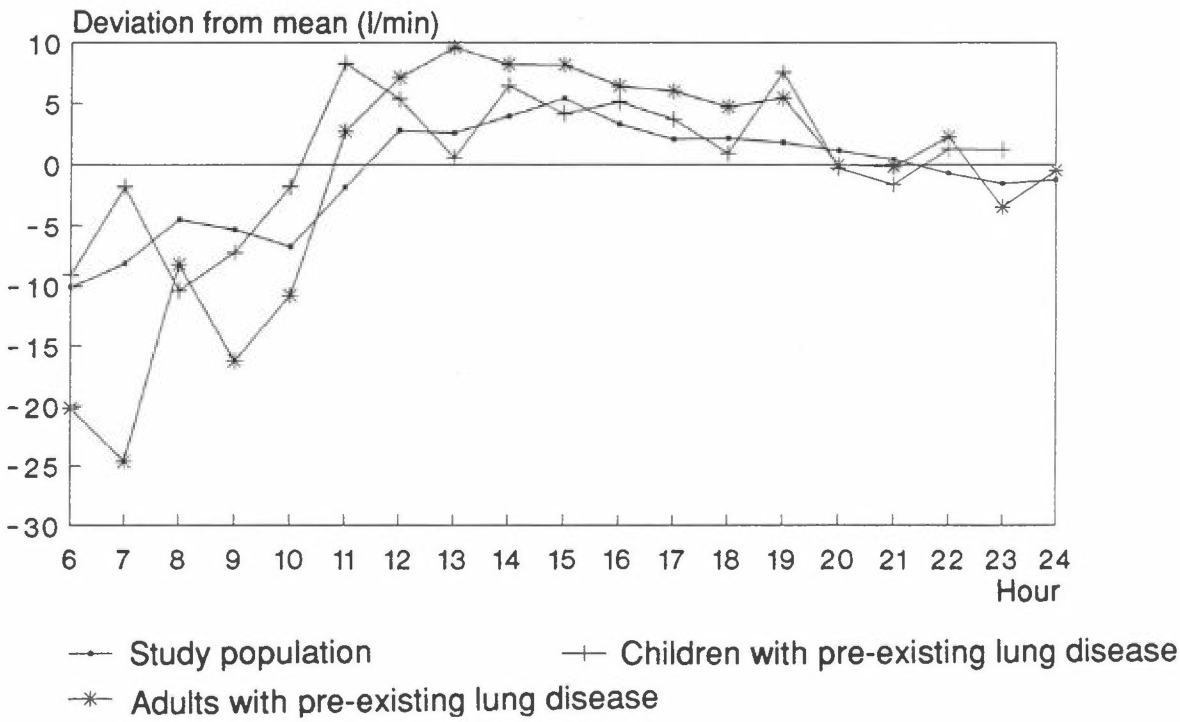


Figure 10.7.2: Deviation from mean PEF values during the day, corrected for individual differences.

it should be noted that the span of the scale in Figure 10.7.1 is much larger than that of Figure 10.7.2. Another reason that adjustment for individual differences is necessary, is that persons with high PEF values may systematically perform the measurements at different times, particularly early in the morning, than persons with low PEF values.

It should also be noted that here only the variation has been estimated on an hourly basis and not adjusted for time since awakening. In Chapter 12 results will be given which indicate that both time of day and time since awakening may influence PEF values.

10.6.3 Follow-up during the week

The daily tasks people regularly perform may be different on different week-days and it therefore may seem plausible that follow-up has varied throughout the week. In Figure 10.8 the proportion of measurements performed on different week-days is shown. On the average 1/7 = 0.143 (14.3%) of the measurements are made each day. It is clear from the figure that the follow-up is less close during the weekend, but there are no extreme variations.

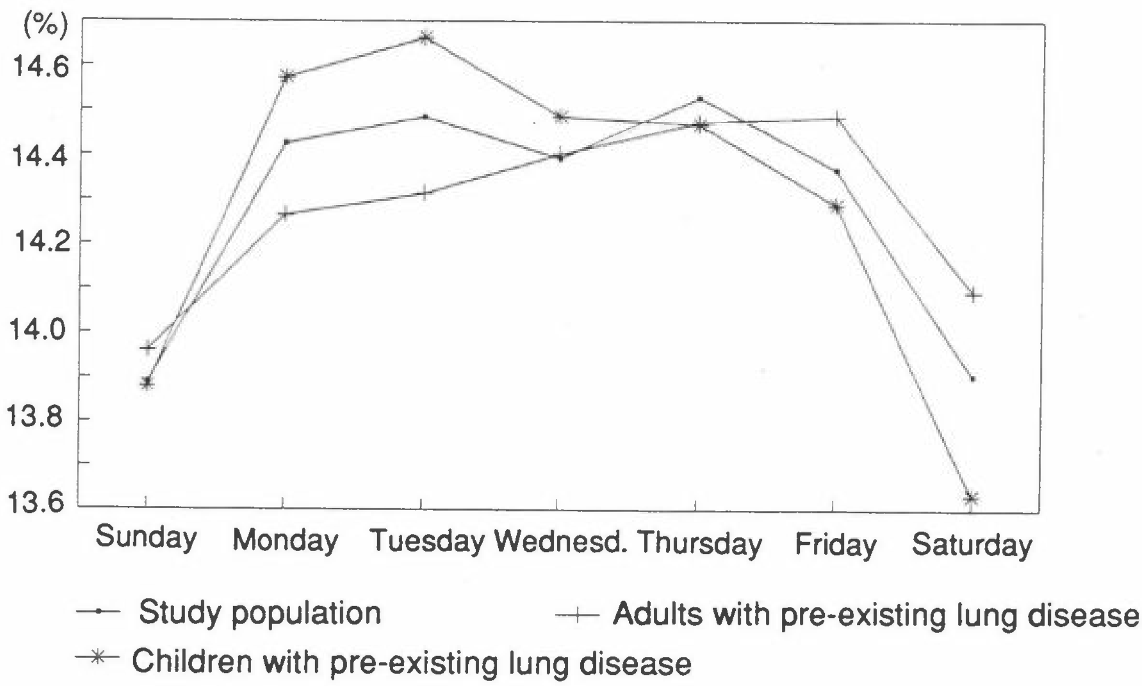


Figure 10.8: Distribution of PEF measurements during the week.

10.6.4 Variation in PEF during the week

In Figure 10.9 results from a two way analysis of variance (without interaction), with the factors individual and day of week is displayed. The figure may be interpreted similarly to Figure 10.7.2. It is weakly indicated that adults, both in the study population and among those with pre-existing lung disease, have a reduction of PEF during the weekend, while the opposite tendency may be present among the children. In either case the effects appear to be small. In this connection it should be noted that the scale in Figure 10.9 is only 1/10th of that in Figure 10.7.2.

10.6.5 Follow-up through the winter and summer periods

Figure 10.10.1 shows the average number of persons over each week who have performed PEF measurements one or more times per day. Figure 10.10.2 gives the average number of times PEF measurements have been performed each day. Here time is counted from the first day of the study, i.e. 4 January, 1988. One will see that there is a drop in participants reporting PEF measurements in the summer period, and in the randomly selected study population a slight decline was also observed in participants throughout both study periods. Further, it is obvious that the adults, both in the randomly selected study population and among those with pre-existing lung disease, report on average 3.8 PEF measurements per day during the winter period. Among the children the average number of PEF measurements decline during the winter period down to approximately 3.4 - 3.5 per day. In the summer period the number among the adults with pre-existing lung disease is reduced to 3.6-3.7 measurements per day. In the randomly selected study population there is a decline from about 3.7 to 3.5 measurements per day in the summer period. The children with pre-existing lung disease maintain a comparable or slightly higher average number of measurements per day in the summer period compared to the winter period.

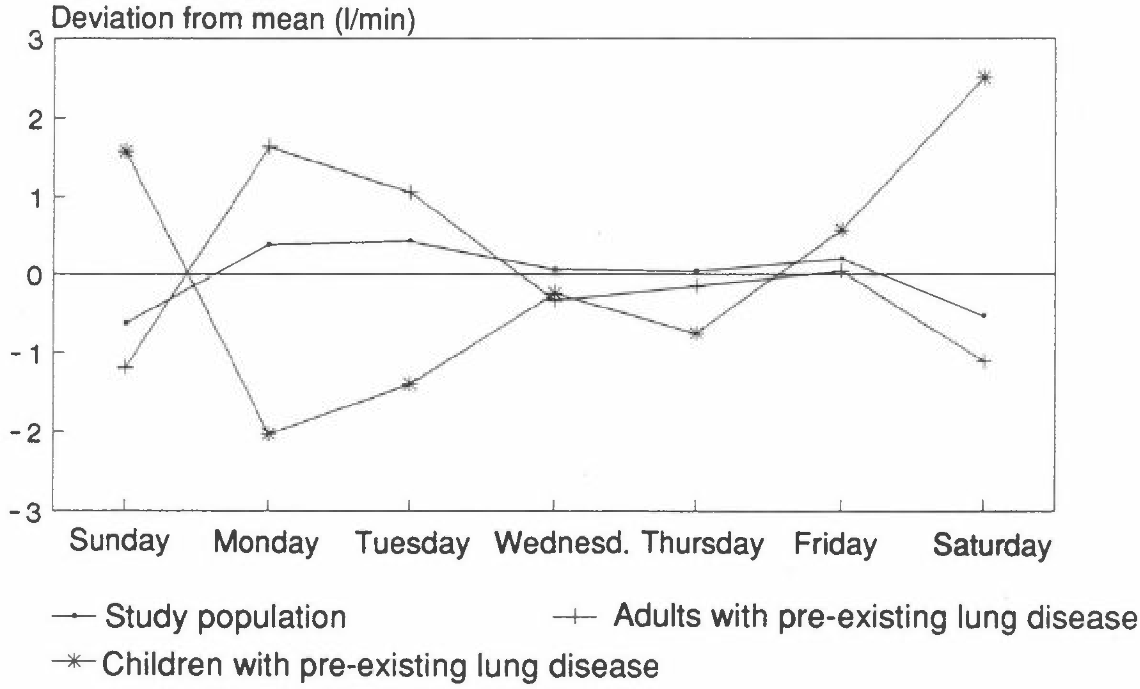


Figure 10.9: Deviation from mean PEF values during the week, corrected for individual differences.

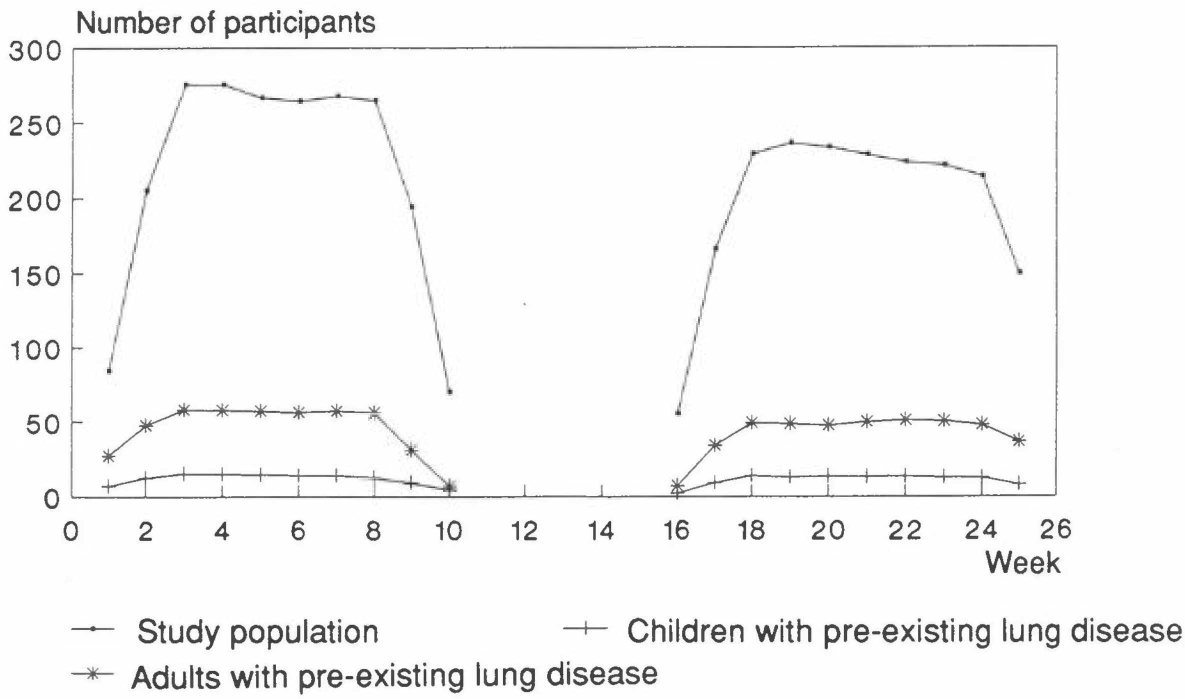


Figure 10.10.1: Number of participants from the first day of the project.

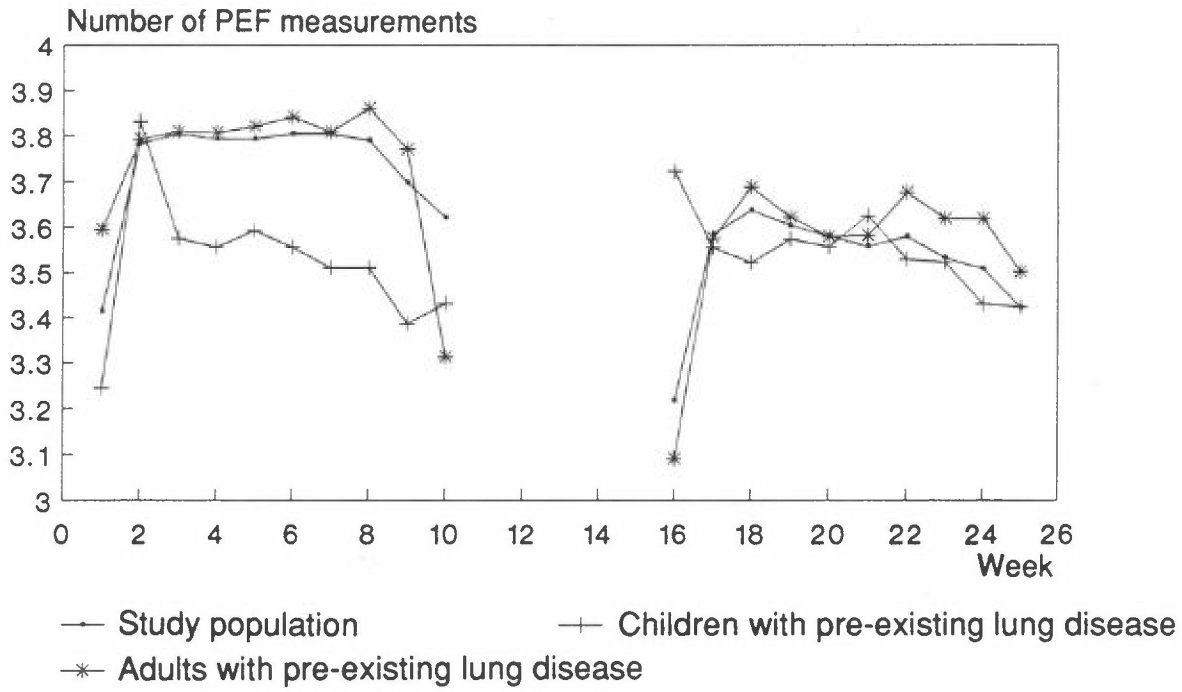


Figure 10.10.2: Mean number of daily PEF measurements during the week from the first day of the project.

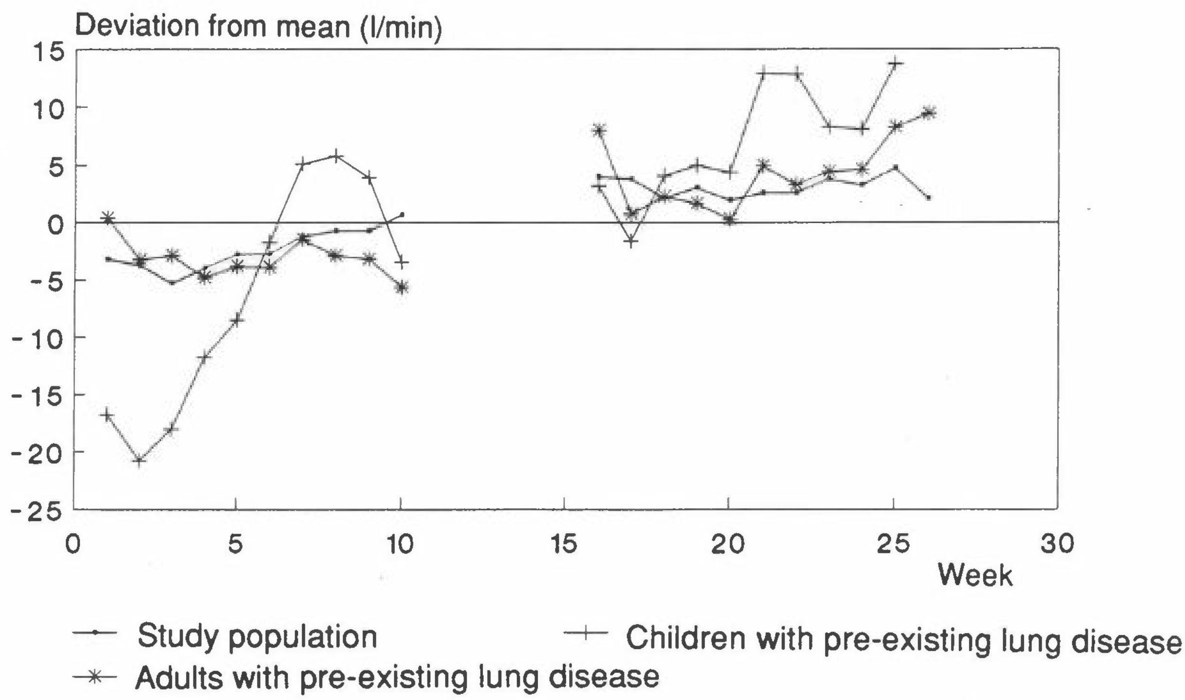


Figure 10.11: Deviation from mean PEF values per week from the first day of the project when values are corrected for individual differences.

10.6.6 Variation in PEF level during the winter and summer periods

Figure 10.11 depicts how the average levels of PEF have varied throughout the winter and summer periods in the three study groups. The figure has been developed, in the same manner as Figures 10.7.2 and 10.9, from a two-way analysis of variance where the factors were individual and week from the start of the study. For all three groups, PEF values are higher in the summer period than in the winter period. There also appears to be an increase in the PEF levels within these periods. The total variation is in the same order of magnitude as the variation within the day (cf. Figure 10.7.2).

The increase in PEF during the study periods may in part be connected to meteorological conditions, especially temperature. Another factor that may have contributed to the increase, is that the elasticity of the spring in the PEF meter may change over time when used. The PEF meters were collected and tested after both periods. The spring of some meters appeared to have become more elastic after having been used, and needed to be replaced. It turned out to be complicated to make use of these test results for correction in further analysis. However, it is assumed that the contribution from the partly defective PEF meters are not large enough to seriously bias the observed temporal effect. There is further no reason to believe that there is any important association between the pollution components and the PEF meters becoming more elastic.

10.6.7 Comparison between PEF measurements made at daily basis and at bi-weekly health examinations

To allow for the use of the self-reported daily PEF measurements for estimation of an effect of pollution, they should correspond well with the PEF measurements made at the bi-weekly health examinations. In Figure 10.12 scatter plots between the averages of the daily PEF measurements and averages of the bi-weekly PEF measurements are shown. For all three groups of participants, a clear linear correlation appears.

Let now

P_D = Average of the daily PEF measurements

and

P_{14} = Average of the PEF measurements at the bi-weekly examinations.

This results in a correlation between P_D and P_{14} of 0.991 for the randomly selected study population, 0.978 for the adults with pre-existing lung disease and 0.982 for the children with pre-existing lung disease. Further, the following regression lines are estimated for the dependence of P_D by P_{14} (the numbers in parentheses are the standard errors for the parameter estimates).

<u>Randomly selected study population</u>:

$$P_D = \underset{(.008)}{1.002}\, P_{14} - \underset{(4.3)}{12.7}$$

<u>Adults with pre-existing lung disease</u>:

$$P_D = \underset{(0.028)}{0.990}\, P_{14} - \underset{(12.8)}{14.5}$$

<u>Children with pre-existing lung disease</u>:

$$P_D = \underset{(0.050)}{0.961}\, P_{14} + \underset{(17.6)}{10.4}$$

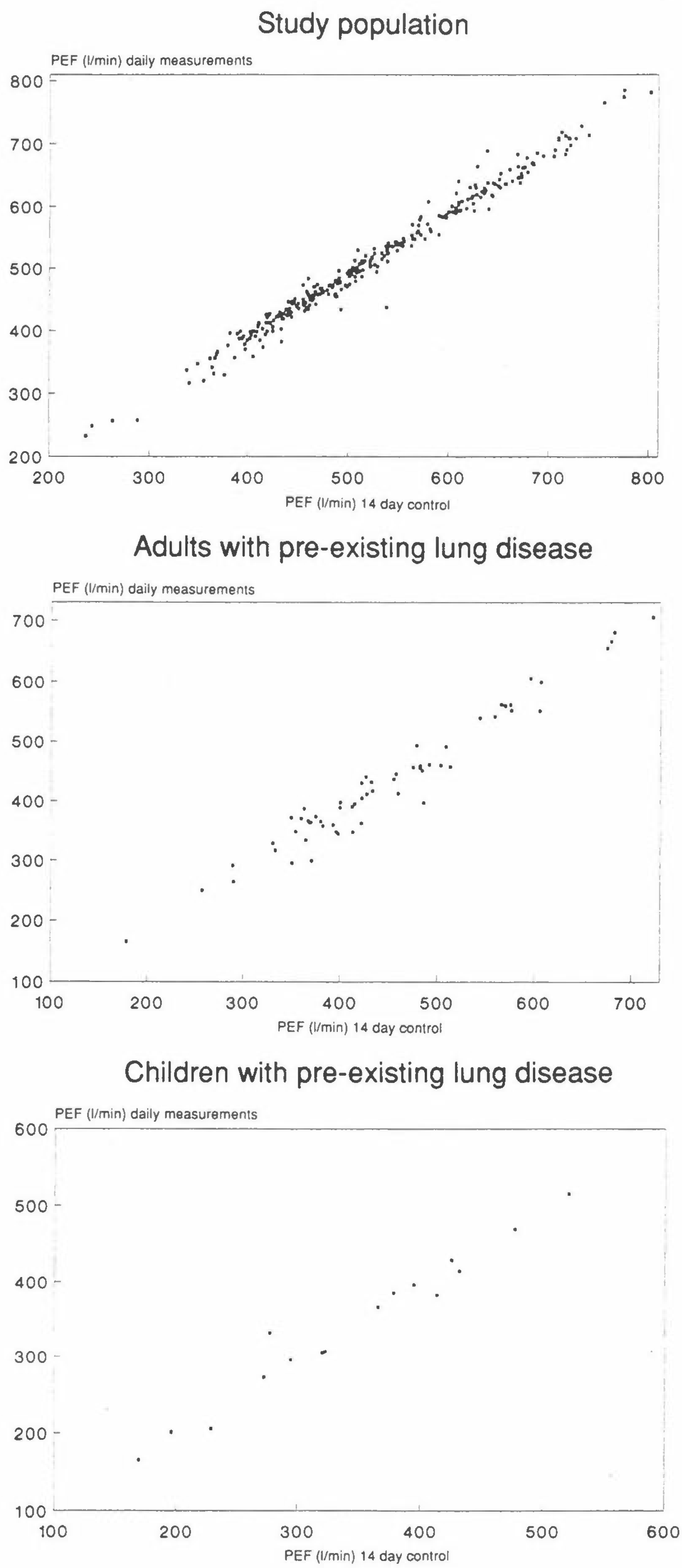


Figure 10.12: Scattergrams for correlation between means of daily PEF measurements and PEF measurements at the 14-day controls.

None of estimated slopes are significantly different from 1, but the intercept in the equation for the randomly selected study population is significantly smaller than zero. This indicates that the daily measurements give values that are slightly smaller than those from the measurements at the bi-weekly examinations. To some degree this may be explained by the fact that the bi-weekly examinations are not carried out very early in the morning or very late in the evening.

10.6.8 Conclusion and summary

The daily PEF recordings corresponded well to the PEF measurements made bi-weekly as part of the health examinations. The analyses show that variation was present during the day and during the study periods. Thus, it is reasonable to assume that exposure factors that change the PEF level by approximately 10 liters per minute should be possible to detect, provided that these factors are determined without considerable uncertainty.

11 THE RELATIONSHIP BETWEEN SELF-REPORTED HEALTH DATA AND AIR POLLUTION

J. Clench-Aas, A. Bartonova, G. Bjerknes-Haugen, N.L. Hjort, K. Halvorsen, S.O. Samuelsen, L.S. Bakketeig

11.1 INTRODUCTION

This investigation attempts to describe the short-term effects of air pollution on human health. Recognition that both subjective and objective short-term health effects can reflect the development of chronic effects has grown in later years. It is therefore possible that subjective short-term symptom reporting is a reflecttion of the development of long-term effects. However, short-term symptoms are more easily measured than chronic effects (Brunekreef et al., 1991).

There were two kinds of health effects assessed in this study: objective (measurable - reported in chapter 12) and subjective (self-reported) effects. Hourly reporting in a diary of symptoms of reduced health was used as a measure of subjective effects. The symptoms chosen were: annoying - noise, general smell and/or industrial smell, headache, dizziness, nausea, feeling feverish, eye irritation, sneezing, throat irritation, coughing, tight chest, difficult breathing, muscle pains, stomach pains, feeling nervous and fatigue (Figure 2.1).

Simple versions of the diary method of determination of air pollution exposure have been used in cohort investigations internationally (Holguin et al., 1985; Silverman et al., 1982). Most studies have been done in areas with one prevailing pollutant. Few have concentrated on a group of air pollution parameters.

Since the interest is to relate the short-term effects of air pollution to individual compounds, it is necessary that the pollutant concentrations vary relatively independently of each other. The geographic placement of several sources emitting different compounds in the Grenland area allows the distribution of the compounds to be relatively independent of each other.

Unlike most previous studies, two main groups of subjects were investigated in this current study, one drawn from a random sample (called study population), and the other a group diagnosed as having pre-existing lung disease (subdivided in adults and children, see Chapter 3 for subject selection). The individual being the basis of investigation in this type of study, problems connected to confounding variables are reduced. For each individual, the data are studied using logistic regression (a specific regression for dichotomous (yes/no) data). The results of the individual regressions are then grouped together to present summary statistics. These individual regressions can be grouped into population subgroups by, for example, such characteristics as gender or smoking habits. The results are presented for all health symptoms grouped together (that is, for a specific hour an individual has been bothered by at least one of the 17 health parameters) and individually for each symptom.

An important point in this study is to investigate whether individual air pollutants have a negative influence on health, as reflected in subjective symptom reporting, and if so, to what degree. It is further desirable to see if different population subgroups behave differently with respect to a possible influence of air pollution on symptom reporting.

This can be simplified to state:

- Does air pollution increase the reporting of symptoms of reduced health in the Grenland area?
- Do current air quality guidelines protect the population from negative effects of air pollution?
- Are there certain subpopulations that are more susceptible to the negative effects of air pollution?

11.2 OVERVIEW OF PREVIOUS STUDIES

There are four main types of studies of the relationship between air pollution and effects on health:

1) Animal studies describe the result of exposure to various doses/concentrations of pollutants on symptoms, morphology, morbidity and mortality. In such studies animals are generally exposed to a set of doses/concentrations to describe a dose/response relationship.

2) Experimental chamber studies measure altered physiological function and presence of symptoms in volunteers who have been exposed to known concentrations of individual components. Such studies are, due to ethical reasons, generally performed with ambient concentrations.

3) Cross-sectional epidemiological studies describe the state of health in a population at a particular time.

4) Epidemiological cohort studies measure a group of individuals during a period of time and compare changes in state of health with changes in exposure to pollution.

Animal studies are useful in defining the effects of high concentrations on specific effects, such as revealing the morphological changes induced by pollutants. The main problem in interpreting the results of animal studies is that different species often show both toxicodynamic and toxicokinetic differences, making extrapolation of data to humans even more difficult. Cross-sectional investigations are useful to document that air pollution may be a factor in decreasing the quality of health in a community. One may find that a co-variation exists between f.ex. reduced lung function and a compound, such as NO_2 or SO_2, but it is not possible to establish a causal connection. Chamber studies increase the possibility of establishing causal relationships between one pollutant or mixtures of specific pollutants and specific short-term health effects. However, a chamber study seldom reflects real life and individuals are not active in their normal routine. In reality, population exposures are very difficult to mimic in chamber exposures.

Cohort studies are an improvement compared to cross-sectional and chamber studies in that they follow the same individuals through time so that each individual is his/her own control. However, cohort investigations require improved measures of exposure to each air pollutant for each individual. Individuals differ in time spent in different micro-environments, often leading to differences in degrees and temporal patterns of air pollution exposure.

A cross-sectional study is helpful in suggesting that a pollutant or a specific combination of pollutants is related to health effects. In order to establish at which concentration a pollutant produces an effect, chamber studies are the most practical. These studies have helped to establish air quality guidelines, and there exist many literature reviews of the effects of air pollution on health.

Briefly, one can summarize some of the findings from animal, cross-sectional and chamber studies relevant to this investigation as follows.

11.2.1 Animal studies

Ozone (O_3)

Ozone primarily affects the respiratory system. The negative effects of ozone are essentially due to its highly oxidative properties. Animal studies have revealed morphological changes in the airways, such as damage to ciliated cells with exposure to concentrations over 200 µg/m^3, hyperplasia of non-ciliated cells, inflammation and increase in collagen (Wright et al., 1990). After 2 to 5 days exposure to increased ozone levels, it appears that adaptation occurs that can last up to 14 days

(WHO, 1987; Wright et al., 1990). Physiological changes reported in animal studies are rapid superficial breathing and increase in airway resistance, increased airway resistance following provocation by bronchoconstrictive substances and decreased respiratory rate. Changes in the immune response with increased sensitivity to respiratory infections have also been reported. Decreased function of the immune system was observed at exposure to concentrations over 500 µg/m^3 (for one week) (Van Loveren et al., 1988).

Nitrogen dioxide (NO_2)

Short-term, high exposure to NO_2 can lead to morphological changes in ciliated cells. Short-term exposure to NO_2 can also increase susceptibility to infections. Long-term exposure can lead to morphological changes resembling emphysema in the lungs as well as increased susceptibility to infections (WHO, 1987).

Sulfur dioxide (SO_2)

SO_2 is a water-soluble gas, where 99% of it is absorbed in the upper airways. In animal studies, exposure to acute concentrations have led to effects on the mechanics of respiration (increase in pulmonary flow resistance and decreased compliance and reduced breathing rate). Morphological effects were observed: increased thickness of the olfactory mucosa, ciliary loss, edema and necrosis of the olfactory mucosa. Effects were more serious in the nasal cavity than in the trachea and bronchi. Results of studies of long-term exposure to SO_2 in animal studies have not led to clear-cut findings. The results differ from species to species. Some studies seem to find slight decreases in pulmonary clearance, however, most studies find very little effects. Long-term exposure in the mouse did not lead to increased susceptibility to bacterial infection but did lead to significant increases in pneumonia after exposure to influenza virus. Generally it can be said that the basic response to SO_2 is decrease in compliance. Animal studies indicate that the effects seem to be mild although approximately 10% of the population may be more SO_2 sensitive than the rest and respond to lower concentrations.

Suspended particles

For particles larger than 0.5 µm, it is the aerodynamic diameter that determines where in the pulmonary system the particle is deposited. Hygroscopic particles become larger in the respiratory tract than they are in outdoor air. With nasal breathing only particles less than 10 µm can reach the lung, whereas with oral breathing larger particles also can reach the lower airways.

Most animal studies of exposure to particles have dealt with exposure to sulfuric acid mist and sulfate aerosols. These studies are reviewed further on. In addition, there have been done many studies on the combination of SO_2 and particles.

11.2.2 Cross-sectional and chamber studies

Ozone (O_3)

Chamber studies of the health effects of ozone have not led to clear results. Indications are that ozone combined with physical activity results in effects both in individuals with and without lung disease from exposure to concentrations from 200 to 740 µg/m³ (.11 - .37 ppm) and higher. After two to five days exposure to increased ozone levels, it appears that adaptation occurs that can last up to 14 days. Oxidant concentrations of 200 µg/m³ ozone or more were associated with irritation to eyes, nose and throat, chest discomfort, cough and headache (EPA, 1986; Linn et al., 1982). These symptoms were already observed at levels corresponding to a 24-h average of 160 µg/m³ per day.

Cross-sectional studies of the effects of ozone are hampered by the presence of other photochemical oxidants. A more extensive literature survey for ozone can be found in Slooff et al. (1989).

Nitrogen dioxide (NO_2)

It is very uncertain what concentrations of NO_2 are necessary to provoke reactions in highly susceptible populations. It is important to distinguish between two different biological end-points used in establishing a health effect. The one is bronchial hyperreactivity assessed with drugs that constrict the bronchial musculature, such as carbachol or methacholine; the other is possible decrease in lung function. In one chamber study (Orehek et al., 1976), 0.1 ppm (200 $\mu g/m^3$) NO_2 was high enough to induce increased bronchial reactivity in individuals with lung disease. Other studies however, have shown no effect at concentrations varying from 0.1 to 1 ppm (2000 $\mu g/m^3$) NO_2 both in those with and without lung disease (Hackney et al., 1978; Morrow, 1984). Ahmed et al. (1982, 1983) also found that concentrations of NO_2 of 0.1 and 0.2 ppm resulted in increased sensitivity to carbachol but not to methacholine. Hazucha et al. (1983) found no effect of NO_2 at a concentration of 0.05 ppm when examining methacholine challenge in asthmatics.

Based on these conflicting reports, it is difficult to judge at what concentration NO_2 is liable to induce an effect in individuals having pre-existing lung disease. The possibility of an effect is present already at 0.1 ppm or 200 $\mu g/m^3$ NO_2. There has been suggested an effect in healthy individuals at 500 $\mu g/m^3$ NO_2.

Studies are lacking of the kind described for SO_2 where exposure to the pollutant is combined with exposure to varying meteorological conditions and activity levels. Further information can be found in a literature review by Lindvall (1985 a,b) and WHO (1987).

<u>Sulfur dioxide (SO_2) and suspended particles</u>

SO_2-induced bronchoconstriction seems to be mediated via the parasympathetic nervous system which regulates smooth muscle tone. The reflex may be triggered by SO_2 which affects receptors present in the upper and lower airways. Chamber studies of asthmatic individuals suggested increased specific airway resistance after exposure to levels of SO_2 of 700 to 1400 $\mu g/m^3$ during exercise.

Increased airway and nasal airflow resistance and a change in the mucociliary flow rate were observed in normal subjects at concentrations at or over 3000 $\mu g/m^3$.

It has been difficult to confirm an effect of SO_2 in chamber studies at the same concentrations as has been indicated in cross-sectional studies. In 1984 an investigation was performed that may partially explain the disparity. Boushey (1984), testing lung function in asthmatic patients, found that physical activity and cold, dry air increased the effect of SO_2.

SO_2, suspended particles and suspended sulfates are often present at relatively high concentrations simultaneously, making it difficult to dissociate their relative effects in cross-sectional studies. However, there seems to be an indication of increased mortality and worsening of patients with pulmonary diseases with exposures exceeding 500 $\mu g/m^3$ SO_2 or 150-240 $\mu g/m^3$ total suspended particles (24-hr mean), and increased respiratory symptoms with exposures over 100 $\mu g/m^3$ for both SO_2 and total suspended particles (annual mean). The latter study also had levels of suspended sulfates at 13 $\mu g/m^3$ (annual mean). Impaired pulmonary function has been observed in asthmatic patients at levels of 700 $\mu g/m^3$ SO_2 (1-hr mean) and in normal individuals at levels of 1100 to 1400 $\mu g/m^3$ (1-hr mean). Increased mucus production and coughing has been reported in non-smokers exposed to concentrations over 115 $\mu g/m^3$. More information is available in a literature review by Camner and Ericsson (1983).

Nitrates and sulfates

In a thorough literature review over the health effects of acidic aerosols and gases (Spengler et al., 1990) the acidic particles are shown to be associated with increased morbidity, mortality and morphological changes in the lung. Even though recognition of this source of pollutant effect on health is recent, the authors were able to reconstruct from descriptions in earlier literature, effects that were probably due to the acidic component. Suggested mechanisms of action are increased mucus viscocity and impairment of mucociliary transport, irritation of ciliated epithelium and increased cellular histamine release leading to airway constriction. Exposure to concentrations over 10 $\mu g/m^3$ increases the frequency of airway diseases in the population.

11.2.3 Cohort studies

After it became more and more evident that population based studies are necessary to investigate the effects of air pollution, the tendency has been to use increasingly the cohort design for such investigations. There arose a simultaneous need for improving the measuring of air pollution exposure. Most of the earlier epidemiological population studies used one to several outdoor stations to measure air pollution. Seldom have portable equipment or exposure models been used. It is now known that air pollution exposure needs to be better described (e.g. Ott, 1985). Exposure in this context means the actual concentration of an air pollutant that an individual is exposed to, dependent on where that individual is at different times. Exposure can be measured in two ways: 1) portable monitoring equipment and 2) combination of a diary with measured concentrations in different micro-environments. The diary method was first described by Fugas (1975) and later developed by Duan (1983). An individual describes changes in micro-environments chronologically during a specific time period and this is then related to measurements/modelling of levels of pollutants. This method has been an integral part of the later cohort studies.

One of the first cohort studies done in this field was by Freziéres et al. (1982) who followed 34 asthmatics for 8 months in Los Angeles, California, USA. Their team measured simultaneously NO_2, SO_2, O_3, CO and particles, pollen and meteorological variables at one station that was within 2 km from each individual's home. Indoor air pollution was not measured. Each participant filled out a diary of airway disease symptoms and use of medication. They measured peak flow (an indicator of lung function) with a Mini-Wright Peak Flow Meter twice a day. All 34 participants had their health thoroughly checked prior to the beginning and all completed the study. The only compound that showed substantial variation during the study was sulfate. Three participants had a sharp reduction in health status with exposure to increased sulfate concentrations. Four seemed improved and the rest had mixed results. The authors' conclusions were that around 9% of the population was very sensitive to ambient sulfate and would have improved health if sulfate concentrations were not to exceed 10 $\mu g/m^3$ on a daily basis. Monthly averages for sulfate in this investigation were between 4 and 25 $\mu g/m^3$.

Perry et al. (1982) completed a similar investigation on 41 asthmatics over a 3 months period in Denver, Colorado, USA. They used diaries for symptom reporting, Mini-Wright Peak Flow Meters for PEF measurements and nebulizer chronologs for medication use. Each participant lived no further than 1.5 km from one of the air quality measuring stations. Air pollution indoors was not measured. Due to a priori exclusion criteria (they removed data if individuals had been out of the area for more than 3 days, or if they had infections of the respiratory system), and to lack of highly polluted days their results were unclear. Maximum monthly averages for SO_2, O_3, sulfate and nitrate were 36, 60, 4 and 4 $\mu g/m^3$ respectively. The investigation showed a correlation between high concentrations of nitrates and both increased symptoms and increased medication use. The authors concluded that the study was weakened because of low concentrations of pollution and too restrictive a priori exclusion criteria.

A study in Canada (Silverman et al., 1982 a, b) expanded air pollution measurements to include indoor measurements and use of portable monitors. Each participant filled out a diary concerning his/her activities for the estimation of air pollution exposure. The investigation found an association between increased concentrations of NO_2 and reduced lung function both in healthy and asthmatic participants, but the results were only significant for the asthmatics. The average 3 months concentrations of NO_2 during the study were between 10 and 50 $\mu g/m^3$ at outdoor stations.

An investigation in Houston, Texas, USA (Holguin et al., 1985) registered activity, symptoms, peak expiratory flow and medication use in 52 asthmatics (primarily children) during six months. Air pollution was measured at outdoor air quality stations, and indoors/outdoors using portable monitors. The air quality stations were no further than 1.5 km from each participant's home and measured O_3, SO_2, NO_2, CO and particles (both fine and coarse), pollen and meteorological variables. All 52 completed the investigation, but some were removed from data analysis because of lack of asthma attack (they did not have such symptoms any longer). This investigation found a significant increase in asthma attack with increased ozone exposure especially if temperatures fell at the same time. Ozone was the only compound that displayed much variation, since concentrations of SO_2 and partly NO_2 were low during the investigation. Typical 6 monthly averages for SO_2, NO_2 and O_3 were 10, 50 and 110 $\mu g/m^3$ respectively.

A Danish study examined the effects of air pollution and weather on asthmatics and persons suffering from chronic bronchitis in 4 Danish cities (Moseholm and Taudorf, 1990). The study extended over 8 months, where each of the 143 participants (73 - asthma, 70 - bronchitis) filled out a daily diary. Air pollution was measured at three stations in Copenhagen and one in each of the three other participating towns. NO_2 and SO_2 were the compounds measured. Average NO_2 concentrations (per 24 h) ranged from 39 to 56 $\mu g/m^3$ whereas SO_2 levels ranged from 15 to 17 $\mu g/m^3$. The authors concluded that approximately half of the participants showed a significant response to weather and air pollution. Of the asthmatic patients, approximately 5% of their response can be associated to changes in air pollution concentrations, whereas 10% in patients with chronic bronchitis.

In a recent substudy of the Six Cities Study of Air pollution and Health (Schwartz et al., 1991) 1800 children filled out daily diaries for a 1 year period. The investigation extended over 4 years. Air pollution concentrations were measured daily in each of the six cities. A set of symptoms was registered. Sulfur dioxide was a significant predictor of cough incidence. In a recent analysis, a cohort of 100 nurses (that eventually was reduced to 35 as they moved away from the school) was followed by a diary daily over a 3 year period (Schwartz et al., 1991). Air pollution was measured at an air quality station within a mile of the school. A set of symptoms was recorded. This study found a significant association between NO_2 concentrations and phlegm production.

In a Norwegian study in the Vålerenga area of Oslo with moderate traffic pollution (Clench-Aas et al., 1991) 160 individuals filled out hourly information over a 14 day period. A set of symptoms was recorded, and PEF was measured using a Mini-Wright Peak Flow Meter. Air pollution was measured at three air quality stations and indoors at several locations. Based on these measurements, known information on number of vehicles per hour on different road segments, conditions of the road (e.g. slope, width, height of adjacent buildings, etc.) and other information (e.g. average speed of vehicles at different hours of the day) emissions of CO and NO_2 were calculated. This information was combined with diary information to calculate exposure to these two compounds for each individual and for each hour. The mean concentration of NO_2 over a 3 months period for two stations was 58 $\mu g/m^3$. Maximum hourly concentrations measured over the registration period were 25 to 30 mg/m^3 CO and 250 to 300 $\mu g/m^3$ NO_2. This study found a significant association between fatigue, sneezing, eye irritation, annoying smell and noise and NO_2 exposure (or other components related to traffic pollution). Based on the estimated regression coefficients, relative risks can be calculated that indicate the increased probability of reporting a given symptom at different levels of pollution exposure. These calculations indicated increased symptom reporting at levels under the current Norwegian hourly air quality guideline of NO_2 (200 $\mu g/m^3$). The WHO hourly quality guideline for NO_2 is 400 $\mu g/m^3$.

11.3 METHODOLOGY

This section describes the principal elements in the methods used in this current investigation. These elements include choice of method for data aggregation, choice of independent variables used in the logistic regression and different aspects of statistical analysis.

Each individual was equipped with a diary (Figure 2.1 and 2.2) that included two sections, one used to calculate exposure (see Chapter 8) and one to report symptoms of reduced health (see also Chapter 9). These symptoms were recorded as yes/no (0/1).

11.3.1 Statistical model

The individual is the unit of investigation. Therefore, the effect of the different compounds on each health symptom is studied on an individual basis. The symptoms were examined also as a total health response but not further subgrouped in the statistical analysis. Results from the above mentioned study in Vålerenga, that was used as a pilot study for this investigation, indicated that it was unadviseable to group health parameters (Clench-Aas, et al., 1991). Hourly data for each individual and for each of 17 health symptoms were analysed using a generally accepted mathematical model for analyzing dichotomous dependent variables as a function of a set of independent variables (Cox and Snell, 1989). A modification of the model and a method for combining the individual results for groups of participants is described in detail in Korn and Whittemore (1979).

Generally, the probability (P) that air pollutants (X) and other independent variables (Z) contribute to a health variable (Y) being 1 (having the symptom) for each individual can be modelled as:

$$P = \exp(\alpha + (X' + Z')\beta)/(1 + \exp(\alpha + (X' + Z')\beta))$$

where α and β are unknown parameters. α is the constant and β is a vector of dimension corresponding to the number of all independent variables X and Z.

For each individual and for each health parameter, the coefficients α and β can be estimated. These estimates can be analysed for individuals grouped into various subpopulations, or for the participant population as a whole. A population or subpopulation estimate of a common value of α and β can be computed.

11.3.2 Compression of data

As one can imagine the data set resulting from such a project design was large. Data was collected for each individual (approx. 400) and each hour (approx. 2500), in a total of almost one million data elements or lines.

It was therefore, desirable and necessary to compress the data. The combination of location of pollution sources, meteorological conditions and people's daily movements led only exceptionally to shorter periods of high pollution exposure.

In general, people were exposed to low concentrations of pollution. In addition, there were few periods with symptom reporting, especially in the study population, where each symptom was reported approximately 2% of the time (see Table 9.3).

The primary methodological problem is the ranking of pollution levels into groups such as low, medium or high. This ranking was intended to serve as a basis for data compression.

In all the methods considered, the average value for each pollution compound was used within each compressed time period (block). If the individual responded for at least one hour during the block for a particular health response, the block was classified with response. The two compression methods that were further used in analysis represent those methods that compressed the data most and least.

The method that compressed the data most was based on presence in different micro-environments as determined by the diary (hereafter referred to as M-micro). This method compressed all adjacent hours in one micro-environment into one time period. For example, as long as an individual was in his home with windows closed, the data were compressed. If the individual then opened the window, which is defined as a new micro-environment, the data was compressed again. For each time period, a mean value of each air pollutant was taken, and the time sequence was retained. The advantage of this method is that uncertainties connected to the estimating of air pollution concentrations (as described in chapters 5, 6 and 7) were smoothed out and potential errors attributable to the exposure estimation method were thus reduced. It is also an advantage that this aggregating method is independent of values of both the dependent and independent variables in the analysis. A disadvantage of this method is that short episodes of high pollution exposure during a period that an individual was indoors would possibly be averaged with low exposure values since the time span of compression could be relatively long. In addition, the method will give greater weight to certain micro-environments that were short (for example travelling). Another disadvantage is that the resulting number of data lines (data elements) could differ substantially between individuals.

The method that compressed the data least was based on each individual's own frequency distribution of air pollution exposure (hereafter referred to as M-indiv). For each individual and for each component a 75th and 90th percentile of exposure concentrations was calculated. These percentiles were then taken as border values between the separate categories low-medium-high for the individual pollutant. As long as all pollutants remained in an unchanged category, the exposure values were averaged and compressed into one time period. The categorization was done separately in the two study periods (winter and summer). The values of individual percentiles differed substantially between individuals. An advantage of this method was that the number of data elements was relatively similar between individuals. This method also treated the different air pollutants equally. A disadvantage was that the category "high" pollution was different for different individuals, giving a higher weight for periods when pollution levels were still low in individuals with lower exposure. In addition, this method is more sensitive to inaccuracies in the exposure estimating method, and uses independent variables as the basis for the classification method.

Two additional methods were judged but not further used in the analysis. For both, the exposure categories were defined for the whole population, not on an individual basis. One method defined categories as less than or equal to 30% of the air quality guideline levels (AQG), from 30% AQG and above the AQG. The AQG used are summarized in Table 11.1. The other had as its basis the total frequency distribution of air pollution exposure in each period. These methods had the advantage of giving equal weight to air pollution exposure for all individuals, but resulted in unequal numbers of data between individuals, used independent variables in the classification systems, and were sensitive to inaccuracies in the pollution exposure estimating method.

Table 11.1: Suggested air quality guideline concentrations.

Component	Averaging time	Concentration ($\mu g/m^3$)	Reference
SO_2	1 hour	350	WHO (1987)
NO_2	1 hour	200	SFT (1982)
O_3	1 hour	100	SFT (1982)
CO	1 hour	25 mg/m^3	SFT (1982)
Suspended particles* (PM_{10})	24 hours	70	WHO (1987)
Total Cl (Cl_x)	24 hours	7,5	Personal communication NILU/National Inst. of Public Health
Cl_x,+SO_4+NO_3 (acid aerosols)	24 hours	20	Personal communication NILU/National Inst. of Public Health

* 60 $\mu g/m^3$ was used as a 1-hour guideline for fine fraction of suspended particles in categorizing based on guidelines.

The results when the four methods are applied are compared together with uncompressed hourly data for two individuals for two compounds for two days in Figure 11.1. It is evident that all methods except M-micro yield quite similar results. In Figure 11.2, one can see that the differences between the methods are primarily a function of how many hours are compressed and that it is mostly in the lower to middle exposure levels that these differences were noticeable, as exemplified by SO_2 and NO_2.

The two aggregation methods that were used, M-micro and M-indiv, allow comparing health responses against current simultaneous exposure to air pollution. It was also desirable to investigate the effects of the previous 24 hour exposure to air pollution on health. This was done by calculating for each hour a previous 24-hour mean exposure concentration for each compound. Thereafter the same method as described for M-indiv was used (hereafter referred to as M-24H).

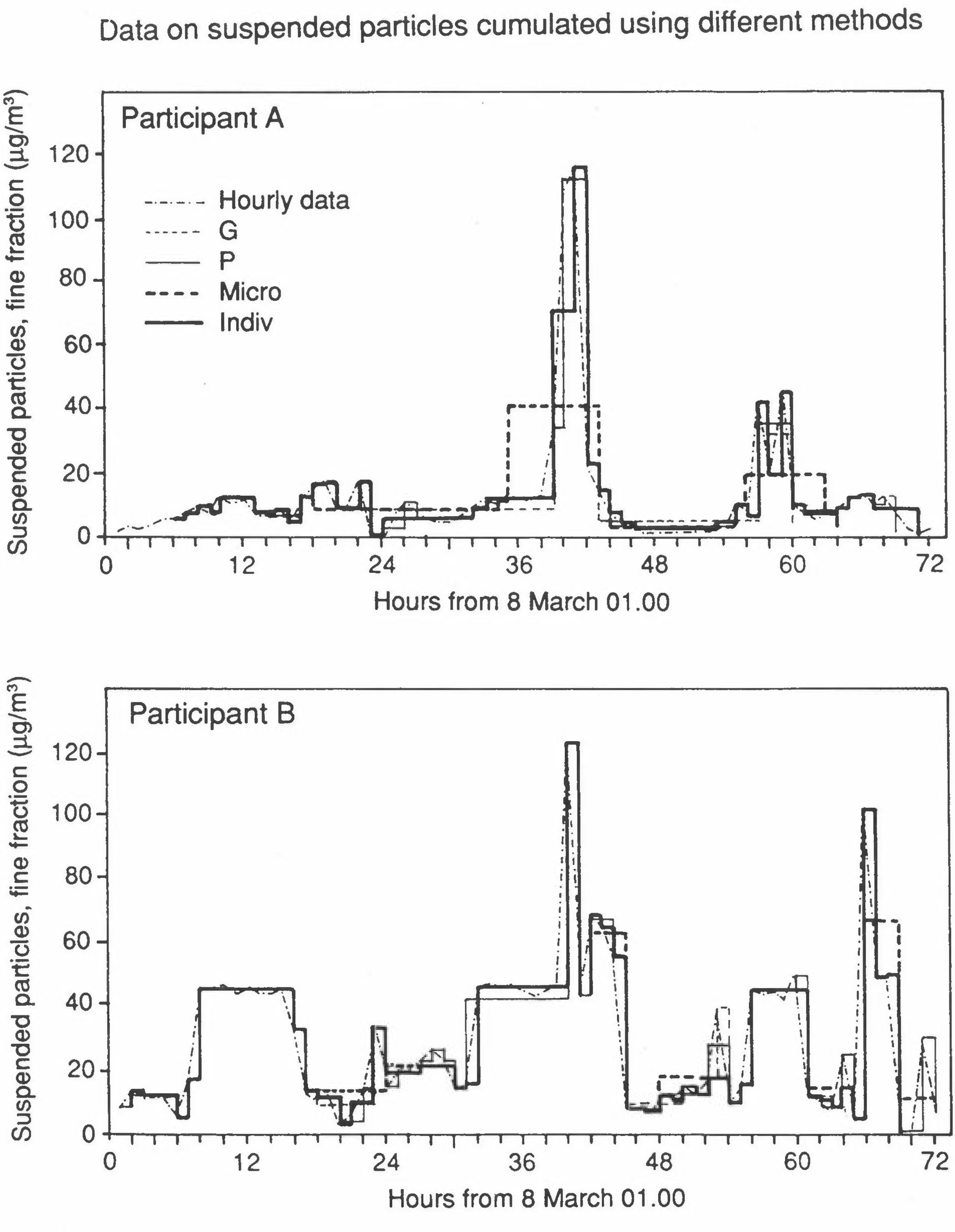


Figure 11.1: Comparison of the resulting exposure estimates of concentrations of SO_2 and particles using four compression methods on the data. The figures show values over 3 days for two individuals. (G=based on air quality guidelines; P=based on common percentiles of exposure; Indiv=based on individual percentiles of exposure; and Micro=based on microenvironment).

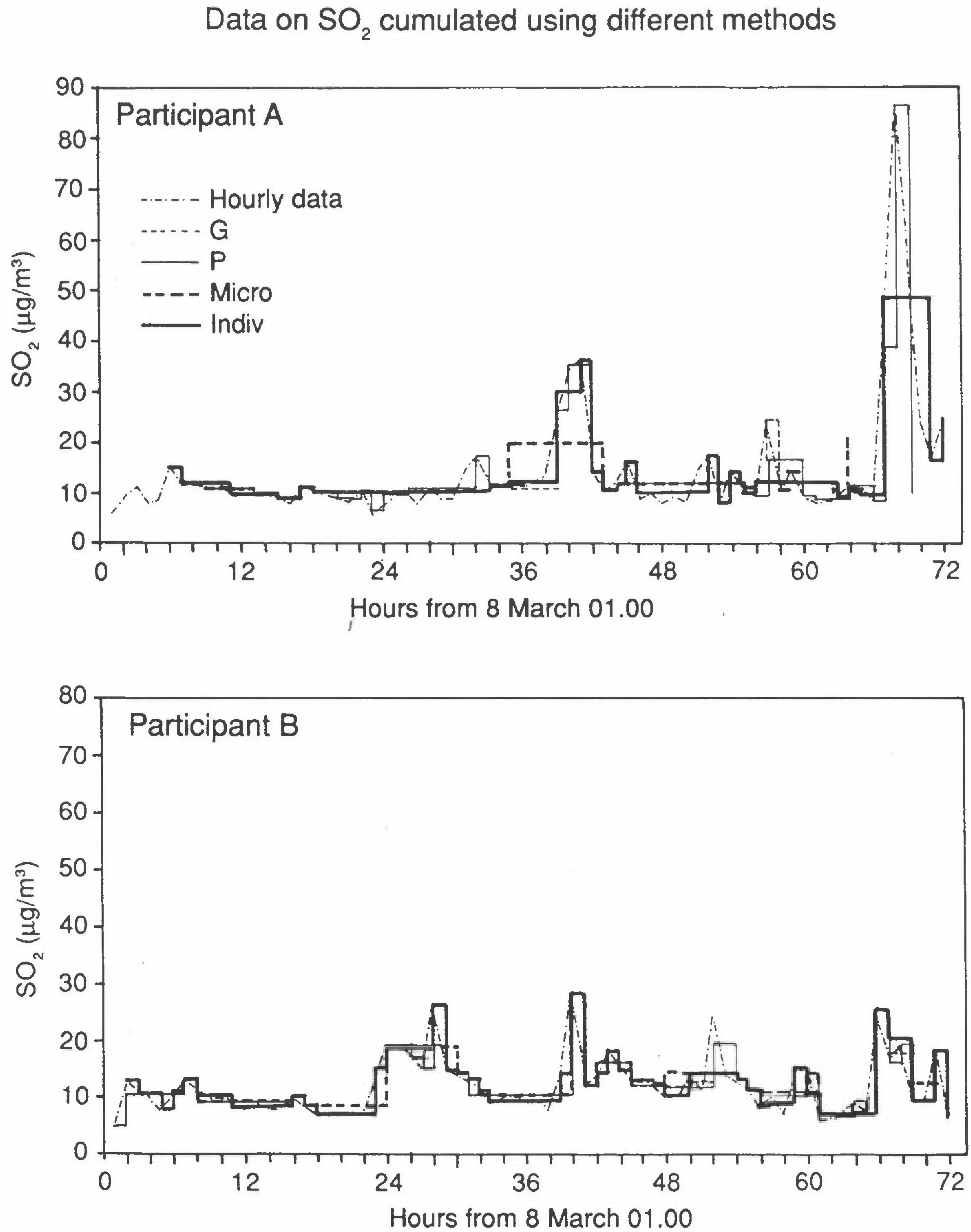


Figure 11.1 cont.:

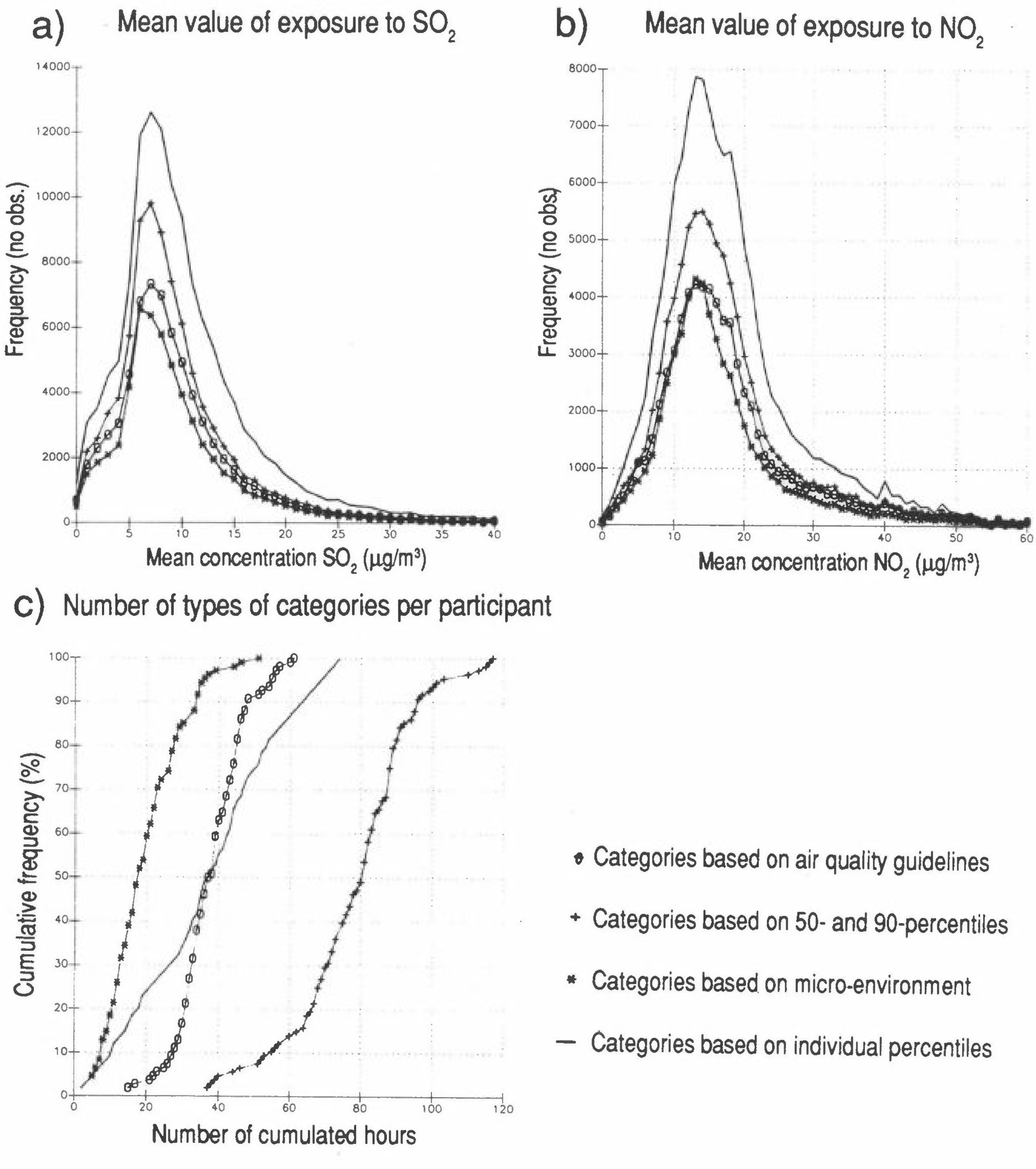


Figure 11.2: Comparison of four compression methods. Figures a) and b) show the frequency distribution of mean exposure to SO_2 and NO_2 resulting from different types of categorizing. For all categorization types, the largest number of time periods is found under medium exposure conditions. Number of time periods per individual vary between 200 and 900 dependent on type of classification. Figure c) shows the cumulative distribution of types of categories per individual with each compression method.

11.3.3 Independent variables in the model

Having chosen a compression method the actual data were compressed. Logistic regression was then run for each individual and for each health parameter (dependent variable) on the compressed data, for each of the three compression types (M-micro, M-indiv and M-24H).

The natural logarithm of the air pollution compounds was chosen since air pollution exposure has a skewed distribution. The air pollution compounds were chosen so as not to be too correlated to each other (see discussion in Chapter 8). The final choice of compounds was: SO_2, NO_2, O_3, suspended particles (fine fraction), SO_4, NO_3 and chlorine. For the correlation matrices, see Table 8.7.

Since lung function sensitivity (objective and subjective measures) is reported to have seasonal variation (Hackney et al., 1989), it seemed wiser to analyse the seasons separately. During the winter the two parameters minimum temperature and relative humidity were added and during the summer analyses the parameters grass and birch pollen were added. In addition to seasonal differences in reporting, it was discovered (see Chapter 9) that there was a peak symptom reporting for many of the health variables in the morning. A variable was added to account for this in the regression (Morning). Finally, people report symptoms primarily for the period during which they are awake, therefore a parameter was added to the equation that accounted for the sleep/wake cycle (Active). This meant a total of 11 independent variables in the logistic regressions.

The goodness-of-fit of the models was evaluated using standard methods, and it was compared between the models. Since no results were found that would change the conclusions substantially, these are not reported here; however, they are described in the expanded report of this chapter.

11.3.4 Autocorrelation

One of the features stressed by Korn and Whittemore in 1979 was the need to account for autocorrelation in the health data. Autocorrelation here means that having a health symptom in one time period is affected by or related to having it the previous period. These authors used examples from studies of patients with asthma. Having an asthmatic attack one day increased the chances of having an attack the following day.

This discussion was recently taken up by Schwartz et al. (1991). As noted by these authors, diary studies yield both information on incidence and prevalence of health symptoms. Incidence and prevalence do not necessarily reflect the same biological processes. Those factors that contribute to the provocation of a symptom need not be the same as those that cause the symptom to endure. They state that using only incidence rates still does not remove autocorrelation in such symptoms as coughing. However, we feel that the problem is complex and the amount of autocorrelation can vary substantially between health symptoms.

This study deals with responses on an hourly basis, or with several time blocks per day, as opposed to a more traditional approach with one data element representing the whole day, or at maximum two half day segments. Autocorrelation of hourly responses is dominated by the great number of hours with no response. More complicated forms of time dependency were not investigated. No variable was therefore included to account for hourly interdependency.

However, several other features were included to address the problems of autocorrelation. An additional analysis was performed using only incidence (onset of health effect). This severely reduced the amount of data adding other statistical complications to interpretation of the results. In other analyses, the parameters that account for a higher incidence of symptom reporting in the morning (Chapter 9) and during the waking period, aided in removing a certain amount of autocorrelation.

Autocorrelation in exposure data was not investigated, but it is reasonable to assume that it is high.

Compressing the data also probably helped to remove a certain degree of autocorrelation. It would follow that M-micro, which compressed the data over longer time periods than M-indiv, would possibly remove more autocorrelation in both symptom reporting and the exposure estimates.

Autocorrelation for many of the symptoms is increased when participants are sick. An additional analysis was performed including a parameter called daily form (rated on a scale of 1 to 5). This analysis did not reveal any substantial differences from the results reported here. Since daily form may in itself be a response variable, reflecting a cumulated health response, it seemed more appropriate not to include it as an independent variable.

11.3.5 Statistical significance

As mentioned earlier, the resulting coefficients from the logistic regressions for each individual and for each health parameter were analysed using the approach suggested by Korn and Whittemore (1979). Weighted averages and estimates that accounted for differences in variability of responses between individuals were calculated. The latter, which allows for testing the effect of the independent variables for the whole population, was used here. The coefficients for different independent variables are considered independent of each other for each individual.

The problem of assessing if the regression coefficients are significantly different from zero, i.e. if we can say that there is an effect of some of the air pollution compounds on health response, is in this situation a very complex one.

At the 5% significance level (two-sided test), critical t-values vary from 2 to 4.3, dependent on sample sizes for each health symptom. Sample sizes vary from 5 to 163. Therefore, for those health symptoms where only 5 people responded in the group, t-values should exceed 4.3 to show statistical significance. For those symptoms with 10 people responding, a critical t-value of 2.3 is applicable. Already at sample sizes of 30 or more, t-values of 2 are applicable.

In the present analysis, we are performing many tests and our estimates are not necessarily independent, since the original "independent" variables are intercorrelated. This means that to achieve the 5% significance level (two-sided test) we should increase the critical values. On the other hand, we do not give weight to the negative associations which we believe are of no biological importance, but rather reflect the structure in the independent variables. In evaluating all sides of this question we chose to consider as significant an association that has a t-value over 2.

We believe, that in a study of this kind, it is important not to discard potential plausible associations, even if we select too many. In our view the error of judging true significant associations as insignificant is more serious than the error of judging as significant associations that really are not.

11.4 RESULTS - CUMULATED HEALTH RESPONSE

For each individual, the health effect symptom variables were also grouped so that for each hour or time period, if any symptoms were reported, the grouped response value was set to 1. For both adult populations (the study population and those with pre-existing lung disease), this grouped variable was then studied as a function of: 1) exposure to each air pollution compound for each season, 2) the individual's presence in different micro-environments, and 3) passive smoking for non-smokers and passive and active smoking for smokers.

One must be careful of over-interpreting grouped data. The grouping ignores important phenomena, such as certain physiological factors (differences between sexes, or between the biological mechanisms that lead to different symptoms, are not accounted for). Certain features of exposure (i.e. diurnal variability) are also not accounted for. Those people who reported symptoms were often over-represented, since there was no weighting of symptom reporting between individuals.

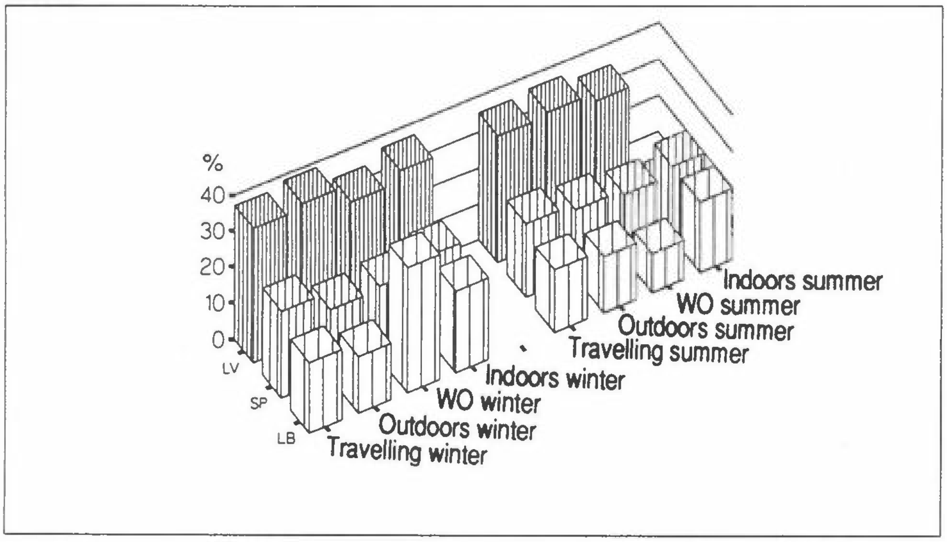
The description presented here will be based on the accompanying graphical representations (Figures 11.3 - 11.6).

Figure 11.3 indicates that even though participants spent most of their time indoors, per cent of time with reporting of symptoms was as high or higher when individuals were outdoors or travelling.

Health effect symptom reporting was higher during those hours with exposure to passive smoking for essentially all population subgroups (Figure 11.4). This was slightly more noticeable in the winter than in summer. Smokers also had more symptom reporting during periods of passive smoking than during periods when they smoked themselves, or did not smoke.

Figure 11.5 presents the cumulated health response as a function of exposure to air pollution compounds SO_2, O_3, and NO_x in two ways. On the left side of the figure the actual number of hours with and without symptoms is presented, for winter and summer (both adult population groups together). On the right side the data are expressed as a per cent in each exposure category. Each of the three compounds is presented individually. One must be cautious in interpreting graphs with only one air pollution compound at a time, since other compounds may be co-varying with that compound. In addition, in such presentations, we have no control over other independent variables that are of importance, e.g. time of day, type of study population, gender etc.

% hours with at least one response
based on micro-environment



Number of registered hours
based on micro-environment

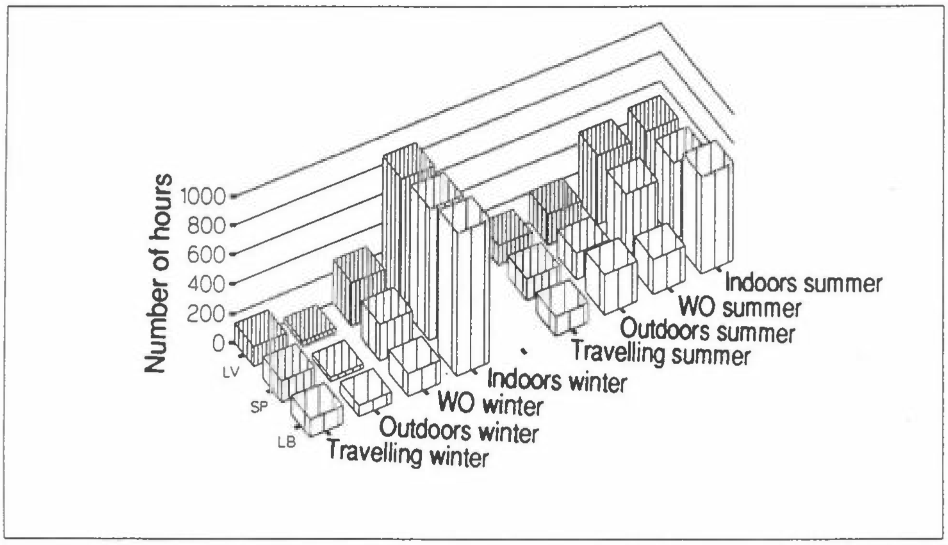
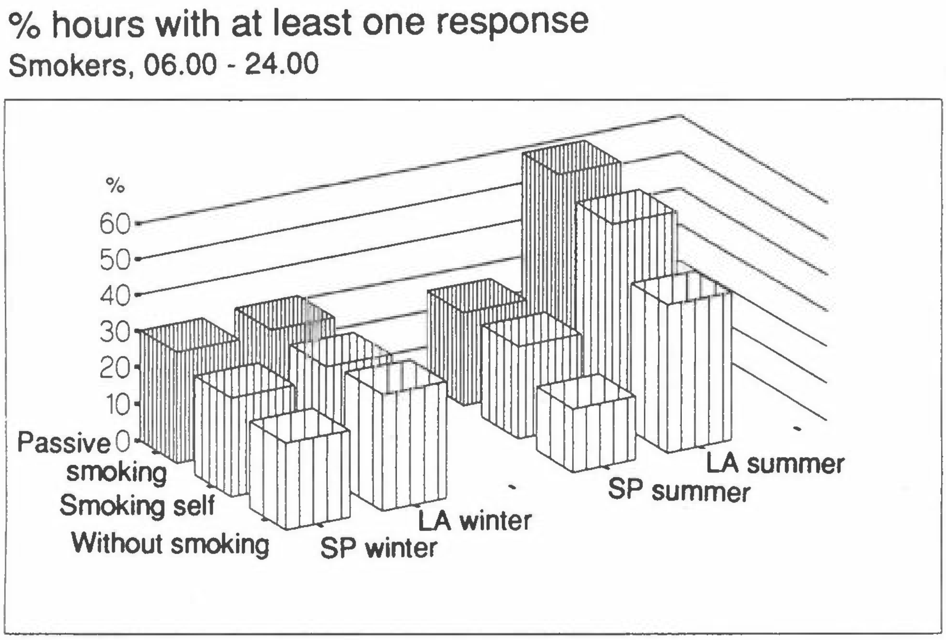


Figure 11.3: Comparison of time spent in certain micro-environments by each population subgroup, and per cent of time with reporting of at least one health symptom as a function of presence in a micro-environment and season:
TRAVEL=travelling; OUT=outdoors; WO=indoors with window open; IN=indoors with window closed.
The comparisons are shown for three population subgroups: LA=adults with pre-existing lung disease; LC=children with pre-existing lung disease; SP=randomly selected study population.



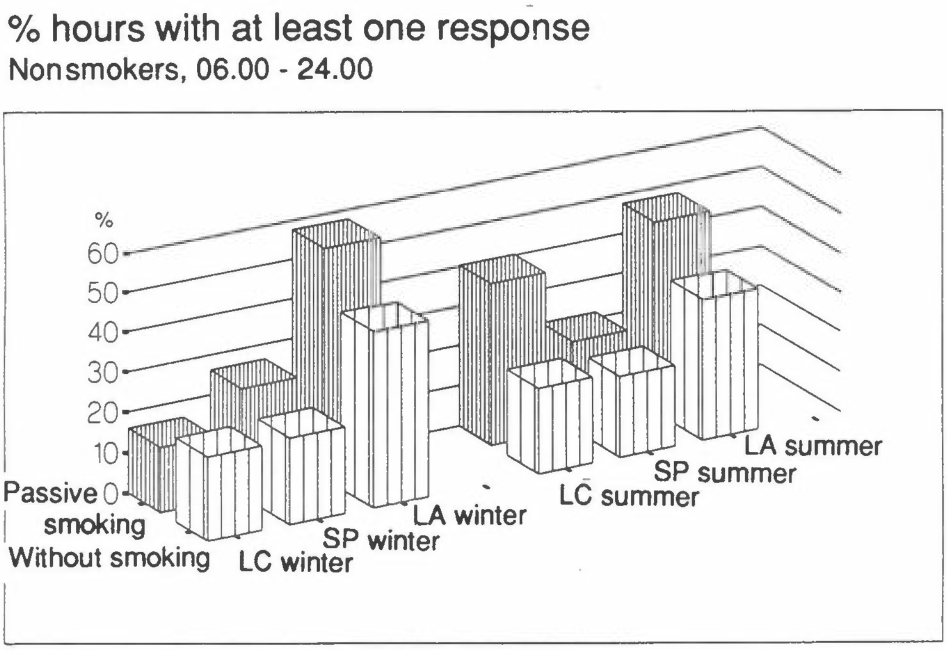


Figure 11.4: Comparison of response rate (per cent of time with reporting of at least one health symptom) as a function of exposure to passive smoking in non-smokers, and smoking or exposure to passive smoking in smokers in summer and winter: LA=adults with pre-existing lung disease; LC=children with pre-existing lung disease; SP=randomly selected study population.

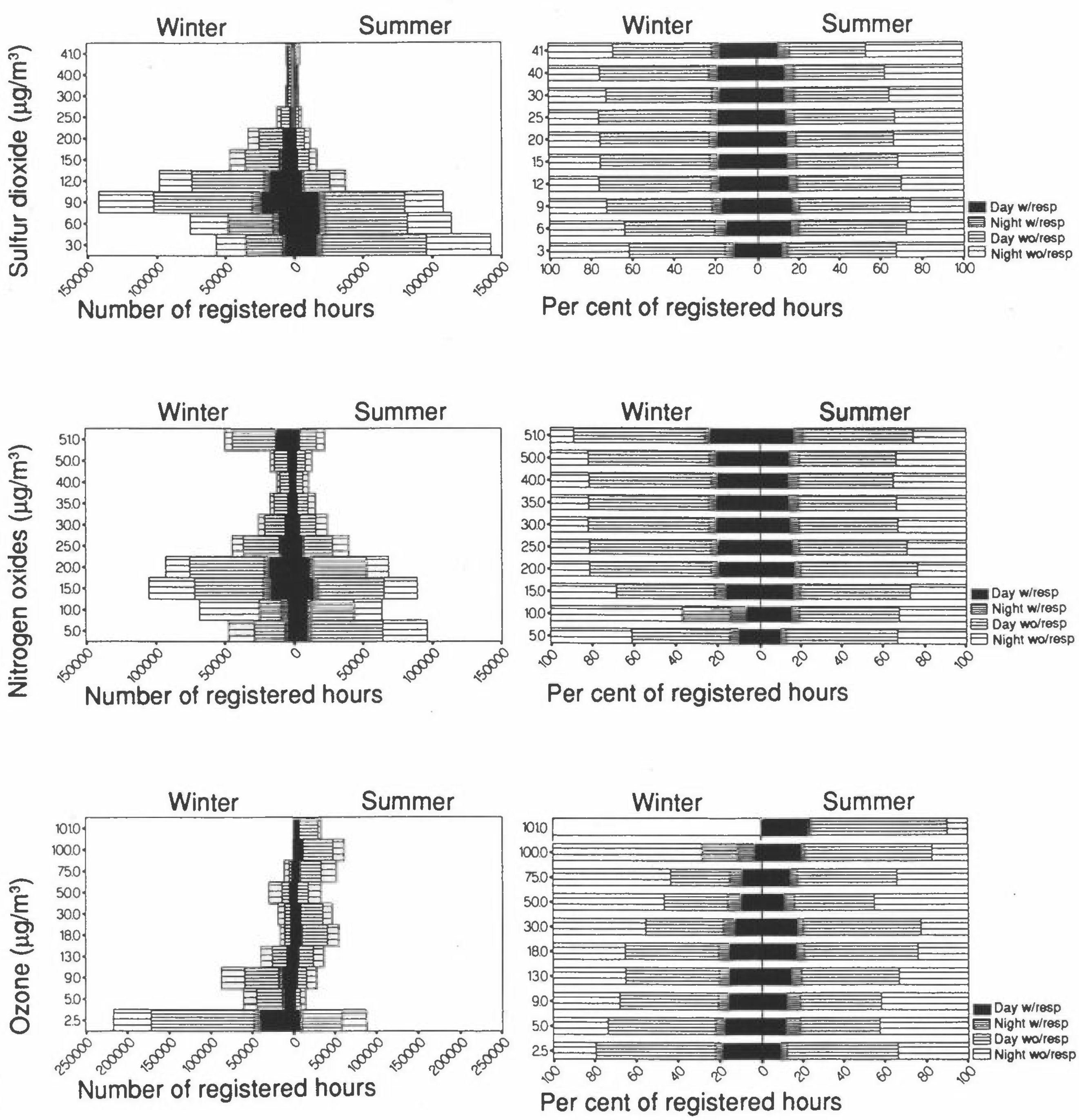


Figure 11.5: Comparison of days (0700 h to 2200 h) and nights (2300 h to 0600 h) with and without a health response in all individuals, winter and summer, for a range of categories of exposure to SO_2, NO_x and O_3. Values are expressed both as number of registered hours and as per cent of registered hours. The concentration axis gives the highest level in a category (except for the highest) so that 3.0 for SO_2 is equivalent to 0 to 3 µg/m³ SO_2. The last category 41.0 covers all concentrations over 40 µg/m³.

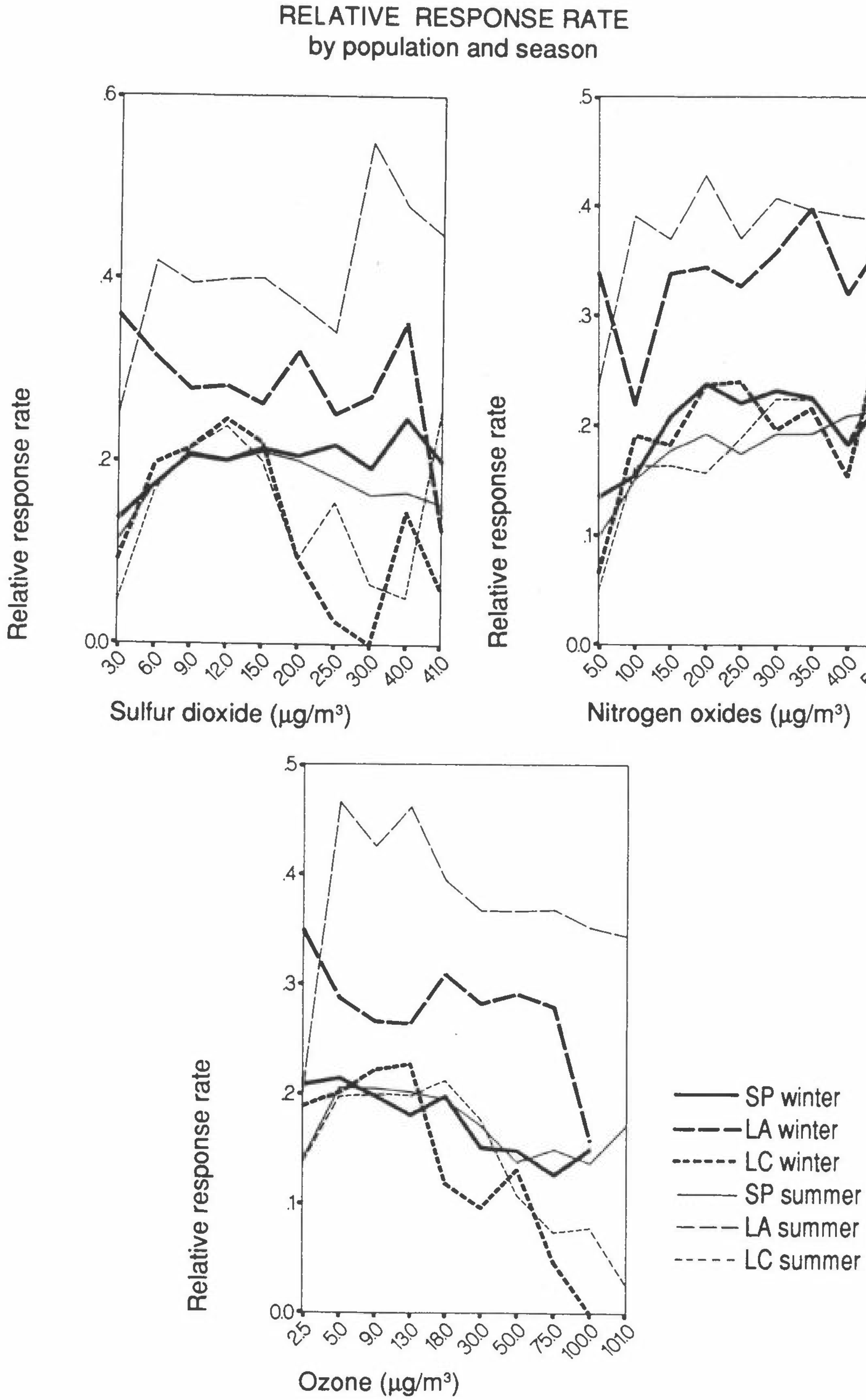


Figure 11.6: The relative response rate (number of hours with reporting of at least one health symptom/number of hours at that exposure level) for each population subgroup for a range of categories of exposure to SO_2, NO_x, O_3, sulfates and nitrates. Winter values are given as thicker lines. LA=adults with pre-existing lung disease, LC=children with pre-existing lung disease and SP=randomly selected study population. The concentrations reflect the upper level of a category (see discussion in the caption to Figure 11.5).

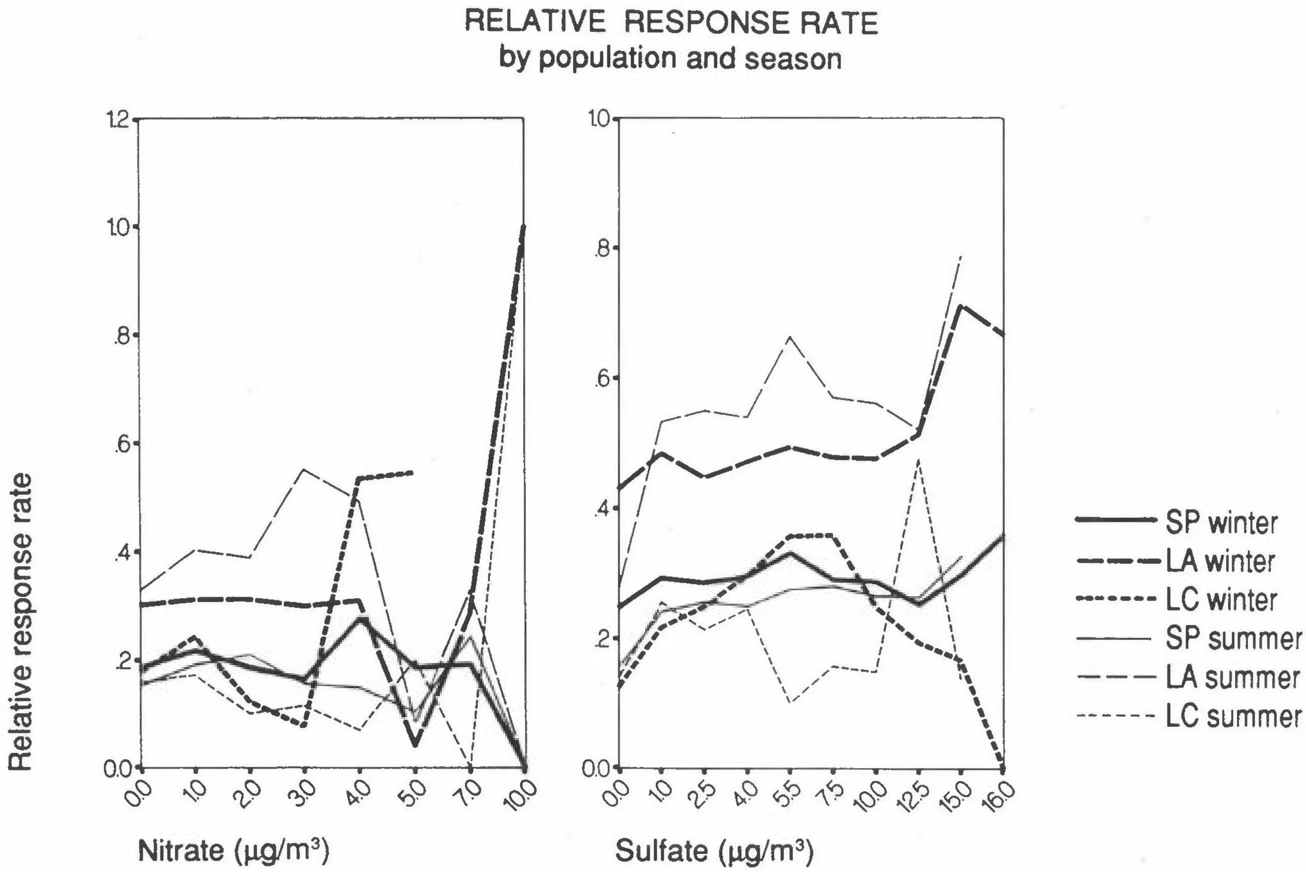


Figure 11.6 cont.

Figure 11.6 summarizes the relative reponse rate (the per cent of time each subgroup has at least one symptom for each specified concentration of pollutant) for: 1) the randomly selected study population, 2) those adults with pre-existing lung disease, and 3) children with pre-existing lung disease for both winter and summer. The figure shows the response rates for five compounds, SO_2, NO_x, O_3, nitrates and sulfates.

The total relative rates of health symptom reporting are higher for those having pre-existing lung disease than for the randomly selected study population. They are higher in winter than in summer. However, the sample sizes in the population with pre-existing lung disease are substantially less (about 60 for the adults and 15 for children compared to 300 for study population) leading to estimates with higher uncertainty when values are presented in this way.

11.5 RESULTS OF THE RELATIONSHIP BETWEEN AIR POLLUTION EXPOSURE AND THE INDIVIDUAL HEALTH SYMPTOM GROUPS, USING M-INDIV COMPRESSION

In order to describe the effects of air pollution exposure on each of the 17 health effect symptoms, it was decided to discuss these grouped in five biologically related groups. These five groups are:

Symptoms of annoyance - annoying noise, general smell and industrial smell.

Symptoms in the upper airways - eyes and throat irritation, sneezing/running nose.

Symptoms in the lower airways - coughing, wheezing or tight chest.

Symptoms of decreased general health - headache, dizziness, nausea, feeling feverish.

Symptoms of stress and fatigue - muscle pains, stomach pains, feeling nervous/restless, fatigue.

This grouping can only be considered as indicative, since it is obvious that some symptoms could easily be placed in other categories as well.

For a description of the interrelationship between health symptom reporting, see Chapter 9 (Tables 9.6 and 9.7). For example, muscle pains and stomach pains are often associated with headache and dizziness. Coughing is often associated with throat irritation, and feeling feverish is often associated with cough, throat irritation, etc.

The results presented below are summarized in Tables 11.2- 11.6 and Figures 11.7-11.11. The regression coefficients presented in the tables (Part A) are representative for each population subgroup. The t-values are given separately (Part B).

Figures 11.7-11.11 show the confidence intervals (CI) for each regression coefficient (mean ± 2 * standard error). The CIs that do not overlap zero indicate significant relationships between compound and symptom. The following description of results will only consider the air pollutant compounds and not focus on the meteorological parameters.

For the sake of discussion, it was necessary to do some simplifications. For one symptom group and one compound, if two symptoms were significant, one positive and one negative, we assumed no significant association.

Tables 11.2-11.6 give weighted means of the regression coefficients estimated for each health effect symptom, for the indicated study groups and seasons, and the value of the t-statistic for this estimate. The t-statistics were computed as a ratio of the regression coefficient and its standard error.

Table 11.7 gives further review of the associations found.

11.5.1 Symptoms of annoyance

There are positive significant associations in the winter between symptoms of annoyance and exposure to ozone and particles and negative significant associations with exposure to chlorine in the randomly selected study population (see Table 11.2., Figure 11.7). In the summer, exposure to nitrates shows positive association whereas exposure to SO_2, NO_2 and particles shows negative associations.

In the population with pre-existing lung disease, both NO_2, particle and sulfate exposure are positively associated with annoyance parameters in the winter, whereas SO_2 and ozone exposure show negative associations. Exposure to particles is also positively associated with symptoms of annoyance in the summer whereas SO_2, sulfate and chlorine exposure is negatively associated.

11.5.2 Symptoms in the upper airways

Nitrates and ozone exposure in the winter are positively correlated with symptoms in the upper airway in the randomly selected study population whereas exposure to SO_2 and sulfates are negatively associated. In the summer NO_2, nitrate and sulfate exposure is positively associated whereas particle exposure is negatively associated.

In the population with pre-existing lung disease there are negative associations found in winter with SO_2 and particle exposure and negative associations with sulfate exposure in the summer (see Table 11.3 and Figure 11.8).

11.5.3 Symptoms in the lower airways

In the winter in the randomly selected study population there are positive associations of symptoms in the lower airways with ozone exposure and negative associations with particle and SO_2 exposure. In the summer, associations are positive with SO_2 exposure and negative with O_3 exposure.

In the population with pre-existing lung disease in the winter, the associations are negative with exposure to particles, NO_2 and nitrates whereas they are positive with sulfate exposure. In the summer there are negative associations with exposure to SO_2, O_3, particles and sulfates (see Table 11.4 and Figure 11.9).

11.5.4 Symptoms of decreased general health

In the winter, in the the randomly selected study population there are negative associations between parameters of decreased health and exposure to SO_2, NO_2 and nitrates, and positive association with chlorine exposure. In the summer, there are positive associations with nitrates and chlorine exposure, whereas there are negative associations with exposure to particles and SO_2.

In the population with pre-existing lung disease in the winter, the associations are negative with exposure to SO_2, sulfates and particles. In the summer there is a marked negative association with exposure to particles in addition to NO_2 and ozone whereas there is a positive association with SO_2 exposure (see Table 11.5 and Figure 11.10).

11.5.5 Symptoms of stress and fatigue

In the winter in the randomly selected study population there is a positive association of symptoms of stress and fatigue with NO_2 exposure whereas there are negative associations with exposure to SO_2, particles and chlorine. In the summer, associations are negative with exposure to SO_2, NO_2, ozone, particles and sulfates.

In the population with pre-existing lung disease in the winter, there are negative associations with SO_2 and nitrate exposure and positive with chlorine exposure. In the summer there are positive associations with exposure to NO_2 and chlorine and negative with exposure to SO_2 and ozone (see Table 11.6 and Figure 11.11).

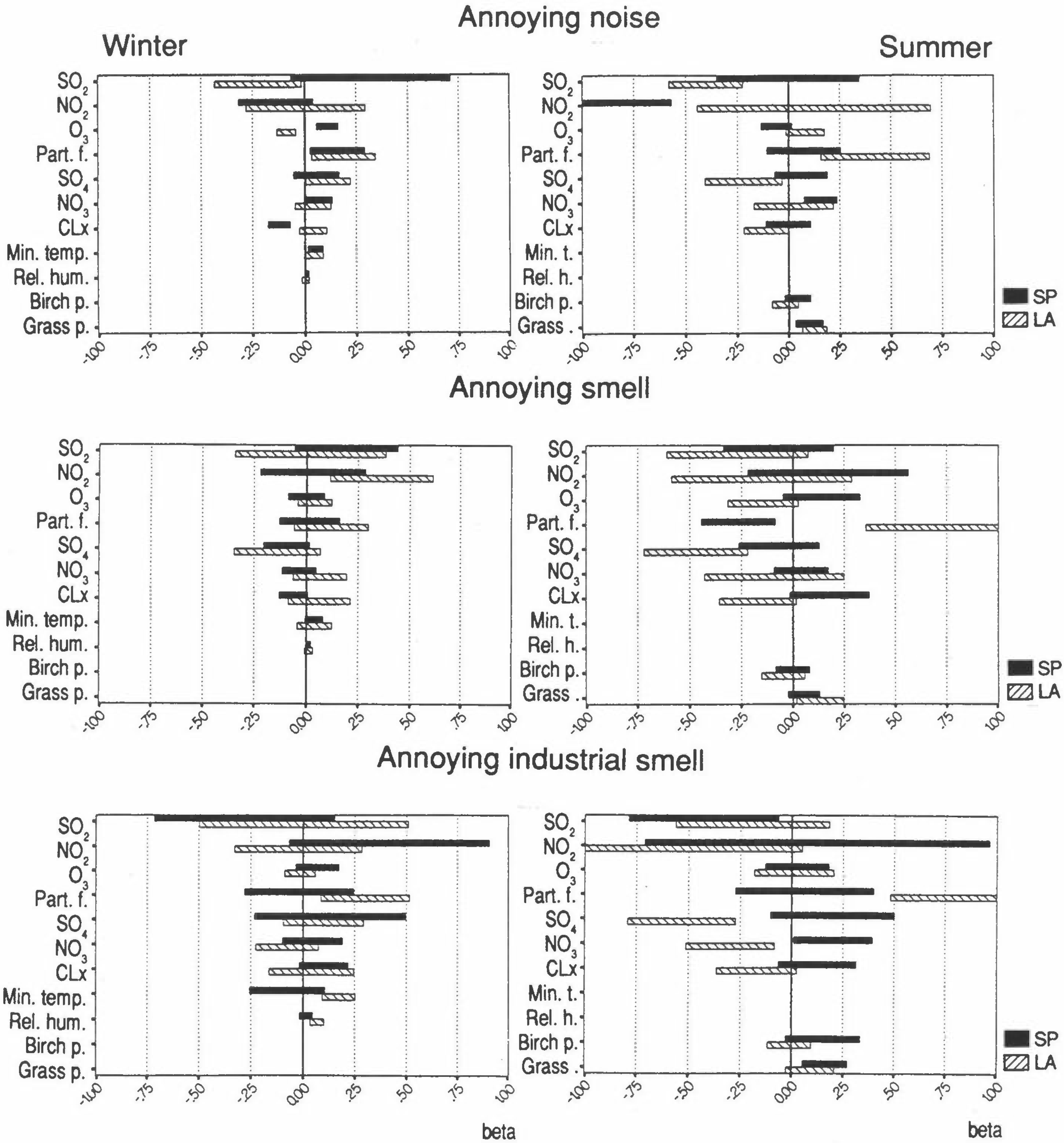


Figure 11.7: <u>Symptoms of annoyance</u>.

The confidence interval CI (mean regression coefficient ± 2 * standard error) for the weighted regression coefficient (β), as calculated for exposure to each pollutant compound and to other independent variables, winter and summer. Significant βs are those where the CI does not overlap 0. SP=randomly selected study population; LA=adults with pre-existing lung disease. See Chapter 15 for additional definitions and abbreviations.

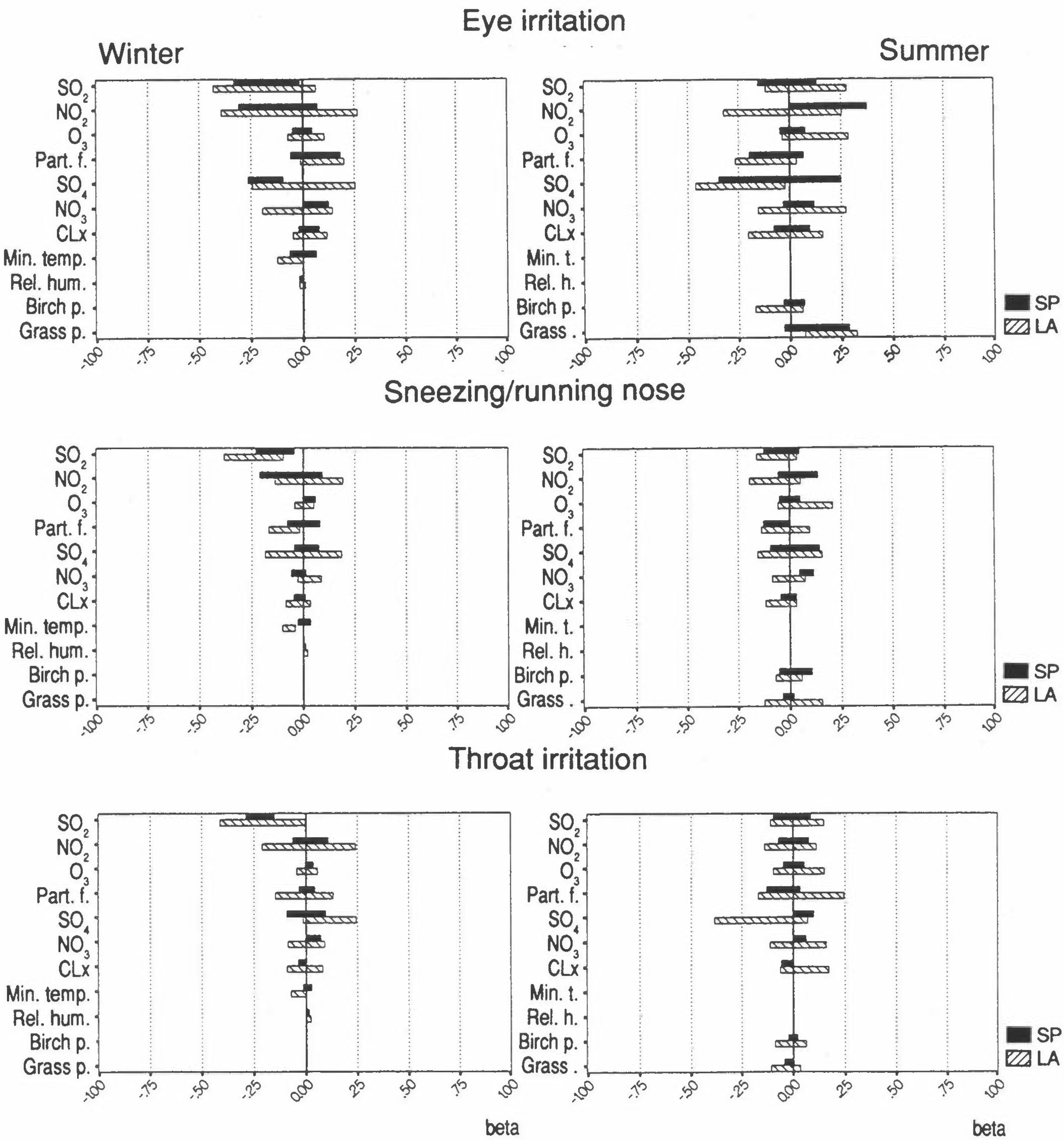


Figure 11.8: Symptoms in the upper airways.

The confidence interval CI (mean regression coefficient ± 2 * standard error) for the weighted regression coefficient (β), as calculated for exposure to each pollutant compound and to other independent variables, winter and summer. Significant βs are those where the CI does not overlap 0. LA=adults with pre-existing lung disease; SP= randomly selected study population.

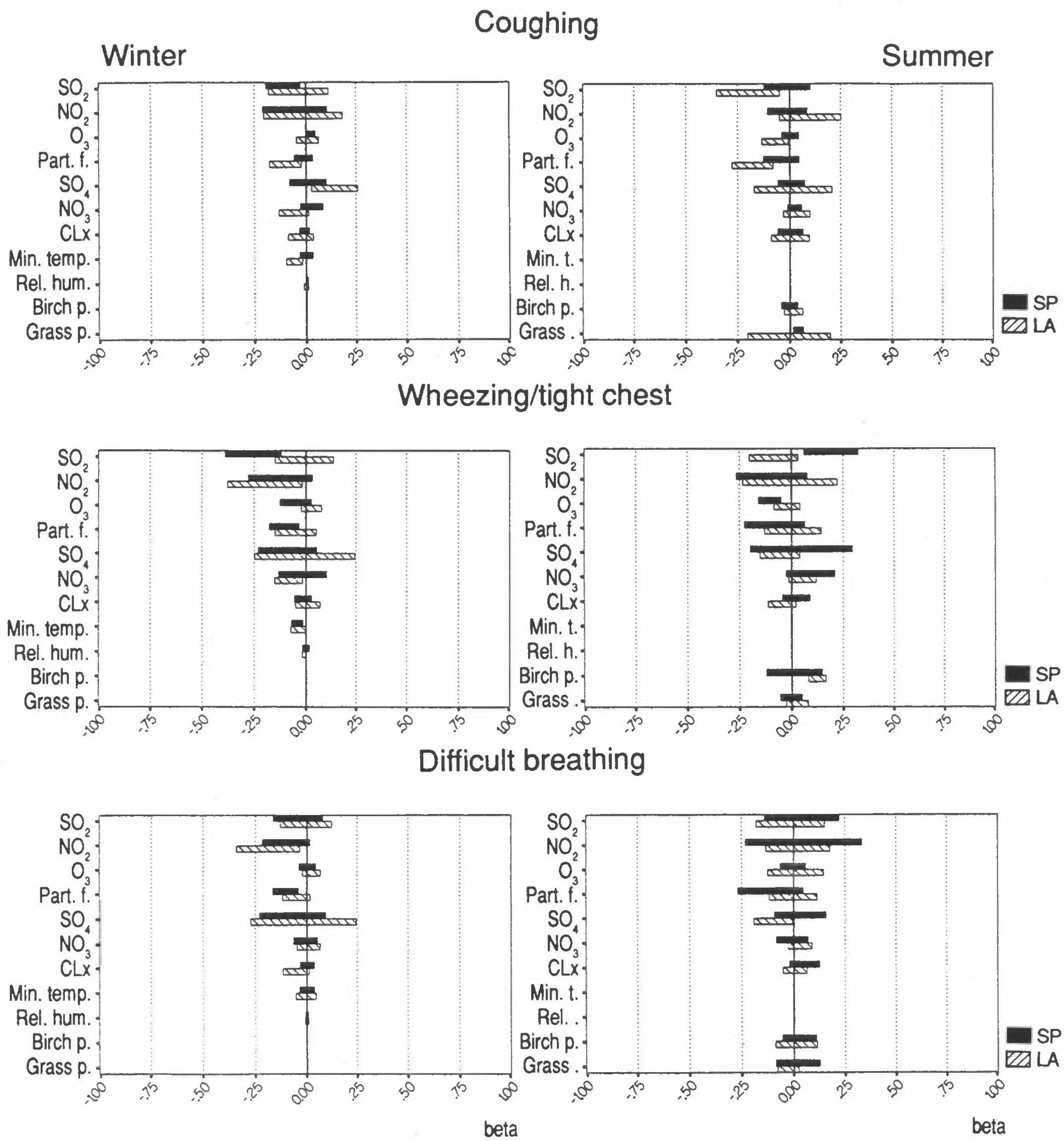


Figure 11.9: <u>Symptoms in the lower airways</u>.

The confidence interval CI (mean regression coefficient ± 2 * standard error) for weighted regression coefficient (β), as calculated for exposure to each pollutant compound and to other independent variables, winter and summer. Significant βs are those where the CI does not overlap 0. LA= adults with pre-existing lung disease; SP=randomly selected study population.

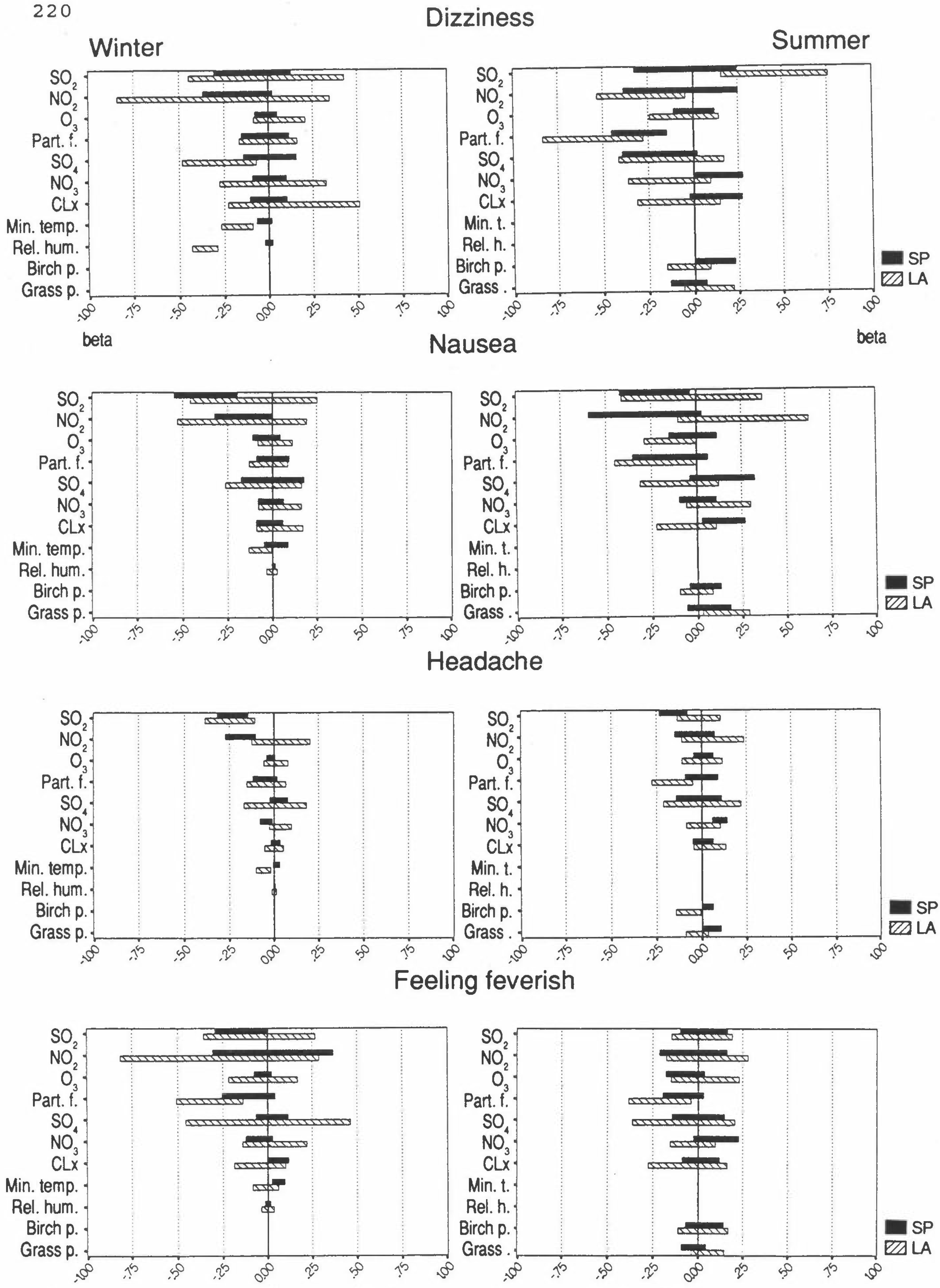


Figure 11.10: Symptoms of decreased general health.
The confidence interval CI (mean regression coefficient ± 2* standard error) for the weighted regression coefficient (β), as calculated for exposure to each pollutant compound and to other independent variables, winter and summer. Significant βs are those where the CI does not overlap 0. LA=adults with pre-existing lung disease; SP=randomly selected study population.

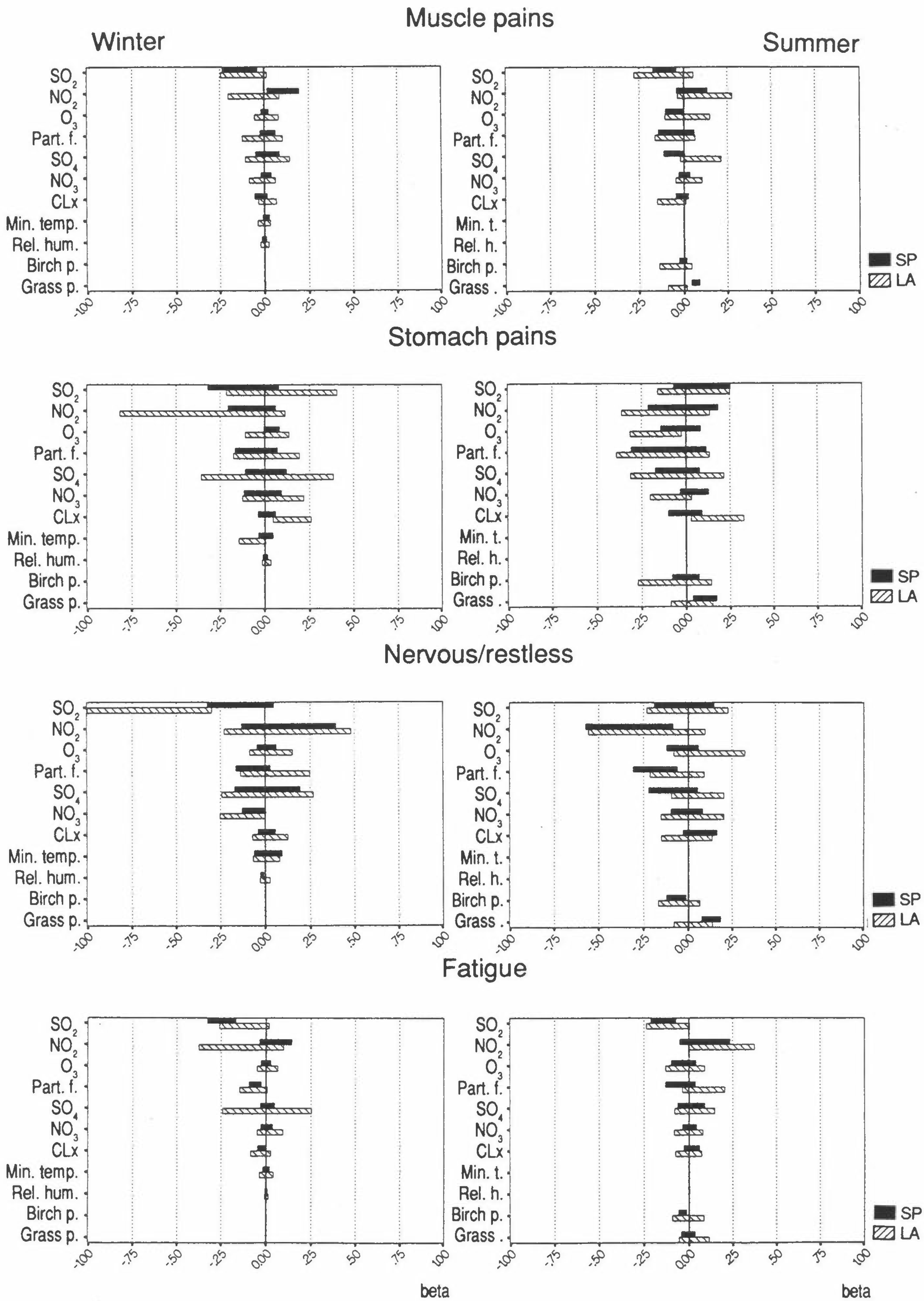


Figure 11.11: Symptoms of stress and fatigue.
See caption to Figure 11.7.

Table 11.2: Symptoms of annoyance.
The results of analysis of the individual logistic regression using the approach suggested by Korn and Whittemore (1979) for each population subgroup and each season, and using the M-indiv method of compression. Only significant results (at the .05 level) are given. Table A gives the regression coefficients and Table B gives the t-value (regression coefficient/standard error).

A)

	Winter			Summer		
	Annoying noise	Annoying smell	Annoying industrial smell	Annoying noise	Annoying smell	Annoying industrial smell
Model						
M-indiv						
Study population						
No. participants	40	40	15	23	30	15
Constant	-9.496	-9.385	-13.980	-4.344	-9.520	-11.325
Active	.551	1.306	1.079	1.489	.986	2.156
Morning	.549	.687	.	.637	.782	.880
SO_2	.	.	.	.	.	-.425
NO_2	.	.	.	-.793	.	.
O_3	.110	.	.	.	.	.
Part-f	.159	.	.	.	-.264	.
SO_4	.	.	.	.	.	.
NO_3	.	.	.	.154	.	.203
CL_x	-.122	.	.	.	.	.
Min.temperature	.052	.	.	x	x	x
Rel. humidity	.010	.012	.	x	x	x
Birch pollen	x	x	x	.	.	.
Grass pollen	x	x	x	.099	.	.163
Adults - lung disease						
No. participants	7	13	5	6	8	6
Constant	-2.371	-12.793	-16.797	.	-17.094	-17.083
Active	.753	1.551	2.072	.	1.905	.
Morning	.552	.681	.754	.	.	.
SO_2	-.224	.	.	-.401	.	.
NO_2	.	.364	.	.	.	.
O_3	-.087	.	.	.	.	.
Part-f	.187	.	.301	.423	.758	1.503
SO_4	.113	.	.	-.219	-.469	-.532
NO_3	.	.	.	.	.	-.296
CL_x	.	.	.	-.109	.	.
Min.temperature	.045	.	.172	x	x	x
Rel. humidity	.	.	.068	x	x	x
Birch pollen	x	x	x	.	.	.
Grass pollen	x	x	x	.125	.133	.

x - the variable is not in the model.

Tabell 11.2. cont.:

B)	Winter			Summer		
	Annoying noise	Annoying smell	Annoying industrial smell	Annoying noise	Annoying smell	Annoying industrial smell
Model						
M-indiv						
Study population						
No. participants	40	40	15	23	30	15
t Constant	-9.61	-9.93	-4.40	-6.04	-5.49	-6.32
t Active	2.29	3.53	2.32	5.33	2.64	3.86
t Morning	2.17	4.24	.	1.97	2.62	2.11
t SO_2	.	.	.	.	.	-2.35
t NO_2	.	.	.	-7.05	.	.
t O_3	4.11	.	.	.	.	.
t Part-f	2.40	.	.	.	-2.95	.
t SO_4	.	.	.	.	.	.
t NO_3	.	.	.	3.87	.	2.13
t CL_x	-4.67	.	.	.	.	.
t Min.temperature	2.82	.	.	x	x	x
t Rel. humidity	2.63	2.41	.	x	x	x
t Birch pollen	x	x	x	.	.	.
t Grass pollen	x	x	x	3.00	.	3.00
Adults - lung disease						
No. participants	7	13	5	6	8	6
t Constant	-2.16	-7.90	-8.85	.	-5.42	-5.41
t Active	4.21	3.62	5.79	.	2.04	.
t Morning	2.53	2.25	2.22	.	.	.
t SO_2	-2.15	.	.	-4.48	.	.
t NO_2	.	2.93	.	.	.	.
t O_3	-3.90	.	.	.	.	.
t Part-f	2.43	.	2.81	3.19	3.77	2.95
t SO_4	2.10	.	.	-2.34	-3.74	-4.12
t NO_3	.	.	.	.	.	-2.76
t CL_x	.	.	.	-2.01	.	.
t Min.temperature	2.03	.	4.32	x	x	x
t Rel. humidity	.	.	4.02	x	x	x
t Birch pollen	x	x	x	.	.	.
t Grass pollen	x	x	x	4.20	2.32	.

x - the variable is not in the model.

Table 11.3: <u>Symptoms in the upper airways</u>.
The results of analysis of the individual logistic regression using the approach suggested by Korn and Whittemore (1979) for each population subgroup and each season, and using the M-indiv method of compression. Only significant results (at the .05 level) are given. Table A gives the regression coefficients and Table B gives the t-value (regression coefficient/standard error).

A)

	Winter			Summer		
	Eye irritation	Sneezing/ running nose	Throat irritation	Eye irritation	Sneezing/ running nose	Throat irritation
Model						
M-indiv						
Study population						
No. participants	48	111	163	34	100	103
Constant	-6.048	-6.921	-6.008	-5.950	-5.017	-4.886
Active	1.498	1.167	1.065	1.267	1.152	1.147
Morning	.	.497	.455	.	.353	.202
SO_2	-.173	-.137	-.221	.	.	.
NO_2	.	.	.	.190	.	.
O_3	.	.033	.	.	.	.
Part-f	.	.	.	.	-.063	.
SO_4	-.179	.	.	.	.	.053
NO_3	.062	.	.038	.	.081	.035
CL_x	.	.	.	.	.	.
Min.temperature	.	.	.	x	x	x
Rel. humidity	-.011	.005	.010	x	x	x
Birch pollen	x	x	x	.	.	.
Grass pollen	x	x	x	.	.	-.023
Adults - lung disease						
No. participants	15	28	27	12	27	30
Constant	-4.747	-6.034	-6.158	-6.786	-3.552	-3.898
Active	1.745	1.390	1.296	1.656	.638	.903
Morning	.747	1.035	.810	.	.821	.735
SO_2	.	-.240	-.208	.	.	.
NO_2	.	.	.	.	.	.
O_3	.	.	.	.	.	.
Part-f	.	-.092	.	.	.	.
SO_4	.	.	.	-.242	.	.
NO_3	.	.	.	.	.	.
CL_x	.	.	.	.	.	.
Min.temperature	-.060	-.070	.	x	x	x
Rel. humidity	.	.011	.012	x	x	x
Birch pollen	x	x	x	.	.	.
Grass pollen	x	x	x	.196	.	.

x - the variable is not in the model.

Table 11.3. cont.:

B)	Winter			Summer		
	Eye irritation	Sneezing/ running nose	Throat irritation	Eye irritation	Sneezing/ running nose	Throat irritation
Model						
M-indiv						
Study population						
No. participants	48	111	163	34	100	103
t Constant	-9.13	-18.42	-21.69	-10.50	-21.67	-25.82
t Active	11.35	15.68	19.58	7.67	16.32	21.54
t Morning	.	5.30	7.78	.	4.38	2.49
t SO_2	-2.20	-2.95	-6.50	.	.	.
t NO_2	.	.	.	2.04	.	.
t O_3	.	2.64	.	.	.	.
t Part-f	.	.	.	.	-2.03	.
t SO_4	-4.23	.	.	.	.	2.34
t NO_3	2.07	.	2.39	.	4.77	2.52
t CL_x	.	.	.	.	.	.
t Min.temperature	.	.	.	x	x	x
t Rel. humidity	-2.79	2.15	5.47	x	x	x
t Birch pollen	x	x	x	.	.	.
t Grass pollen	x	x	x	.	.	-2.24
Adults - lung disease						
No. participants	15	28	27	12	27	30
t Constant	-4.46	-9.39	-7.83	-7.24	-8.85	-8.09
t Active	6.22	10.62	8.27	2.20	4.82	5.60
t Morning	2.03	6.96	4.20	.	4.46	3.89
t SO_2	.	-3.35	-2.03	.	.	.
t NO_2	.	.	.	.	.	.
t O_3	.	.	.	.	.	.
t Part-f	.	-2.47	.	.	.	.
t SO_4	.	.	.	-2.20	.	.
t NO_3	.	.	.	.	.	.
t CL_x	.	.	.	.	.	.
t Min.temperature	-1.99	-4.56	.	x	x	x
t Rel. humidity	.	2.24	2.01	x	x	x
t Birch pollen	x	x	x	.	.	.
t Grass pollen	x	x	x	3.13	.	.

x - the variable is not in the model.

Table 11.4: Symptoms in the lower airways.
The results of analysis of the individual logistic regression using the approach suggested by Korn and Whittemore (1979) for each population subgroup and each season, and using the M-indiv method of compression. Only significant results (at the .05 level) are given. Table A gives the regression coefficients and Table B gives the t-value (regression coefficient/standard error).

A)

	Winter			Summer		
	Coughing	Wheezing/ tight chest	Difficult breathing	Coughing	Wheezing/ tight chest	Difficult breathing
Modell						
M-indiv						
Study population						
No. participants	101	41	56	73	32	35
Constant	-4.968	-2.594	-3.564	-3.649	-5.057	-5.127
Active	.846	.866	1.098	.767	1.207	.537
Morning	.739	.671	.441	.485	.	.758
SO_2	-.110	-.254	.	.	.193	.
NO_2	.	.	.	.	.	.
O_3	.025	.	.	.	-.103	.
Part-f	.	-.105	-.104	.	.	.
SO_4	.	.	.	.	.	.
NO_3	.	.	.	.	.	.
CL_x	.	.	.	.	.	.
Min.temperature	.	-.042	.	x	x	x
Rel. humidity	.005	.	.	x	x	x
Birch pollen	x	x	x	.	.	.
Grass pollen	x	x	x	.041	.	.
Adults - lung disease						
No. participants	22	25	35	27	24	30
Constant	-3.487	-2.651	-3.918	-2.503	-2.016	-3.763
Active	.509	.811	1.420	.324	.616	.836
Morning	1.169	.839	.629	.704	.403	.420
SO_2	.	.	.	-.200	.	.
NO_2	.	-.197	-.187	.	.	.
O_3	.	.	.	-.071	.	.
Part-f	-.099	.	.	-.178	.	.
SO_4	.143	.	.	.	.	-.099
NO_3	.	-.084	.	.	.	.
CL_x	.	.	.	.	.	.
Min.temperature	-.057	-.038	.	x	x	x
Rel. humidity	.	.	.	x	x	x
Birch pollen	x	x	x	.	.123	.
Grass pollen	x	x	x	.	.	.

x - the variable is not in the model.

Table 11.4. cont.:

B)	Winter			Summer		
	Coughing	Wheezing/ tight chest	Difficult breathing	Coughing	Wheezing/ tight chest	Difficult breathing
Model						
M-indiv						
Study population						
No. participants	101	41	56	73	32	35
t Constant	-14.96	-4.87	-.30	-15.91	-10.45	-11.69
t Active	12.66	7.80	11.43	11.38	8.56	4.47
t Morning	5.86	3.24	3.87	4.29	.	3.56
t SO_2	-2.65	-3.78	.	.	2.95	.
t NO_2	.	.	.	.	.	.
t O_3	2.34	.	.	.	-3.86	.
t Part-f	.	-2.91	-3.31	.	.	.
t SO_4	.	.	.	.	.	.
t NO_3	.	.	.	.	.	.
t CL_x	.	.	.	.	.	.
t Min.temperature	.	-3.03	.	x	x	x
t Rel. humidity	2.28	.	.	x	x	x
t Birch pollen	x	x	x	.	.	.
t Grass pollen	x	x	x	3.38	.	.
Adults - lung disease						
No. participants	22	25	35	27	24	30
t Constant	-4.94	-4.16	-7.04	-6.50	-5.48	-10.83
t Active	2.39	4.00	8.32	2.69	4.90	7.75
t Morning	6.91	5.20	3.02	4.06	2.48	2.91
t SO_2	.	.	.	-2.65	.	.
t NO_2	.	-2.20	-2.45	.	.	.
t O_3	.	.	.	-2.27	.	.
t Part-f	-2.56	.	.	-3.64	.	.
t SO_4	2.50	.	.	.	.	-2.12
t NO_3	.	-2.52	.	.	.	.
t CL_x	.	.	.	.	.	.
t Min.temperature	-2.83	-2.16	.	x	x	x
t Rel. humidity	.	.	.	x	x	x
t Birch pollen	x	x	x	.	5.98	.
t Grass pollen	x	x	x	.	.	.

x - the variable is not in the model.

Table 11.5: <u>Symptoms of decreased general health</u>.
The results of analysis of the individual logistic regression using the approach suggested by Korn and Whittemore (1979) for each population subgroup and each season, and using the M-indiv method of compression. Only significant results (at the .05 level) are given. Table A gives the regression coefficients and Table B gives the t-values (regression coefficient/standard error).

A)

	Winter				Summer			
	Headache	Dizziness	Nausea	Feeling feverish	Headache	Dizziness	Nausea	Feeling feverish
Model								
M-indiv								
Study population								
No. participants	163	39	73	68	107	22	38	53
Constant	-5.923	-4.410	-6.950	-6.866	-6.285	-7.304	-7.573	-6.336
Active	1.285	.699	.607	.	1.152	.659	.530	.523
Morning	.411	1.042	.605	.565	.302	.	.896	.
SO_2	-.231	.	-.370	-.147	-.155	.	-.227	.
NO_2	-.187	.	-.163	.	.	.	.	.
O_3	.	.	.	.	.	.	.	.
Part-f	.	.	.	.	.	-.299	.	.
SO_4	.	.	.	.	.	.	.	.
NO_3	-.044	.	.	.	.100	.142	.	.
CL_x	.	.	.	.063	.	.	.148	.
Min.temperature	.	.	.	.060	x	x	x	x
Rel. humidity	.	.	.	.	x	x	x	x
Birch pollen	x	x	x	x	.035	.117	.	.
Grass pollen	x	x	x	x	.057	.	.	.
Adults - lung disease								
No. participants	41	8	19	15	23	8	6	14
Constant	-6.112	-4.719	-5.627	-7.931	-6.180	-2.870	-6.164	-5.474
Active	1.136	1.267	.558	.	1.075	.972	1.535	1.054
Morning	.325	.	.674	.	.	.	.	.
SO_2	-.246	.	.	.	.	.457	.	.
NO_2	.	.	.	.	.	-.287	.	.
O_3	.	.	.	.	.	.	-.144	.
Part-f	.	.	.	-.321	-.162	-.556	-.226	-.211
SO_4	.	-.276	.	.	.	.	.	.
NO_3	.	.	.	.	.	.	.	.
CL_x	.	.	.	.	.	.	.	.
Min.temperature	-.059	-.179	-.070	.	x	x	x	x
Rel. humidity	.	-.360	.	.	x	x	x	x
Birch pollen	x	x	x	x	-.076	.	.	.
Grass pollen	x	x	x	x	.	.	.157	.

x - the variable is not in the model.

Table 11.5. cont.:

B)	Winter				Summer			
	Headache	Dizziness	Nausea	Feeling feverish	Headache	Dizziness	Nausea	Feeling feverish
Model								
M-indiv								
Study population								
No. participants	163	39	73	68	107	22	38	53
t Constant	-16.40	-4.63	-8.08	-8.31	-20.49	-5.11	-6.33	-11.50
t Active	17.27	3.60	4.41	.	13.19	2.01	2.36	4.15
t Morning	4.45	4.38	4.11	4.19	2.47	.	3.44	.
t SO_2	-5.40	.	-4.22	-2.03	-4.00	.	-2.35	.
t NO_2	-4.44	.	-2.07	.	.	.	.	.
t O_3	.	.	.	.	.	.	.	.
t Part-f	.	.	.	.	.	-3.92	.	.
t SO_4	.	.	.	.	.	.	.	.
t NO_3	-2.62	.	.	.	4.77	2.15	.	.
t CL_x	.	.	.	2.29	.	.	2.47	.
t Min.temperature	.	.	.	3.32	x	x	x	x
t Rel.humidity	.	.	.	.	x	x	x	x
t Birch pollen	x	x	x	x	2.63	2.16	.	.
t Grass pollen	x	x	x	x	2.39	.	.	.
Adults - lung disease								
No. participants	41	8	19	15	23	8	6	14
t Constant	-10.05	-2.52	-4.63	-3.93	-10.68	-2.93	-5.23	-5.74
t Active	7.98	3.12	2.43	.	4.89	2.42	3.32	4.05
t Morning	2.09	.	3.11	.	.	.	.	.
t SO_2	-3.51	.	.	.	.	3.04	.	.
t NO_2	.	.	.	.	.	-2.36	.	.
t O_3	.	.	.	.	.	.	-2.01	.
t Part-f	.	.	.	-3.49	-2.88	-4.00	-2.00	-2.46
t SO_4	.	-2.66	.	.	.	.	.	.
t NO_3	.	.	.	.	.	.	.	.
t CL_x	.	.	.	.	.	.	.	.
t Min.temperature	-2.94	-4.04	-2.22	.	x	x	x	x
t Rel. humidity	.	-10.23	.	.	x	x	x	x
t Birch pollen	x	x	x	x	-2.26	.	.	.
t Grass pollen	x	x	x	x	.	.	2.41	.

x - the variable is not in the model.

Table 11.6: <u>Symptoms of stress and fatigue</u>.
The results of analysis of the individual logistic regression using the approach suggested by Korn and Whittemore (1979) for each population subgroup and each season, and using the M-indiv method of compression. Only significant results (at the .05 level) are given. Table A gives the regression coefficients and Table B gives the t-value (regression coefficient/standard error).

A)

	Winter				Summer			
	Muscle pains	Stomach pains	Nervous/ uneasy	Fatigue	Muscle pains	Stomach pains	Nervous/ uneasy	Fatigue
Model								
M-indiv								
Study population								
No. participants	121	83	40	154	89	44	28	105
Constant	-4.172	-5.251	-4.828	-5.246	-5.248	-6.717	-5.909	-6.120
Active	1.307	1.102	1.168	1.332	1.557	.899	1.291	1.375
Morning	.	.300	.391	-.207	.	.	.377	.
SO_2	-.136	.	.	-.248	-.106	.	.	-.141
NO_2	.106	.	.	.	.	.	-.330	.
O_3	.	.	.	.	-.054	.	.	.
Part-f	.	.	.	-.059	.	.	-.184	.
SO_4	.	.	.	.	-.059	.	.	.
NO_3	.	.	.	.	.	.	.	.
CL_x	.	.	.	-.025	.	.	.	.
Min.temperature	.	.	.	.	x	x	x	x
Rel. humidity	.	.	-.018	.	x	x	x	x
Birch pollen	x	x	x	x	.	.	-.067	-.036
Grass pollen	x	x	x	x	.065	.104	.129	.
Adults - lung disease								
No. participants	22	16	9	29	17	11	6	24
Constant	-3.309	-6.520	-6.446	-5.108	-4.789	.	-4.744	-5.128
Active	1.518	.	1.163	1.393	1.684	1.015	1.463	1.526
Morning	.	.774	.	.	.753	.	.	.
SO_2	.	.	-.647	.	.	.	.	.
NO_2	.	.	.	.	.	.	.	.187
O_3	.	.	.	.	.	-.169	.	.
Part-f	.	.	.	.	.	.	.	.
SO_4	.	.	.	.	.	.	.	.
NO_3	.	.	-.127	.	.	.	.	.
CL_x	.	.152	.	.	.	.179	.	.
Min.temperature	.	.	.	.	x	x	x	x
Rel. humidity	.	.	.	.	x	x	x	x
Birch pollen	x	x	x	x	.	.	.	.
Grass pollen	x	x	x	x	.	.	.	.

x - the variable is not in the model.

Table 11.6. cont.:

B)	Winter				Summer			
	Muscle pains	Stomach pains	Nervous/ uneasy	Fatigue	Muscle pains	Stomach pains	Nervous/ uneasy	Fatigue
Model								
M-indiv								
Study population								
No. participants	121	83	40	154	89	44	28	105
t Constant	-13.83	-8.19	-6.96	-17.89	-23.78	-7.32	-7.70	-23.56
t Active	21.01	8.85	8.46	21.15	23.96	4.72	2.51	18.00
t Morning	.	2.37	2.78	-2.89	.	.	1.97	.
t SO_2	-2.78	.	.	-6.28	-3.26	.	.	-4.08
t NO_2	2.42	.	.	.	.	.	-2.70	.
t O_3	.	.	.	.	-2.25	.	.	.
t Part-f	.	.	.	-3.55	.	.	-3.01	.
t SO_4	.	.	.	.	-2.22	.	.	.
t NO_3	.	.	.	.	.	.	.	.
t CL_x	.	.	.	-2.34	.	.	.	.
t Min.temperature	.	.	.	.	x	x	x	x
t Rel. humidity	.	.	-4.44	.	x	x	x	x
t Birch pollen	x	x	x	x	.	.	-2.46	-3.24
t Grass pollen	x	x	x	x	5.66	3.09	4.72	.
Adults - lung disease								
No. participants	22	16	9	29	17	11	6	24
t Constant	-5.73	-3.65	-4.69	-7.82	-10.25	.	-4.33	-11.65
t Active	12.17	.	3.76	9.37	3.72	3.22	3.36	9.91
t Morning	.	2.55	.	.	3.45	.	.	.
t SO_2	.	.	-3.71	.	.	.	.	.
t NO_2	.	.	.	.	.	.	.	1.99
t O_3	.	.	.	.	.	-2.34	.	.
t SVF	.	.	.	.	.	.	.	.
t SO_4	.	.	.	.	.	.	.	.
t NO_3	.	.	-2.03	.	.	.	.	.
t CL_x	.	2.87	.	.	.	2.38	.	.
t Min.temperature	.	.	.	.	x	x	x	x
t Rel. humidity	.	.	.	.	x	x	x	x
t Birch pollen	x	x	x	x	.	.	.	.
t Grass pollen	x	x	x	x	.	.	.	.

x - the variable is not in the model.

11.6 RESULTS OF THE ANALYSIS OF THE HEALTH EFFECTS OF AIR POLLUTION USING THE M-MICRO COMPRESSION METHOD

As indicated previously, the M-micro method of compression had the advantage of smoothing the air pollution exposure estimates, resulting in fewer data points per individual so that the analysis was made more manageable. In addition, those hours are compressed into one block that have the same type of error resulting from the algorithm used in the exposure estimating model. A comparison of the results obtained using the two compression methods can be made using Figure 11.12. Many of the negative associations with SO_2 disappear using the M-micro method. Positive winter associations with O_3 and nitrates are strengthened. A summary of the positive and negative associations (with t-values over two) is given in Table 11.7.

11.7 RESULTS OF THE RELATIONSHIP BETWEEN AIR POLLUTION EXPOSURE THE PREVIOUS 24 HOURS AND THE INDIVIDUAL HEALTH SYMPTOMS

For symptoms of annoyance there are no significant positive relationships in the randomly selected study population in the winter, whereas in the summer, ozone and chlorine exposure show positive relationships. On the other hand, negative associations are shown with exposure to NO_2 and chlorine in the winter, and with exposure to SO_2 and particles in the summer.

For symptoms of annoyance there are significant positive relationships with chlorine exposure in the population of adults with pre-existing lung disease in the winter, and with exposure to particles in the summer. On the other hand, associations with NO_2, ozone, sulfate and chlorine exposure are negative in the winter.

There are positive significant relationships between symptoms in the upper airways and exposure to particles in the randomly selected study population both in the winter and summer, whereas the associations are negative with SO_2, sulfate and nitrate exposure in the winter, and with NO_2 and ozone exposure in the summer.

In the population of adults with pre-existing lung disease, relationships are positive between symptoms in the upper airways and nitrate exposure in the summer, whereas the associations are negative with exposure to SO_2, NO_2, ozone and sulfates in the winter and with exposure to particles in the summer.

There are positive significant relationships between symptoms in the lower airways and SO_2 and ozone exposure in the randomly selected study population in the summer, whereas the associations are negative with SO_2, nitrate and chlorine exposure in the winter, and with NO_2 and chlorine exposure in the summer.

In the population of adults with pre-existing lung disease, the relationships between symptoms in the lower airways and NO_2 and sulfate exposure in the summer are positively significant whereas the associations are negative with SO_2 and NO_2 exposure in the winter and with exposure to particles in the summer.

There are positive significant relationships between symptoms of decreased general health and NO_2 exposure in the randomly selected study population in the winter, whereas the associations are negative with exposure to ozone, particles and nitrates in the winter, and with exposure to particles and chlorine in the summer.

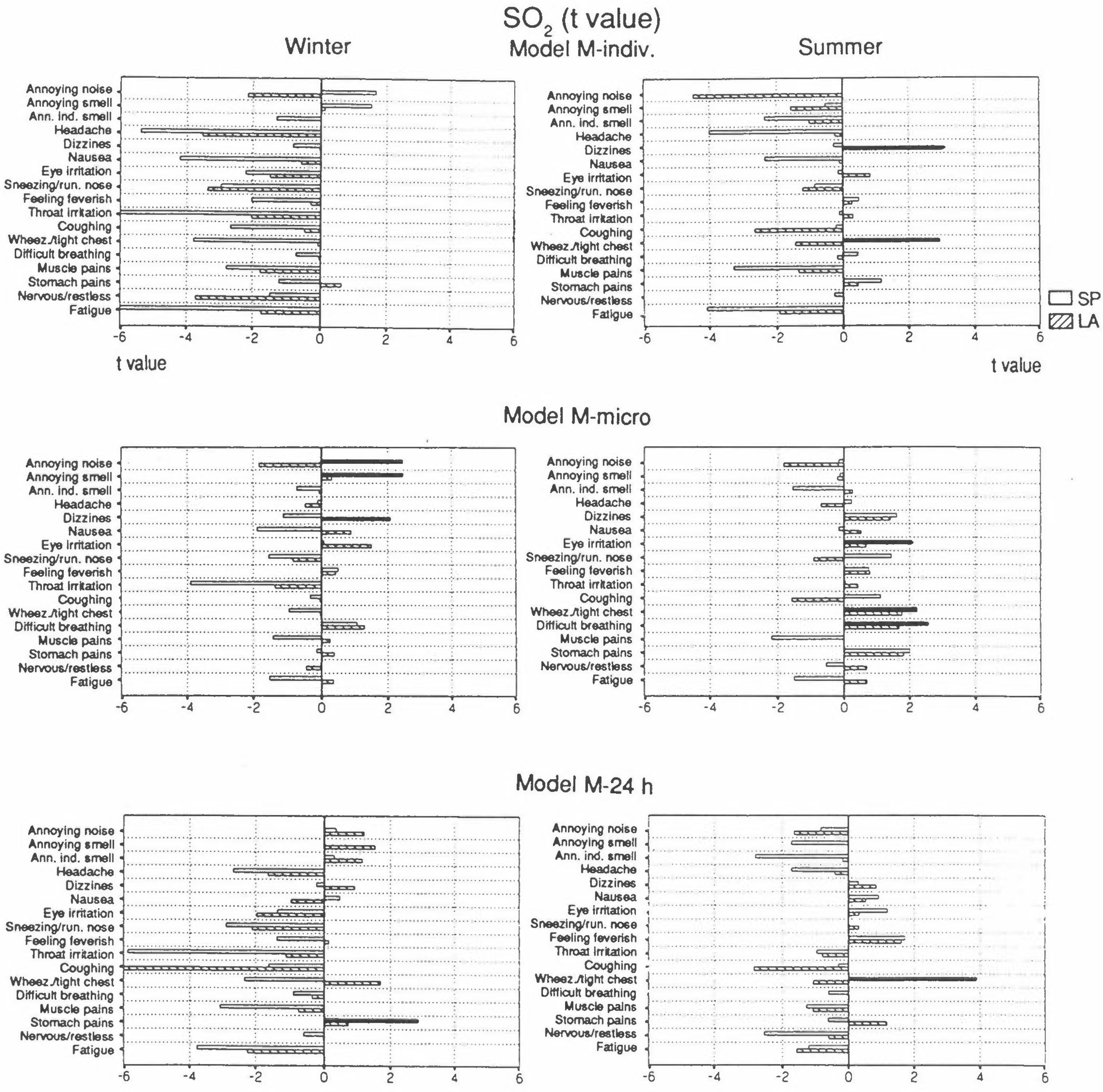


Figure 11.12: A graphical display of the t-value for all health symptoms and for each of the air pollution compounds, meteorological parameters and pollen. The graphs show differences between calculated values for winter and summer, and between the M-indiv and M-micro methods of compressing the data. In addition, the results for the analyses of the data with exposure the last 24 hours are included. Those positive significant associations (t-value greater than 2) are blackened. LA=adults with pre-existing lung disease; SP=randomly selected study population.

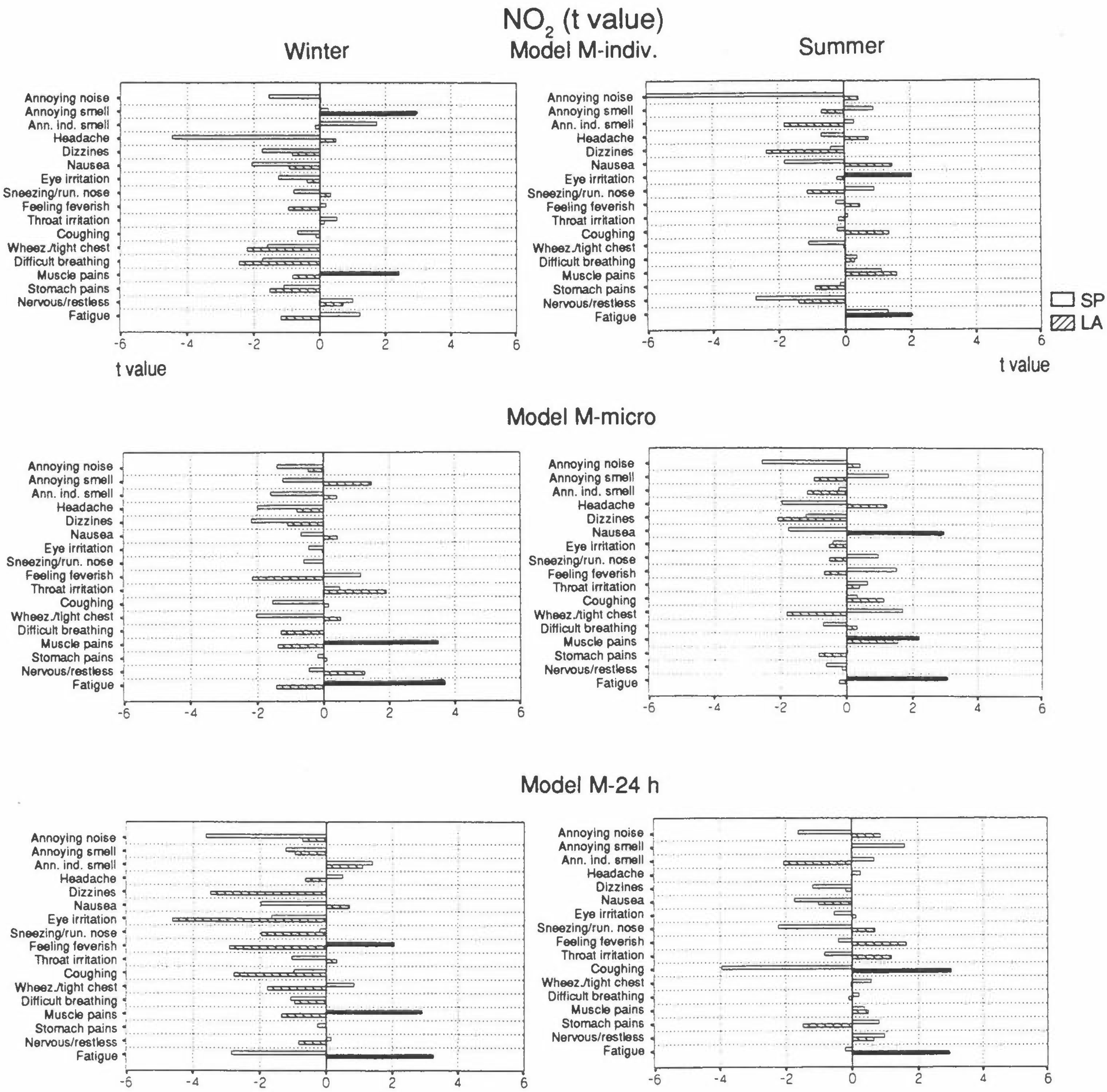


Figure 11.12 cont.

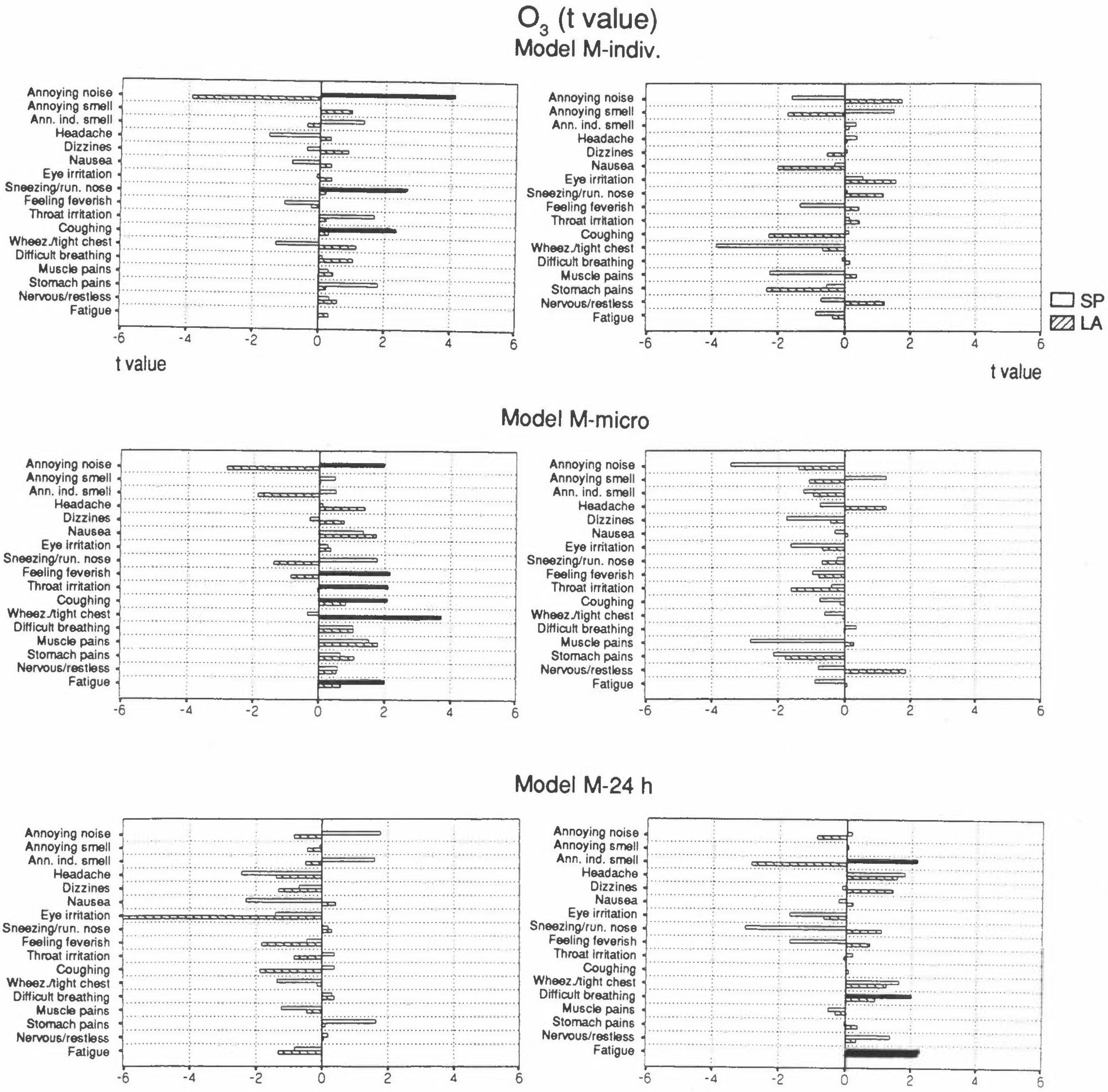


Figure 11.12 cont.

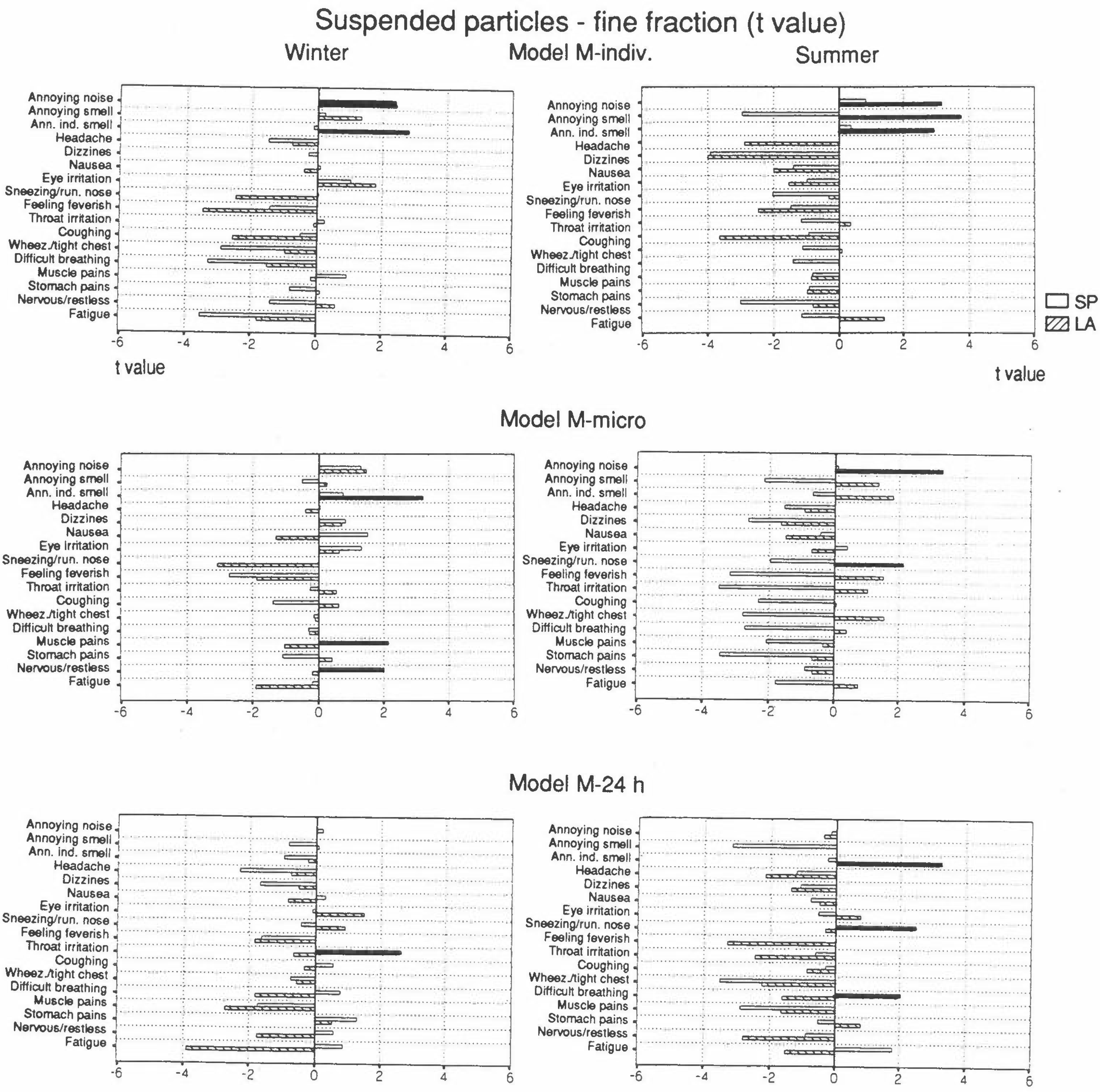


Figure 11.12 cont.

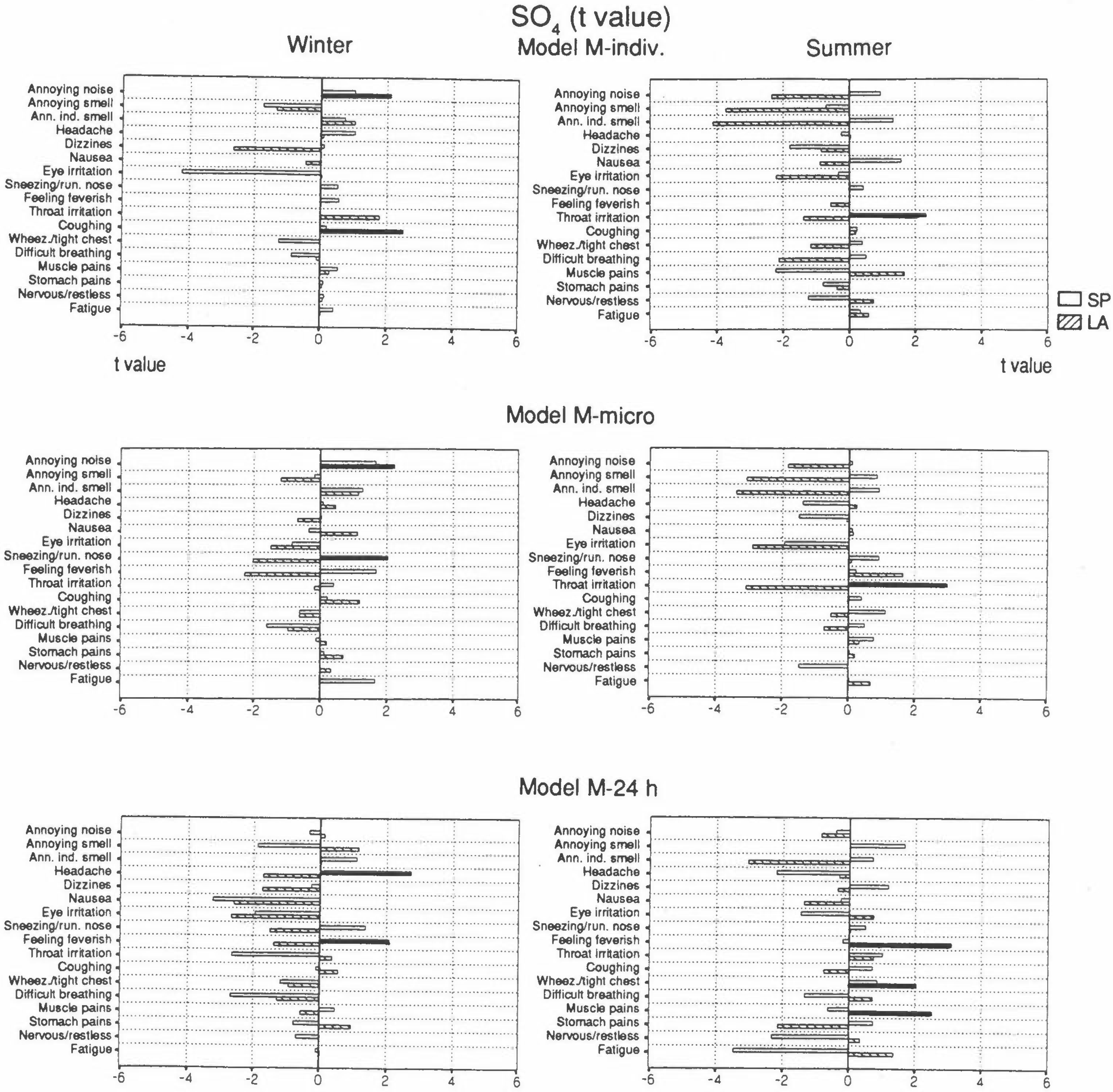


Figure 11.12 cont.

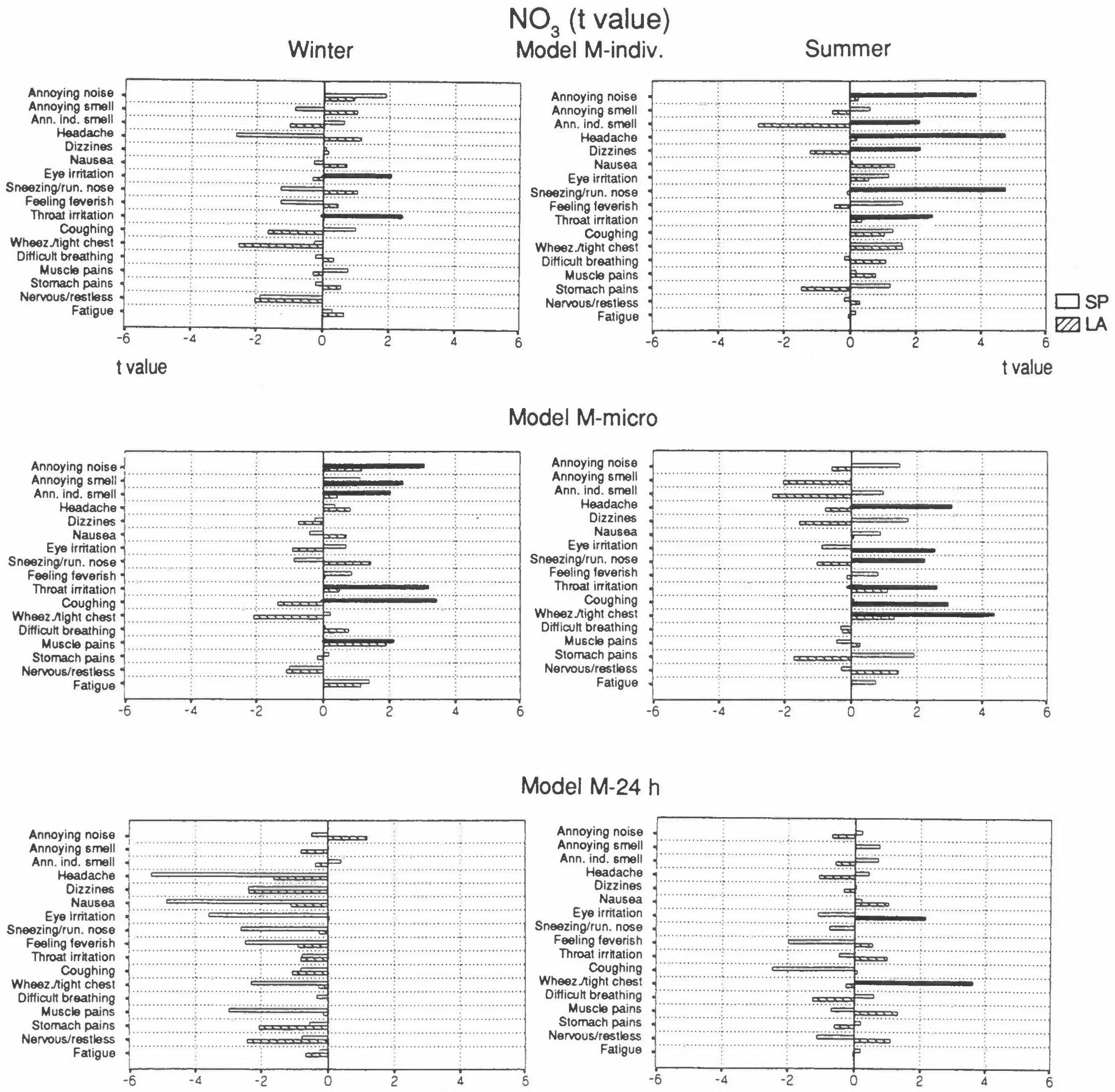


Figure 11.12 cont.

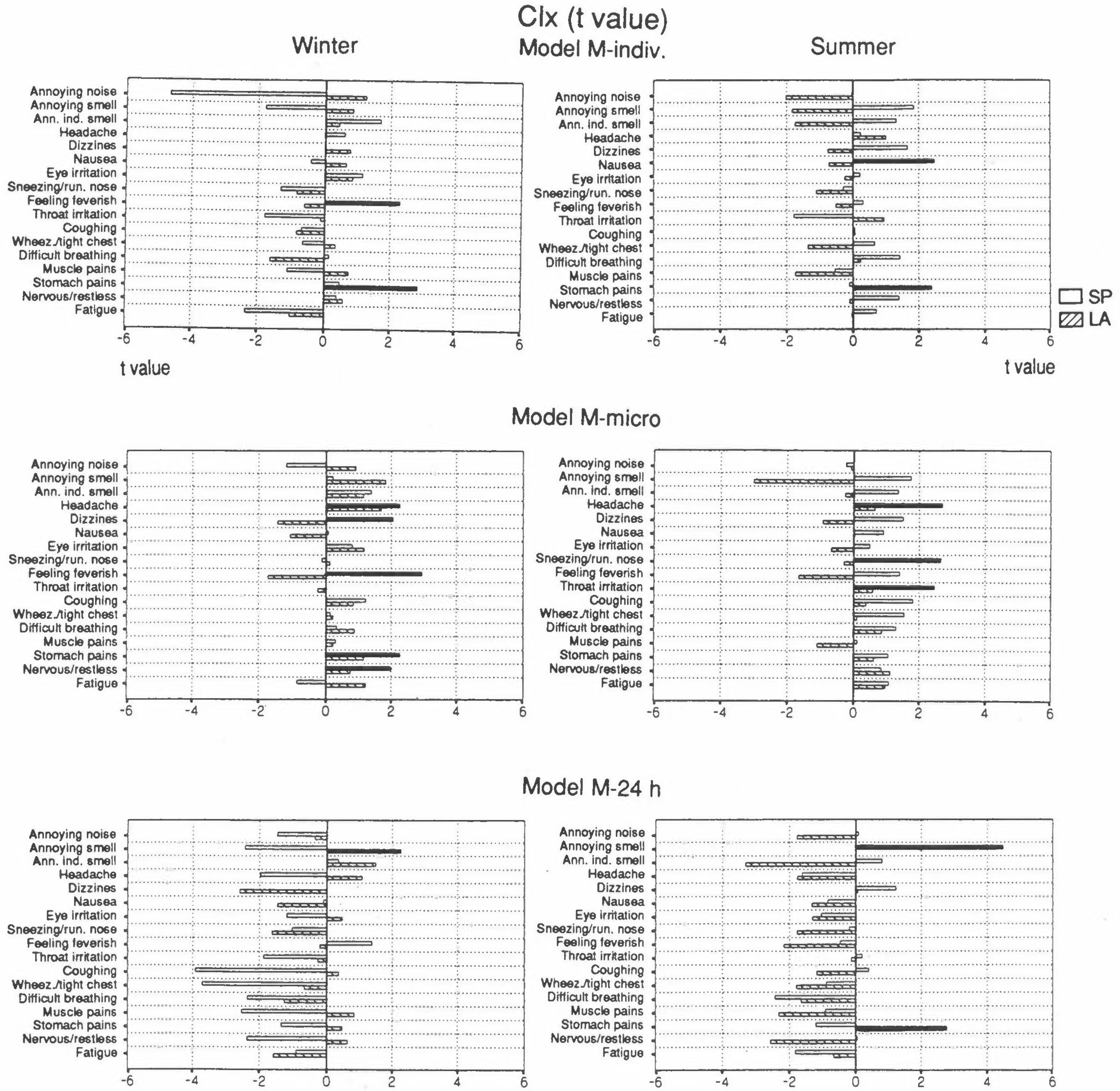


Figure 11.12 cont.

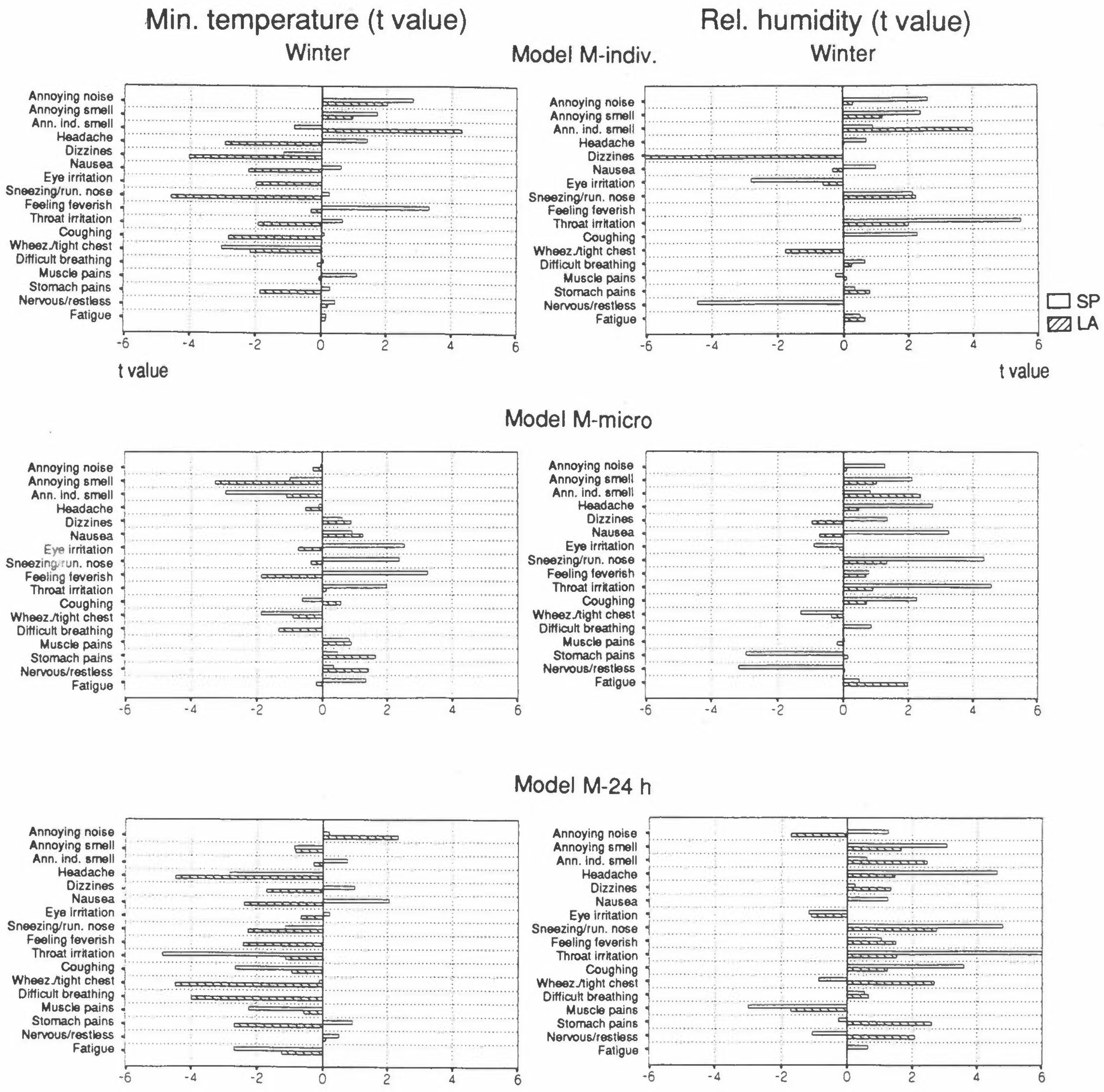


Figure 11.12 cont.

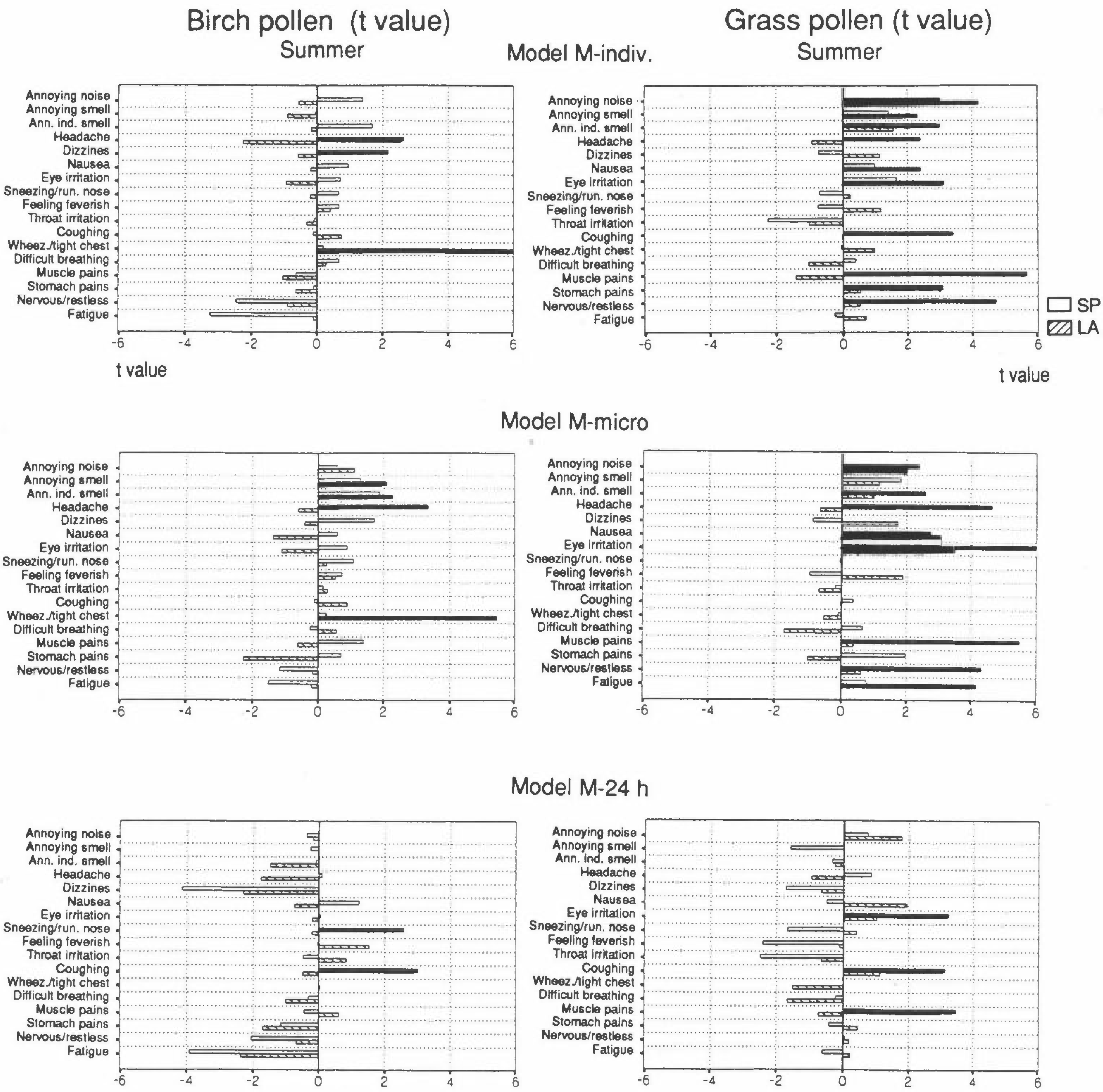


Figure 11.12 cont.

In the population of adults with pre-existing lung disease, the positive relationships between symptoms of decreased general health and sulfate exposure in the summer are significant, whereas the associations are negative with exposure to NO_2, sulfates, nitrates and chlorine in the winter and with exposure to particles and chlorine in the summer.

There are positive significant relationships between symptoms of stress and fatigue and ozone exposure in the randomly selected study population in the summer, whereas the associations are negative with nitrate and chlorine exposure in the winter, and with exposure to SO_2, particles and sulfates in the summer.

In the population of adults with pre-existing lung disease, there are positive significant relationships between symptoms of stress and fatigue and NO_2 exposure both in the winter and summer, where there are also found positive associations with ozone exposure. The associations are negative with exposure to SO_2, particles and nitrates in the winter and with exposure to particles in the summer. The results are reviewed in Table 11.7.

11.8 DISCUSSION

It is an advantage to be able to compare the relative effects on health of exposure to different air pollutants. Therefore, in this investigation all the air pollution compounds were entered simultaneously in the regression calculation. This was not done in the studies described by Schwartz et al. (1991) or the Houston study (Holguin et al., 1985). This may be the reason that previous studies did not discuss the importance or meaning of negative associations. The present logistic regression analyses resulted in several apparent negative associations.

It is difficult to rationalize the physiological implication of a negative association in short-term (mostly hour for hour) health responses. It seems to imply that at higher exposure

Table 11.7: A tabular comparison of the three analysis methods, for the winter and summer periods respectively, 1) based on the M-indiv (IND) compression method, 2) based on the M-micro (MIC) compression method, and 3) based on exposure the previous 24 hours (24H). Table A show the positive associations and B the negative associations by groups of health symptoms and by population groups. The maximum number of associations is 4 for symptoms of decreased general health and stress/fatigue and 3 for the other symptom groups. In groups with no positive (Table A) or negative (Table B) associations the cell is left blank.

a/ Positive associations	Winter														
	Annoyance			Decreased general health			Upper airways			Lower airways			Stress/ fatigue		
	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H
Study population															
SO_2		2													1
NO_2						1							1	2	1
O_3	1				1		1	1		1	1			1	
Part-f	1								1					2	
SO_4						2		1							
NO_3		2					2	1			1			1	
CL_x				1	3									1	
Min. temperature	1			1	1	1		2							
Rel. humidity	2	1	1		2	1	2	2	2	1	1	1			
Adults - lung disease															
SO_2					1										
NO_2	1														1
O_3											1				
Part-f	2	1													
SO_4	1	1								1					
NO_3		1													
CL_x			1										1		
Min. temperature	2		1												
Rel. humidity	1	1	1				2		1			1			2

b/ Negative associations	Winter														
	Annoyance			Decreased general health			Upper airways			Lower airways			Stress/ fatigue		
	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H
Study population															
SO_2				3		1	3	1	2	2		1	2		2
NO_2			1	2	1						1				1
O_3						2									
Part-f					1	1				2			1		
SO_4						1	1		1			1			
NO_3				1		4			2			1			1
CL_x	1		1									3	1		2
Min. temperature		1				1			1	1		1			2
Rel. humidity							1						1	2	1
Adults - lung desease															
SO_2	1			1			2		1			1	1		1
NO_2					1	2			1	2		1			
O_3	1	1							1						
Part-f				1			1	1		1					2
SO_4				1	1	1		1	1						
NO_3						1				1	1		1		2
CL_x						1									
Min. temperature		1		3		3	1		1	2		2			1
Rel. humidity				1											

Table 11.7 cont.

a/ Positive associations	Summer														
	Annoyance			Decreased general health			Upper airways			Lower airways			Stress/ fatigue		
	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H
Study population															
SO_2								1		1	2	1		1	
NO_2							1							2	
O_3			1									1			1
Part-f									1			1			
SO_4							1	1							
NO_3	2			2	1		2	2			1	1			
CL_x			1	1	1			2							
Birch pollen				2	1				1			1			
Grass pollen	2	2		1	2			1	1	1		1	3	2	1
Adults - lung disease															
SO_2				1											
NO_2					1							1			1
O_3															1
Part-f	3	1	1					1							
SO_4						1						1			1
NO_3								1	1		1				
CL_x													1		1
Birch pollen		2								1	1				
Grass pollen	2			1	1		1	1						1	

b/ Negative associations	Summer														
	Annoyance			Decreased general health			Upper airways			Lower airways			Stress/ fatigue		
	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H	IND	MIC	24H
Study population															
SO_2	1		1	2									2	1	1
NO_2	1	1							1			1	1		
O_3		1							1	1			1	2	
Part-f	1	1	1	1	2		1	1			3	1	1	2	1
SO_4						1							1		2
NO_3												1			
CL_x												1			
Birch pollen						1							2		2
Grass pollen						1	1		1						
Adults - lung disease															
SO_2	1									1		1			
NO_2			1	1	1										
O_3			1	1						1			1		
Part-f				3		2			1	1		1			1
SO_4	3	2	1				1	2		1					1
NO_3	1	2													
CL_x	1	1	1			1									2
Birch pollen				1		1								1	1
Grass pollen															

IND - model M-indiv
MIC - model M-micro
24H - model M-24h

Table 11.8: Comparison of pollution concentrations and results obtained in experimental chamber studies and cohort studies to outdoor air pollution concentrations measured in Grenland.

Study type		Components				
Author/investi-gation	Averaging time	SO_2 $\mu g/m^3$	NO_2 $\mu g/m^3$	O_3 $\mu g/m^3$	Sulfate $\mu g/m^3$	Nitrate $\mu g/m^2$
<u>Chamber study</u> (various authors)	Minutes to several hours	650^{*A}	200^{*A} 500^{H}	200-700* $A_{-}H$		
<u>Cohort studies</u>						
Perry et al., 1982	Monthly averages	8-36		12-60	f: 1,65-4.0 c: 0.30-0.64	f: 0,26-3.33* c: 0,01-0,33
Freziéres et al., 1982	Monthly averages				t: 4,3-25,7*	
Holguin et al., 1985	Monthly averages	10	40-60	110*		
Silverman et al. 1982 a,b)	3 month average					
Moseholm and Taudorf, 1990 (max 24 hours)		9 ± 13 81*	31 ± 22* 110*			
Clench-Aas et al., 1991 (max hour)			250-300*			
Values measured in Grenland 1988	Monthly average	2-36	10-66	36-84	2-5	0-2,5
	Maximum - hour	2027	192	185		
	Maximum - 24 h	320	84	179	17,8	12,7

*Observed significant effects on health
[A]in asthmatics
[H]in healthy individuals

f: fine fraction
c: coarse fraction
t: total

levels of a specified compound, the compound inhibits the immediate development of the symptom. Although this theoretically can happen, it is rather unlikely. A more likely explanation is that negative associations may result from the interactions between compounds. We chose here to report the negative associations but interpret them as equal to a null association.

The judgements presented in the following section are based on an evaluation of the results found using M-indiv, M-micro and M-24h and summarized in Table 11.7. Table 11.8 compares air pollution concentrations measured in the Grenland study to those in some of the major references of similar studies. In general, the observed exposure levels in this study are low, perhaps with the exception of exposure to ozone and suspended particles.

There were too few children (17) in this study to allow meaningful statistical analysis. Therefore, they are not reported. The results of the analysis for the group of adults with pre-existing lung disease, in addition to the randomly selected study population, are presented. But as indicated in paragraph 11.5, the results could be considered uncertain. As indicated in Chapter 10, most of the individuals with pre-existing lung disease were taking steroids (37) or other lung medication (11), with only 12 free of medication. Also, as decribed in Chapter 3, there were no detailed selection criteria for this group. Short-term effects on the airways can primarily be expected in individuals with a reversible form of a chronic lung disease. Therefore, the lack of significant results in this group can either be due to the use of medication or the lack of selection criteria. Positive associations between exposure during the previous 24 hours to NO_2 and sulfates and symptoms in the lower airways, and between exposure during ozone and NO_2 and fatigue were found in adults with pre-existing lung disease. This may be a function of the known increased reporting of symptoms in the lower airways in asthmatics in the early morning.

The results reported here are based on analysis of those participants that indicated that they were bothered by a given symptom of health effect. For example, if 48 individuals indicated that they were bothered by eye irritation, the regression coefficients and significance testing are based on these 48 individuals. The number of participants used to calculate group coefficients in each population subgroup and for each health effect symptom is given in Table 11.9. The table also gives the number of children with pre-existing lung disease having each symptom.

Sulfur dioxide exposure was negatively associated with most health symptoms using the M-indiv compression method. These negative associations were not observed when using the M-micro compression method. It was difficult, using the geographical dispersion model, to specify the exact hour and location that a pollution plume swept an area. The M-micro method smoothed such inaccuracies at the highest exposure levels.

However, both methods indicate an effect of SO_2 in the summer on the lower airways in the study population, and in the population with pre-existing lung disease on symptoms of decreased general health. Exposure to SO_2 the previous 24 hours was associated with symptoms in the lower airways in the study population in the summer. These results indicate an effect of SO_2 on the lower airways despite the fact that most SO_2 is absorbed by the upper airways. However, as indicated in paragraph 11.2.2, in findings reported in animal studies and experimental chamber studies, SO_2 may affect receptors in the upper airway that control smooth muscle tone. The work of Boushay (1984) would have predicted a greater effect in winter.

NO_2 exposure came both from Herøya and from boat and car traffic. Additional exposure to car traffic resulted in extra concentrations in the exposure estimation model. NO_2 exposure resulted in positive associations with symptoms of stress and fatigue, symptoms in the upper airways and with symptoms of decreased general health. Similar findings were also found in an investigation in an area with much traffic in Oslo (Clench-Aas et al., 1991).

Ozone was positively related to increased symptoms in the upper and lower airways, however only in the winter. This was an interesting finding since ozone concentrations are usually higher in the summer than winter. It may be possible that in winter an irritating effect of O_3 is strengthened by lower temperatures. It is believed that the effects of ozone are potentiated by exposure to other pollutants (Hazucha et al., 1975, Kagawa and Tsuru, 1979; Kleinman et al., 1981; and Mustafa and

Tierney, 1978). Effects were seen in the summer when associating exposure the previous 24 hours with symptoms of stress/ fatigue and symptoms in the lower airways. Ozone concentrations were not as high as those measured in the Houston study which found significant health effects. Concentrations of ozone were higher for a greater number of days in the summer than winter (see Chapter 4). This may mean that in summer individuals became adapted to ozone whereas in winter this was not the case.

The elements entered into estimating exposure to fine fraction of suspended particles: concentrations in the geographic area where individuals were at that time; exposure to cigarette smoke; exposure to vehicular traffic. The estimate mixed quite different sources of particles. Therefore exposure to the fine fraction of suspended particles was often higher indoors than outdoors. A positive association was revealed between exposure to suspended particles and reporting of symptoms of annoyance, however, surprisingly the results for the other symptoms indicated primarily negative relations that were seen using both the M-indiv and M-micro compressions. When a factor was entered into the regression to account for presence indoors (that indicated significantly higher response rates indoors for most of the health variables) most of the negative associations disappeared. Exposure to particles the previous 24 hours was associated with symptoms of decreased general health in the winter and in the upper and lower airways in the summer.

Nitrates and sulfates are comprised of both acidic and alkaline components. However, it is the acidic components that are the most biologically active. Nitrates and to a much lesser degree sulfates were associated with symptoms in the upper and lower airways and of decreased general health that was especially noticeable in the summer. Results of a factor analysis of the measured concentrations of the various components at four measuring sites during the investigation period reveal that nitrates are often associated to emissions from Herøya in the winter and to long-range transport in the summer. Concentrations of nitrates in Grenland were at the same level as those in the Perry et al., (1982) study which found a significant effect, but sulfate concentrations were lower than those measured in the Freziéres et al. (1982) study.

Chlorine concentrations were estimated purely based on emissions from one factory at Herøya and therefore can only be considered as a marker for that industry rather than reflecting actual concentrations. Chlorine exposure was positively associated with symptoms of decreased general health in the randomly selected study population and with symptoms of stress and fatigue. A positive association was indicated for annoying smell.

Pollen in the summer was positively associated with several health symptoms in all five categories for both the randomly selected study population and those with pre-existing lung disease. However, the calculated regression coefficients were nearly doubled in the group with pre-existing lung disease indicating a much lower tolerance in these individuals to pollen than observed in the study population.

Finally it should be mentioned that one of the aims of the investigation was to investigate the possible effects of interactions of pollutant compounds. As indicated in Chapter 8, the pollutants selected for analysis were relatively unrelated to each other, at least for most participants. This diminishes the possibility of examining pollution interactions. When investigating frequencies of categorized pollution exposure data prior to aggregation, situations with more than one pollutant classified as high were relatively rare (see Chapter 8, Table 8.8).

Earlier investigations have shown that not all individuals are equally sensitive to the effects of a given air pollutant. The literature often cites between 5 and 15% of asthmatics as showing significant associations between health effect and low to moderately high pollution exposure (values as for example indicated in Table 11.8).

It is assumed that measurable effects can be expected with exposure to air pollution in sensitive individuals. Sensitive individuals are those with increased sensitivity to pollution. This increased sensitivity can be caused by many factors, for example, type of breathing (nasal or oral), decreased immune defense or by genetic differences (Brunekreef et al., 1991).

We attempted to use these data to ascertain if there exists and then describe the population that is sensitive to air pollution. We tried to investigate subgroups of the two population groups (randomly selected study population and adults with pre existing lung disease) defined by gender, age, working in an environment with possible additional exposure, and by smoking. There seem to be no clearly defined groups of at risk individuals that apply to all the symptoms. Due to relatively small numbers of participants with symptoms in the resulting groups the analysis does not permit drawing conclusions.

Even though this study does not yet suggest biological factors that distinguish populations that are sensitive to pollution in general or to a specific air pollutant, the problem is an interesting and important one. Therefore, in this study we defined the sensitive population based on statistical significance. Those individuals that had a positive significant association between individual air pollutant compounds and reported symptom were defined as sensitive. The sensitivity was defined separately for each compound and each health symptom. An overview of the total number of participants that had positive significant associations for each reported symptom, is given in Table 11.9 and for each compound in Table 11.10.

This study indicates that in the randomly selected study population, as many as 38% of the individuals having a symptom had significant positive associations between a single compound and the individual symptom of health effect (see Table 11.10). However, if one looks at the total number of people that had a positive association to at least one air pollutant compound (column PS in Table 11.9) the percentage rises to over 50%.

It is current in epidemiological studies to refer to relative risk or odds ratio. Relative risk is a measure of the increased chances of reporting symptoms with increased exposure to air pollution. The regression coefficients may be used to calculate the increase. Thus, the combined group regression coefficients derived in this investigation were used to give a type of dose-response description of the results. When doing this, it was assumed that a certain value of relative risk can be considered to represent a health effect. A relative risk of 1.5 was chosen, that represents an increase of 50% in the probability of reporting a symptom of a health effect. Since relative risk is a ratio of the probability of one exposure level to the probability at a reference level, it is necessary to choose a level of exposure to each pollutant that can be considered as a reference. A level near the 10 percentile of exposure (see Table 8.9) was chosen. It is also possible to then calculate the level of exposure necessary to reach a relative risk of 1.5. This calculation was repeated for each compound using the highest estimated significant combined group regression coefficient in each health symptom group in the randomly selected study population (regression coefficients are given in Tables 11.2 to 11.6). The results of this calculation are summarized in Table 11.11 and Figure 11.13.

Table 11.9: Overview of number of participants with positive significant associations between air pollution exposure and symptom reporting. The table is divided by season and study groups. The number of participants reporting an individual symptom = No. w. response; number of participants with at least one positive significant association between a pollutant compound and the response = No. w. PS. The M-indiv model was used, only associations with air pollutant compound is considered (seven compounds).

	Winter		Summer	
	No. w. resp.	No. w. PS	No. w. resp.	No. w. PS
Response type				
Annoying noise				
Study population	40	18	23	10
Children with lung disease	0	0	0	0
Adults with lung disease	7	4	6	5
Annoying smell				
Study population	40	17	30	11
Children with lung disease	1	0	1	1
Adults with lung disease	13	7	8	2
Annoying industrial smell				
Study population	15	8	15	8
Children with lung disease	1	1	0	0
Adults with lung disease	5	3	6	1
Headache				
Study population	163	75	107	50
Children with lung disease	8	2	6	3
Adults with lung disease	41	18	23	11
Dizziness				
Study population	39	10	22	8
Children with lung disease	5	0	3	0
Adults with lung disease	8	1	8	2
Nausea				
Study population	72	21	37	9
Children with lung disease	6	2	5	3
Adults with lung disease	19	10	6	4
Eye irritation				
Study population	48	22	34	16
Children with lung disease	3	1	2	1
Adults with lung disease	14	2	12	4
Sneezing/running nose				
Study population	111	59	100	58
Children with lung disease	6	5	9	7
Adults with lung disease	28	15	27	15
Feeling feverish				
Study population	67	33	53	23
Children with lung disease	2	0	6	4
Adults with lung disease	15	6	13	6

Table 11.9 cont.

	Winter		Summer	
	No. w. resp.	No. w. PS	No. w. resp.	No. w. PS
Response type				
Throat irritation				
Study population	163	88	103	70
Children with lung disease	10	6	7	6
Adults with lung disease	27	12	30	18
Coughing				
Study population	100	55	73	36
Children with lung disease	10	5	10	7
Adults with lung disease	22	11	27	14
Wheezing/tight chest				
Study population	41	23	32	18
Children with lung disease	12	6	7	4
Adults with lung disease	25	14	24	11
Difficult breathing				
Study population	56	25	35	22
Children with lung disease	5	2	6	4
Adults with lung disease	35	16	30	17
Muscle pains				
Study population	121	73	89	57
Children with lung disease	5	1	0	0
Adults with lung disease	22	13	17	9
Stomach pains				
Study population	81	36	44	20
Children with lung disease	6	1	1	0
Adults with lung disease	16	6	10	2
Nervous/restless				
Study population	38	18	28	9
Children with lung disease	0	0	0	0
Adults with lung disease	9	4	6	4
Fatigue				
Study population	154	80	103	52
Children with lung disease	8	2	6	4
Adults with lung disease	29	16	24	11

Table 11.10: Per cent of responders with a significantly positive regression coefficient for individual compound (5% level, two-tailed test), winter and summer. The number of individuals reporting a symptom in the randomly selected study population (100%) is given in the first column.

Health Effect Parameter	Winter							
	No. with symptoms	SO_2	NO_2	O_3	Part-f	SO_4	NO_3	Cl_x
Annoying noise	40	18	5	18	18	8	13	3
Annoying smell	40	8	13	10	15	5	3	13
Annoying industrial smell	15	7	7	13	7	7	13	13
Headache	163	1	6	17	4	15	12	14
Dizziness	39	3	5	8	3	10	3	5
Nausea	72	1	6	7	6	11	8	3
Eye irritation	48	2	6	8	10	17	17	15
Sneezing/running nose	111	5	9	15	16	26	22	9
Feeling feverish	67	7	10	7	9	24	15	12
Throat irritation	163	6	15	15	17	25	25	10
Coughing	100	9	6	17	14	23	18	13
Wheezing/tight chest	41	12	10	24	15	15	12	15
Difficult breathing	56	9	11	11	14	13	9	11
Muscle pains	121	8	14	24	14	29	15	17
Stomach pains	81	5	6	12	4	23	7	10
Nervous/restless	38	5	11	16	3	24	13	21
Fatigue	154	5	10	14	13	22	18	14

Health Effect Parameter	Summer							
	No. with symptoms	SO_2	NO_2	O_3	Part-f	SO_4	NO_3	Cl_x
Annoying noise	23	13	9	4	30	4	17	4
Annoying smell	30	7	10	13		10	10	10
Annoying industrial smell	15		13	7	7	13	20	20
Headache	107	3	7	17	11	15	21	7
Dizziness	22		9	5	5	14	27	
Nausea	37		5	5	5	8		8
Eye irritation	34		12	12	6	24	12	9
Sneezing/running nose	100	5	12	14	5	27	25	9
Feeling feverish	53	6	4	6	4	15	21	9
Throat irritation	103	12	9	26	8	38	36	4
Coughing	73	10	12	22	5	26	21	7
Wheezing/tight chest	32	16	6	6	6	19	25	6
Difficult breathing	35	14	20	14	11	29	9	11
Muscle pains	89	7	18	11	12	33	15	10
Stomach pains	44	9	5	7	5	16	18	2
Nervous/restless	28	11	4	4		11	11	7
Fatigue	103	10	12	9	4	23	14	6

Table 11.11: The calculated pollutant exposure level that leads to a relative risk of 1.5 for each health symptom group. The reference pollution (used as equivalent to a relative risk of 1) is given in the last column. The calculations used the largest positive significant group regression coefficient (from either winter or summer) in each symptom group. a) calculated concentration for all individuals reporting the symptom, b) calculated concentrations for those participants with positive significant associations between the health symptom and each pollutant (sensitive individuals). The table is based on values obtained for the randomly selected study population.

a) Air Pollutant	Group of health effect variables					Reference level of exposure
	Annoyance	Symptoms of decreased general health	Symptoms in upper airways	Symptoms in lower airways	Symptoms related to stress	
SO_2 (μg/m^3)				41		5
NO_2 "			42		229	5
O_3 "	199		#	#		5
Part-f "	64					5
SO_4 "			1051			0.5
NO_3 "	1	1.7	15			0.1
Cl_x "		15.5				1
Pollen (No.)	3	3.6		10	3.2	0

b) Air Pollutant	Group of health effect variables					Reference level of exposure
	Annoyance	Symptoms of decreased general health	Symptoms in upper airways	Symptoms in lower airways	Symtoms related to stress	
SO_2 (μg/m^3)				7		5
NO_2 "			6		7	5
O_3 "	27		19	29		5
Part-f "	6					5
SO_4 "			0.7			0.5
NO_3 "	0.2	0.3	0.3			0.1
Cl_x "		2.4				1
Pollen (No.)	1.5	1.6		1.5	1.5	0

Above highest observed concentration.
Method for calculating pollutant level X in the table:
(Relative risk is equal to 1.5, reference level = R, and regression coefficient = β).
Pollutants: $X = \exp((\ln 1.5)/\beta + \ln R)$ Pollen: $X = (\ln 1.5)/\beta + R$

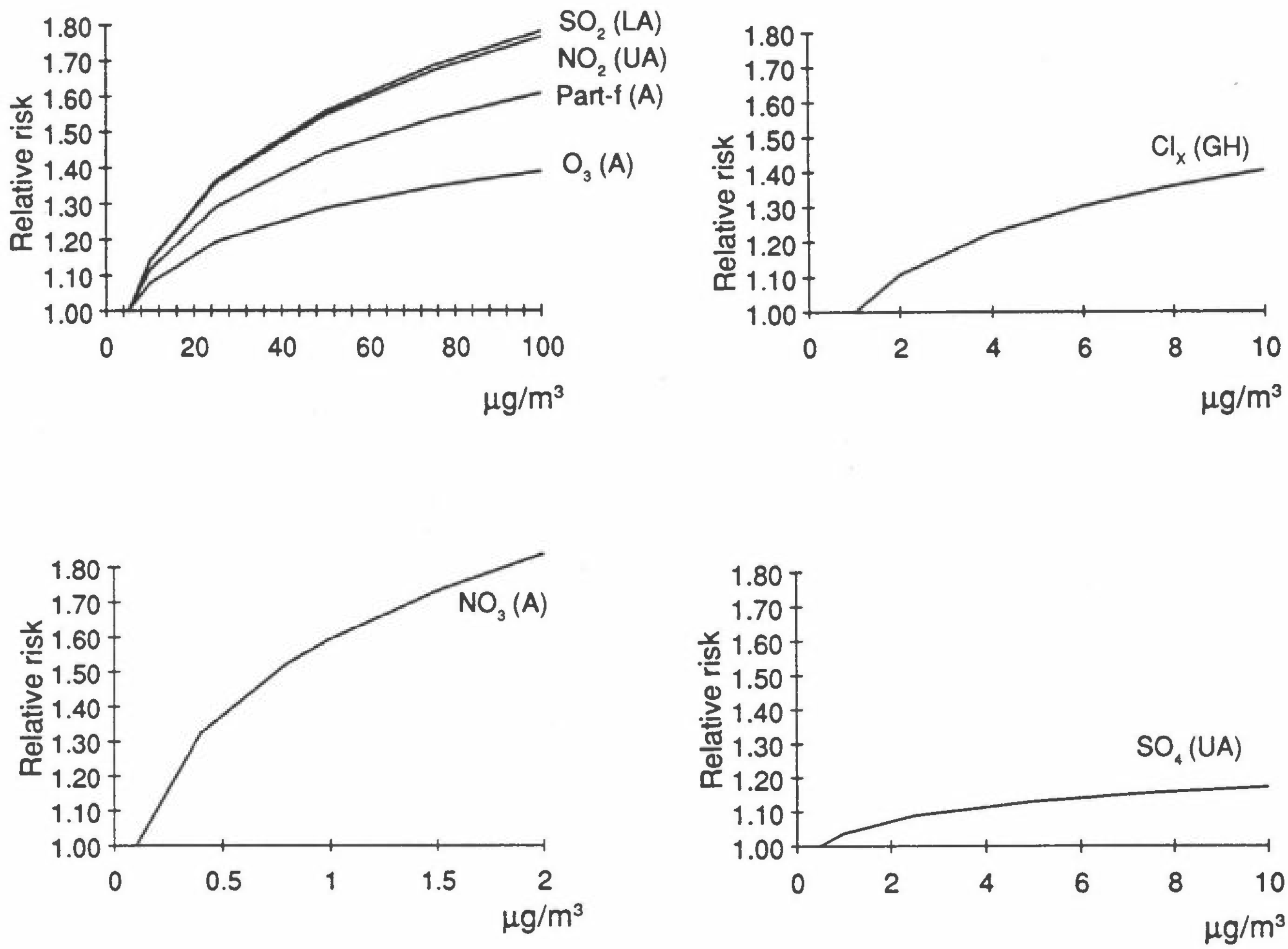


Figure 11.13: The largest observed relative risk for reporting individual symptoms (maximum for all symptoms). The maximum was found in these groups:
GH: Symptoms of decreased general health
UA: Symptoms in the upper airways
LA: Symptoms in the lower airways
A : Symptoms of annoyance

As shown in part A of Table 11.11 the concentrations of exposure to SO_2 and NO_2 necessary to increase the probability of reporting symptoms in the upper or lower airways were under the air quality guidelines. The concentration of suspended particles is near the guidelines and the levels of nitrates for two groups of symptoms within levels currently measured in Grenland. However, it must be stressed that these values are "exposure values", not values measured at outdoor monitoring stations.

For those relationships calculated in part A of Table 11.11 (significant as reported in Tables 11.2-11.6), we also recalculated the exposure concentrations using the average regression coefficients of the sensitive test population in the randomly selected study population. The results of these calculations are summarized in part B of Table 11.11. Comparing the calculated levels in parts A and B of Table 11.11 indicates that the concentrations of exposure to air pollutants necessary to increase by 50% the probability of reporting some of the health symptoms are much lower in the sensitive population. However, it should be stressed that the assumptions inherent in the definitions of the sensitive population and the values of exposure considered as reference determine these results.

This investigation supports the notion that the reporting of symptoms of reduced health is associated with increased exposure to such pollutants as ozone, NO_x, SO_2, and especially nitrates and sulfates. Associations between health effects and exposure to these compounds have been suggested in other similar studies (see paragraph 11.2.3).

11.9 CONCLUSION

The Grenland area has a rather unique air pollution situation as compared to that of other previously published investigations. Because of substantial contribution from several geographically distinct point sources, many air pollutants showed at times relatively high concentrations, that were independent of each other. SO_2 primarily originated from one industrial source in Skien, chlorine from the other factory complex in Porsgrunn. Sulfates and nitrates originated both from industrial sources and long-range transport. Ozone was most often associated with long-range transport, and NO_2 with traffic pollution. The relationship between concentrations of pollutants indoors and outdoors was accounted for through a large measurement program.

Pollutants from each of the primary pollution sources seem to show associations with health effects as measured by symptom reporting. Industrial emissions (as indicated by SO_2, chlorine and nitrate exposure), vehicular and boat traffic emissions (as indicated by NO_2) and long-range transport (as indicated by nitrates, sulfates and ozone) all showed associations with increased symptom reporting. Not all compounds seem to affect all parameters equally. The two most convincing associations were between O_3 in the winter and nitrates (both seasons) and reporting of symptoms in the upper and lower airways.

These effects were noted even though exposures were generally lower than concentrations given by international air quality guidelines. Air pollution concentrations during the winter registration period were lower than would have been measured during a colder winter.

The study population which closely represented a random population seemed to show more associations between air pollution exposure and health symptom reporting than the population with pre-existing lung disease. This was rather unexpected, since most studies show rather an increased sensitivity towards air pollution in individuals with respiratory disease. The population with pre-existing lung disease was, however, possibly not homogenous enough with respect to medication use or selection criteria to reveal significant effects. The results presented in this conclusion therefore concern only the randomly selected study population.

Statistical analysis of self reported symptoms of health effects show an association in the winter between symptoms in the upper airways and nitrate exposure. In the summer, the data suggest an association between nitrate exposure and symptoms of annoyance, symptoms in the upper and lower airways and symptoms of decreased general health.

Symptoms of decreased general health in the winter and symptoms in the upper airways in the summer seem to be associated with sulfate exposure.

Symptoms of annoyance and symptoms in the upper airways revealed an association both seasons with the fine fraction of suspended particles. In the summer, symptoms in the lower airways also covaried with exposure to suspended particles.

Symptoms in the lower airways in the summer covaried with sulfur dioxide exposure.

Nitrogen oxide exposure in the winter seems to be associated with symptoms of decreased general health and symptoms related to stress and fatigue, and in the summer with symptoms in the upper and lower airways.

In the winter, ozone exposure covaries with symptoms in both the upper and lower airways, and in the summer with symptoms in the lower airways, as well as fatigue and annoyance.

Chlorine seems to be associated with symptoms of decreased general health both seasons.

In addition, there were effects on all symptom groups of exposure to pollen in the summer.

In the results found there seem to be a group of individuals that show a positive correlation between reporting of symptoms and exposure to air pollution. These individuals can be considered as more sensitive than others to pollution in Grenland. Together, this group represents from 1 to 15% of the randomly selected study population, dependent on effect parameter and pollutant. Further research is necessary to describe this group in more detail.

Using averages of calculated regression coefficients, one can calculate the level of exposure to pollution that is associated with a health effect. A 50% increase in the probability of reporting a health effect symptom was chosen to characterize an adverse health effect.

The levels of pollution that lead to such an effect were calculated for the different compounds. Calculations were done both for the entire randomly selected study population and for a subpopulation defined as sensitive. The resulting concentrations are then compared to international and Norwegian proposed air quality guidelines.

The results reveal increased reporting of certain health effect symptoms for the sensitive population at levels of exposure clearly under air quality guidelines.

Even though subjective symptom reporting does not necessarily indicate a major health effect, it should reflect a general state of well-being which is important to account for when assessing the impact of air pollutants.

12 EFFECTS OF AIR CONTAMINANTS ON OBJECTIVE PARAMETERS OF HEALTH

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12.1 INTRODUCTION

The daily PEF measurements may be looked upon to be intermediary between the subjective self-reported complaints and the results of the objective 14-day medical controls. On the one hand, the PEF measurements are self-reported, but on the other hand they should be viewed as an objective variable parameter, since the values are a registration of a parameter of lung function. The measured values are directly related to lung function, but PEF measurements are somewhat less specific than FVC and $FEV_{1.0}$, which both measure lung volume directly. PEF is the determination of the highest air velocity during exhalation and thus is a measure of ventilation capacity.

When the mucous membranes of the airways are exposed to irritant substances, both production of mucus and edema may eventually ensue. Irritants may also result in muscular contractions in the airway passages. These effects may then lead to a reduction in the diameter of the bronchi and bronchioli thereby decreasing the air flow. The PEF measurements were undertaken four times a day, this was viewed as being often enough to evaluate possible short-term effects of air contaminants on lung function.

It is possible to perform an analysis according to that undertaken in Chapter 11, in two steps:

1) individual analysis of effect, in a way that each individual person is his/her own control;
2) analysis of effect on a population basis using the individual results from the first step.

In this chapter the results will be presented of the analysis of possible correlations between air contaminants and self-reported PEF. Air contaminant levels one hour before the PEF measurement have been used as exposure inputs. The analyses presented are multivariate, i.e. the effects of several factors are studied simultaneously. Just as with the subjective complaints, it is to be expected that the subsequent PEF measurements are correlated, i.e. they show auto-correlation. This problem is analysed by using PEF measurements from the previous day as an independent variable. Other factors that have been used in the analysis are time of day, time since awakening, self-reported form, outdoor temperature, smoking and passive smoking.

12.2 STATISTICAL METHOD

The statistical analysis has been performed in two steps, in analogy with the Korn-Whittemore model.

1) A linear regression model on an individual basis, where one uses the air contamination variables one hour before the PEF measurement, smoking, passive smoking, temperature, time of day and the mean PEF value from the previous 24-hours as explanatory variables.

2) For each individual a number of parameter estimates from each regression is obtained, with their corresponding t-values, etc. One then tests if the center of the distribution of the t-values is higher than zero with sign tests and Wilcoxon-tests. Rejection of these tests indicates an effect of the independent variable. These tests may also be performed within subgroups of the participants, e.g. in the randomly selected study population, adults with pre-existing lung disease and children with pre-existing lung disease, or in categories based on drugs used. It is also possible to determine the magnitude of the effect quantitatively for all individuals or subgroups.

This statistical analysis deviates somewhat from the Korn-Whittemore model which is based on logistic regression in Step 1). This was not proper in the present situation since PEF measurements are continuous. The corresponding Step 2) in the Korn-Whittemore model is a more formal variance component analysis. Here, this step is performed in a somewhat simpler fashion, but still based on the main concept of the Korn-Whittemore model. Non-parametric methods are being used, since these have the advantage that extreme values will have little effect.

Auto-correlation has been taken into account by using PEF measurements from the previous day as independent variables. A more formal time-series model would have been preferable, especially if one wishes to study auto-correlation in PEF. However, it is improbable that the effect of contamination and other risk factors should have been eliminated by the present somewhat intuitive approach.

In Step 2) non-parametric tests are performed on the estimated regression parameters, or more correctly their t-values. The t-value of a parameter β_i for individual "i" is given by:

$$t_i = \hat{\beta}_i \;/\; sd(\hat{\beta}_i)$$

where $\hat{\beta}_i$ is the estimate for β_i and $sd(\hat{\beta}_i)$ its standard error. The variance for t_i is:

$$Var(t_i) = Var(\hat{\beta}_i) \;/\; sd(\hat{\beta}_i)^2 = 1$$

i.e. the t-values have the same variance for all individuals. Further, the t-values under the null-hypothesis (there is no effect of the independent variable) have the expected value of 0. It should be pointed out that for using the Wilcoxon test, the quantities one studies should come from the same distribution. By using the t-values, one is at least guaranteed that the two first moments are equal.

The first of the two tests that were used is the sign test. Here one counts the number of positive and negative t-values and evaluates if the number deviates so far from the mean that one cannot ascribe the deviation to chance. To use the sign test, it does not matter if one applies the t-values or the parameter estimates, since both will either be positive or negative. In contrast, when one uses the Wilcoxon test, which is based on a ranking of the absolute values of the numbers, it is important to apply the t-values. If then many t-values are slightly less than 0, but all the large absolute numbers from t-values are positive ones, the Wilcoxon test will reveal an effect of the dependent variable which the sign test will not have revealed. The Wilcoxon test generally has greater power than the sign test.

To develop estimates on a population level of the effect of a dependent variable for the PEF values, the following scheme has been used:

A weighted mean $\hat{\beta}$ of the $\hat{\beta}_i$-s is calculated, where the weights are, with v_i = Var(β_i);

$$W_i = (1 / v_i) / \sum_{i=1}^{n} (1 / v_i)$$

The variance for the estimator $\hat{\beta}$ is given by:

$$Var(\hat{\beta}) = 1 / \sum_{i=1}^{n} W_i$$

Thus, it is possible to take into account the fact that some individuals have performed fewer PEF measurements than others, and that some individuals may have had larger variations in PEF or in dependent variables.

After having performed the individual regression, an individual-oriented file was constructed with all the regression results. It was thus easy to perform alternative groupings of the individuals to analyse the influence of the dependent variables in the various subgroups. However, a problem in this respect is that the groups very soon become rather small, so that it will be impossible to disregard trends due to accidental noise.

The results for two different sets of subgroups are presented. The first analysis splits up the individuals according to the study design: the randomly selected study population, adults with pre-existing lung disease and children with pre-existing lung disease as described in Chapter 3. The second subgrouping is based on use of medication for respiratory problems. The participants described their medication use in two ways:

1) Continuous medication on the cover of the diary.
2) Drugs taken every day on the back of each individual diary.

The drugs used for respiratory problems were simply divided into two categories: Steroids and other antasthmatics. Should one individual have used steroids (described on the cover or more than once in the diary), he or she is classified as a steroid user. If the individual never has used steroids, but has described use of another antasthmatic (on the cover or more than once on the diary), he or she is classified as user of other antasthmatics. Individuals who have not described any use of medication for respiratory problems are grouped in a third category.

Table 12.1 shows how the categories of medication use are distributed among the three study groups.

Table 12.1: Distribution of drug categories in the study groups.

Study group	Steroids	Other antasthmatics	No antasthmatics	Total
Study population	6	8	275	289
Adults with pre-existing lung disease	37	11	12	60
Children with pre-existing lung disease	7	5	4	16
Total	50	24	291	365

12.3 REGRESSION MODELS

A series of in all 16 models was analysed. These models differ with respect to the variables which have been used, if some variables are logarithmically transformed and if they are analysed separately for the winter or summer periods. However, only the model which was best after a total evaluation is presented in this report.

The various regression models only showed marginal differences.

In the reported regression model the following variables are included:

1) Estimated CO exposure one hour before the PEF measurement.
2) Estimated Cl_x exposure one hour before the PEF measurement.
3) Estimated O_3 exposure one hour before the PEF measurement.
4) Estimated SO_2 exposure one hour before the PEF measurement.
5) Estimated NO_x exposure one hour before the PEF measurement.
6) Estimated suspended particle exposure one hour before the PEF measurement.
7) Estimated SO_4 exposure one hour before the PEF measurement.
8) Estimated NO_3 exposure one hour before the PEF measurement.
9) Number of cigarettes smoked one hour before the PEF measurement.
10) Indicator for exposure to passive smoke one hour before the PEF measurement.
11) Temperature one hour before the PEF measurement.
12) Average PEF value from the previous day (Lag-PEF).
13) Morning indicator, i.e. hour earlier than 10 a.m. when the PEF measurement was undertaken.
14) Evening indicator, i.e. hour later than 7 p.m. when the PEF measurement was undertaken.
15) Self-reported form, scale from 1 (poor) - 5 (excellent).
16) PEF measurement undertaken at the time the individual also reports being asleep.
17) PEF measurement undertaken one hour after the individual got out of bed.

Variable 16) may seem improbable, but is acceptable if an individual for example got out of bed at 7.50 a.m. and immediately performed the PEF measurement. In this case, the individual should have reported both to be asleep and to perform the PEF measurement in the eighth hour. It is also possible that some individuals got out of bed in the middle of the night and performed the PEF measurement.

12.4 RESULTS

Table 12.2 shows the t-values of the sign tests and the corresponding t-values of the Wilcoxon test for all the variables included in the regression model. The table should be read in the following manner: a positive t-value indicates that PEF increases with the corresponding variable, and a negative value that it decreases, i.e. enhanced and reduced lung function, respectively. Should the absolute size of the t-values be large, this indicates that the correlation with the PEF value simply is not due to chance. To avoid confusion, it should be realized that these t-values are derived from tests of the t-values from the regression analysis.

There seems to be a positive correlation between PEF and temperature, Lag-PEF and form, whereas there is a negative correlation between PEF and time of day (morning and evening, first hour after awakening and "at sleep"). Passive smoking is in the border area of significant correlation, whereas for all of the other air contaminant variables no such correlation can be demonstrated.

In Tables 12.3 and 12.4 the t-values for the Wilcoxon tests are given for the three categories based on medication use. For the exposure variables the picture seems to be quite similar to the results of the individual regression model (Table 12.2), but for the temperature, Lag-PEF, form and morning/evening variables there appears to be a lesser effect for those on medication and for those with pre-existing lung disease. However, this is due to the small number of individuals in these groups.

Table 12.2: The t-values of the sign tests and the Wilcoxon tests for all variables.

Variable	Sign tests	Wilcoxon
CO	+ 0.12	+ 0.42
Cl_x	0.00	- 0.36
O_3	+ 0.63	+ 1.86
SO_2	- 0.52	+ 0.89
NO_x	- 0.21	+ 0.38
Susp. particles	+ 1.36	+ 1.73
SO_4	+ 1.05	+ 1.43
NO_3	+ 0.63	+ 0.62
Smoke	+ 1.51	+ 1.62
Passive smoke	- 1.98	- 2.04
Temperature	+ 4.09	+ 4.58
Lag-PEF	+17.85	+16.41
Morning	- 5.84	- 7.33
Evening	- 5.88	- 7.12
Form	+11.93	+13.61
Hour 1	-11.93	-12.64
Asleep	-10.73	-13.54

Table 12.3: The t-values for the Wilcoxon test of the three study groups.

Variable	Randomly selected study population	Adults with pre-existing lung disease	Children with pre-existing lung disease
CO	+ 0.92	- 1.78	+ 2.04
Cl_x	- 1.73	- 0.28	+ 1.76
O_3	+ 1.70	+ 0.78	- 0.05
SO_2	+ 0.89	+ 1.20	- 1.86
NO_x	+ 0.14	+ 1.03	- 0.67
Susp. particles	+ 1.48	+ 1.37	- 0.57
SO_4	+ 0.88	+ 0.18	+ 2.43
NO_3	+ 1.51	- 1.10	- 1.34
Smoke	+ 0.73	+ 2.25	-
Passive smoke	- 1.48	- 1.97	+ 0.70
Temperature	+ 3.67	+ 2.69	+ 1.14
Lag-PEF	+14.67	+ 6.48	+ 3.46
Morning	- 5.94	- 4.15	- 1.42
Evening	- 6.40	- 2.69	- 1.55
Form	+11.70	+ 5.94	+ 3.46
Hour 1	-12.16	- 5.48	- 3.26
Asleep	-10.97	- 6.02	- 2.59

Table 12.4: The t-values of the Wilcoxon tests for the three categories based on medication use.

Variable	Steroids	Other antasthmatics	No antasthmatics
CO	- 1.90	+ 1.35	+ 1.06
Cl_x	+ 0.88	- 1.46	- 1.36
O_3	- 0.07	+ 0.06	+ 2.05
SO_2	- 0.05	- 0.06	+ 1.02
NO_x	+ 0.60	- 0.09	+ 0.21
Susp. particles	- 0.19	+ 0.09	+ 1.97
SO_4	+ 1.73	+ 1.09	+ 0.58
NO_3	+ 1.36	- 0.74	+ 1.42
Smoke	+ 0.77	+ 1.86	+ 1.07
Passive smoke	- 1.91	+ 0.52	- 1.75
Temperature	+ 3.57	+ 1.31	+ 3.28
Lag-PEF	+ 6.05	+ 4.26	+14.67
Morning	- 4.23	- 1.41	- 6.02
Evening	- 2.57	- 1.51	- 6.57
Form	+ 5.48	+ 3.57	+11.88
Hour 1	- 4.68	- 4.00	-12.24
Asleep	- 4.69	- 4.17	-11.15

In table 12.5 the estimates of the total effects and their respective standard errors are presented for the independent variables in the individual regression model with weighting of the parameter estimates.

Table 12.5: Total population estimates for the effects of the independent variables in the regression model.

Variable	Weighted estimates		Number of individuals
	Estimate	St.error	
CO	0.253	0.192	295
Cl_x	-0.015	0.013	363
O_3	0.003	0.002	363
SO_2	0.004	0.004	363
NO_x	-0.000	0.002	363
Susp. particles	0.006	0.002	363
SO_4	0.029	0.015	363
NO_3	0.033	0.015	143
Smoke	0.275	0.050	143
Passive smoke	-0.339	0.245	229
Temperature	0.075	0.007	363
Lag-PEF	0.549	0.003	363
Morning	-2.619	0.161	348
Evening	-1.709	0.095	363
Form	3.573	0.074	348
Hour 1	-5.047	0.189	358
Asleep	-6.549	0.210	359

The explanation of for instance the estimate 3.573 for form is that with an increase in self-reported form of one point, the estimated increase in PEF recording that day is the value of 3.573. By taking the standard error of the estimate into account, one merely can state that the increase is somewhere between approximately 3.4 and 3.7. An increase of two points in self-reported form gives a corresponding average increase of between 6.8 and 7.4. Further, one finds an effect of being asleep or just having gotten out of bed of approximately -6.

If the time of awakening has been before 9 a.m., one must also take into account that this is in the morning, the PEF measurements will therefore on the average be approximately -8 below the measurements in the middle of the day. Further, if yesterday's PEF measurement was 10 points below the mean one will predict that today's value will be approximately 5.5 $\approx (10 \cdot 0.549)$ points below the mean. The effects of the exposure variables are on the whole not significant, but the evaluation of the estimates for the effects of these variables are similar to that described above. If a contamination component is changed by one point (relative to a given unit), the value of PEF will on the average change correspondingly with the given parameter estimate.

In Tables 12.6 and 12.7 are given weighted effect estimates corresponding to Table 12.5 for individuals with pre-existing lung disease and categories based on medication use, respectively. It seems as the effects of morning/evening variations and form are stronger among those using medication and among those individuals with pre-existing lung disease.

Table 12.6: Total estimates of the effects of the independent variables in the individual regression model within the study groups (weighted estimates).

Variable	Study population		Adults with pre-existing lung disease		Children with pre-existing lung disease	
	Estimate	St.error	Estimate	St.error	Estimate	St.error
CO	0.299	0.200	-0.519	0.682	4.755	3.001
Cl_x	-0.017	0.013	-0.005	0.048	0.090	0.113
O_3	0.003	0.002	0.003	0.006	0.024	0.013
SO_2	0.003	0.004	0.024	0.014	-0.055	0.035
NO_x	-0.000	0.002	0.005	0.005	-0.007	0.015
Susp. particles	0.006	0.002	0.017	0.008	-0.004	0.023
SO_4	0.017	0.016	0.061	0.051	0.551	0.126
NO_3	0.073	0.053	-0.319	0.176	-0.572	0.431
Smoke	0.226	0.117	1.820	0.674	-	-
Passive smoke	-0.337	0.264	-0.609	0.677	3.963	2.790
Temperature	0.071	0.008	0.125	0.023	0.050	0.055
Lag-PEF	0.565	0.004	0.465	0.008	0.538	0.014
Morning	-2.427	0.170	-4.732	0.548	-1.776	1.528
Evening	-1.534	0.100	-3.187	0.319	-3.267	0.737
Form	3.190	0.078	6.542	0.265	8.952	0.511
Hour 1	-4.740	0.199	-8.031	0.664	-7.386	1.521
Asleep	-6.146	0.221	-10.580	0.706	-6.973	1.719

Table 12.7: Total estimates of the effects of the independent variables in the individual regression model for various categories by medication use (weighted estimates).

Category	Steroids		Other antasthmatics		No antasthmatics	
Variable	Estimate	St.error	Estimate	St.error	Estimate	St.error
CO	-0.483	0.764	1.242	0.818	0.244	0.204
Cl_x	0.041	0.056	-0.059	0.089	-0.017	0.013
O_3	-0.001	0.006	0.002	0.008	0.004	0.002
SO_2	0.003	0.014	-0.045	0.022	0.005	0.004
NO_x	0.004	0.006	-0.004	0.008	-0.000	0.002
Susp. particles	-0.000	0.010	-0.004	0.009	0.007	0.002
SO_4	0.141	0.056	0.104	0.072	0.016	0.016
NO_3	-0.454	0.194	-0.076	0.254	0.074	0.053
Smoke	0.563	0.780	0.995	0.432	0.212	0.121
Passive smoke	-1.619	0.790	4.913	1.497	-0.359	0.261
Temperature	0.211	0.026	0.058	0.036	0.064	0.008
Lag-PEF	0.479	0.009	0.544	0.012	0.561	0.004
Morning	-4.806	0.601	-3.765	0.887	-0.400	0.171
Evening	-3.032	0.353	-0.555	0.453	-1.658	0.101
Form	7.910	0.318	6.187	0.394	3.212	0.078
Hour 1	-7.453	0.713	-10.208	1.034	-4.667	0.199
Asleep	-9.456	0.779	-11.532	1.163	-6.133	0.222

12.5 DISCUSSION

Investigations of the effects of various air contamination components on human health reviewed in the literature (WHO, 1987), reveal large interindividual variations in responses. In general, one sees responses at lower concentrations in epidemiological investigations compared to controlled studies or experimental settings. In the epidemiological studies it is reasonable to assume that the contamination component under study acts together with other etiological factors present. For NO_2, effects on lung function have been demonstrated in controlled studies at 460 $\mu g/m^3$ and at 200 $\mu g/m^3$ in epidemiological studies. For suspended particles (the fine fraction below 2.5 μm) values for reported effects on lung function vary from 2 000 $\mu g/m^3$ in controlled studies down to annual averages of 96 $\mu g/m^3$ in epidemiological studies. SO_2 is mostly taken up in the upper airways, but may induce more pronounced health effects in the lower airways after increased breathing or when suspended particles are present at the same time. For some asthmatics, decreases in lung function have been described at SO_2 concentrations of 725 $\mu g/m^3$. One investigation of morbidity in children have described an increase at such low annual averages as from 35 $\mu g/m^3$ to 56 $\mu g/m^3$ of suspended particles (<10 μm) and SO_2, respectively. Acid aerosols (SO_4) affect lung function in animal experiments between 100 and 500 $\mu g/m^3$, whereas increased rates of illness appears to be demonstrated at concentrations at or above 10 $\mu g/m^3$. For ozone reduced lung function is reported at 160 $\mu g/m^3$ and higher.

The present air contaminant values in Grenland are for most of the components below the values where significant effects on lung function have been reported.

The use of PEF as a measure for lung function on airways resistance has obvious practical and resource-saving advantages, even if it does not provide as complete information as spirometric measurements. There has now been developed small and relatively inexpensive PEF meters which study individuals can bring with them for repeated and frequent registrations. PEF has therefore been used in several previous epidemiological investigations (Freziéres et al., 1982; Perry et al., 1983; Wagner et al., 1983; Holguin et al., 1985). It appears that most investigators have used PEF as one of several possibilities for determining whether an individual has had an asthmatic attack. For continuous measurement of the degree of airway obstruction, PEF appears to have been used less, since in experimental chamber studies spirometry has generally been used.

In the Grenland study one has attempted to reveal whether there is a correlation between air contamination and lung function, as measured by PEF registration (see Chapter 10), and not primarily to describe a no-effect level for air contaminants.

How large the t-values of the tests need to be before one will assign a statistically significant correlation is difficult to answer, since very explicit hypotheses were not formulated in advance. However, the criterion that the t-values (in absolute values) should be larger than two has been used to assign a significant result. The t-values will show a natural variation, so that when one performs many correlations the level of significance should be increased. t-values larger than 3.0 (in absolute values) should indicate a significant correlation. If the t-values are above e.g. 5.0 there is undoubtedly a significant correlation.

Even if there are significant correlations, this does not mean that there is a causal relationship between the independent variable and the PEF measurement. It is for instance possible that the relationship is due to the fact that the independent variable only is correlated to a causal factor which is not present in the regression model.

From Tables 12.4 and 12.3 an apparent reduction in many of the t-values is seen among those using medication and among those with pre-existing lung disease, compared to those not using antasthmatics and the randomly selected study population, respectively. This could be due to facts such as that medication eliminates the effects, or that there are much fewer individuals in these groups than among those who do not use drugs or belong to the study population. In fact, if there is the same effect in two groups with n_1 and n_2 individuals, one would expect that the relationship between the t-values of the two groups are of the magnitude equal to $\sqrt{(n_1/n_2)}$. In general, this correspondence holds true between the t-values for stated variables between the different groups.

The Tables 12.6 and 12.7 appear to show a larger effect of morning/evening and form among the drug users and those with pre-existing lung disease than the rest. Formal tests of such differences may be achieved by calculating the differences between the estimates divided by the square root of the sum of their squared standard errors. This value approaches a normal distribution when the number of observations in both groups becomes large enough. However, in the present situation one should be hesitant to apply this test because the number of individuals with pre-existing lung disease is small.

12.6 CONCLUSION

A clear auto-correlation in self-reported PEF has been demonstrated. Further, there are strong correlations between PEF and time of day, temperature and self-reported form. Estimated effects of the exposure variables including smoking and passive smoking on PEF, were not significant. With the exception of passive smoking and chlorine compounds, the estimated effects were positive. It must therefore be concluded that there has not been demonstrated any relationship between exposure and lung function as measured by PEF.

This does not mean that such a relationship does not exist. It is possible that the effect is so small that this investigation is not large enough to reveal such a relationship. It is also possible that a lack of association is caused by uncertainties in the exposure estimates or the recorded PEF measurements. On the other hand, it can also mean that the air contamination level in the two study periods was below those thresholds which must be surpassed for lung function to be compromised.

13 EPILOGUE

L. S. Bakketeig and O. F. Skogvold

The aim of the investigation in Grenland was to examine whether or not air pollutants, singly or in combination, have an effect on human health.

The region of Grenland in Telemark in Southern Norway, is well-suited for such an investigation. Air pollutants are emitted from geographically distinct sources. Therefore, high concentrations of single pollutants can arise locally and independently of other pollutants.

A cohort or longitudinal design was chosen, where a group of individuals was followed in detail for two 2-months periods. The group consisted of healthy adults and those with pre-existing lung disease (aged 18 to 75) and children with pre-existing lung disease (aged 4 to 17).

Air pollution concentrations were followed hour by hour through both study periods, and participants' whereabouts and health status were registered on an equally detailed basis. A set of objective health parameters were measured in addition to the self-reported symptoms of health effects.

The project was successfully completed. A total of 397 individuals took part in the registration. One randomly selected group was ideally to represent the population of the area of Grenland. Of a total of 800 individuals randomly chosen from a complete register of people living in the chosen area, 312 accepted to participate and completed the study. This group is of course biased slightly due to self selection. However, it is still felt that the conclusions reached for this group can be applied to the population of the Grenland area.

Eighty five individuals with pre-existing lung disease were recruited from the patient files of the local hospitals in Porsgrunn and Skien. These are considered to be representative for the population of individuals with pre-existing lung disease.

Air pollution measurements were carried out for two winter and two spring months. The two winter months were milder than the previous winters, and air pollution concentrations were thus lower than in comparable months in earlier years. The late spring months were more representative for a "normal" late spring.

What about the investigation methods?

Air pollution concentrations were measured in the field using the most modern technology. Measurements were taken at a total of 9 air quality stations, and a model allowed estimating the concentration of pollution for each area where individuals were at each time point.

Participants continually registered their whereabouts. Such registrations allowed estimating each individual's pollutant exposure. Health effects were measured using self-reporting of symptoms. This is an established method used in many countries, especially the U.S., but such a method has been used relatively little in Norway. The experience gained from performing the Grenland investigation is that important health information can be acquired using such time-consuming methods, at least in highly motivated populations. Simple objective measurements were also included in the investigation, in that self-measured peak expiratory flow (PEF) was measured four times a day. These PEF measurements showed internal consistency, 24-hour variability, associations with temperature and self-reported daily form that suggests that they were reliable and would be able to detect an effect of air pollution if exposure was high enough.

What are the principal findings of the investigation?

In the investigation area, sulfur dioxide and chlorine are typical pollutants originating from local industry. Nitrogen dioxide originates largely from traffic pollution. Nitrates and sulfates originate both from industry and long range transport of pollution from sources outside the country, whereas ozone originates principally from long range transport. All types of pollution showed certain associations with reporting of symptoms of health effects. The most explicit was the associations between exposure to ozone and nitrates and symptoms in the upper and lower airways. The effects were seen mostly in the summer (with the exception of ozone) despite the relatively low pollution concentrations. This may reflect differences in biological sensitivity independent of climate. The increases in reporting of symptoms seemed to occur even though concentrations of pollutant exposure were generally under air quality guidelines for the different compounds.

This investigation was however, unable to determine unequivocally a relation between pollution and measured lung function. This was the case both in the randomly selected study population and in the population with pre-existing lung disease. This is in contrast to the results of analysis of symptom reporting which perhaps indicates that lung function measurement is a less sensitive method than systematic, repeated registration of symptoms.

The study focused on short-term effects. Long-term effects were not studied. Even though symptoms of decreased well-being and annoyance must be considered as less serious than for example the development of cancer, they may affect many more people. Other short-term health effects can exist without being discovered in this study because they are either of a type not investigated or because the effect is so slight.

The study showed that air pollution concentrations in the Grenland area are much lower than previously. But even though concentrations are generally under air quality guidelines, it was possible to demonstrate associations with subjective symptoms of health effects. Most of the people living in the region are seldom or only slightly bothered, but there exists a sensitive group that reacts more often than the average population. This group should be better described and is a challenge for future research.

The investigation in Grenland represented a major effort from both public authorities and the participating institutions. The study participants were very cooperative. The study was as thorough as possible using the currently available methods. In the future it may be possible to improve such studies with for example use of personal portable samplers to improve air pollutant exposure estimates. In addition, improved methods to detect adverse effects of air pollution at an early stage using for example molecular biological methods will presumably be available. The findings in this investigation should be taken into account in a revision of the current air quality guidelines.

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15 GLOSSARY

Active	- Indicator variable in logistic regression. Active=1 when asleep, Active=2 when awake.
Asthma	- Asthma is a symptomatic condition, characterized by airway constriction that varies substantially in a relatively short time. Underlying causal factors can be allergic and non- allergic. Objective criteria for diagnosis are 10-15% reversibility of the spirometry values with use of local bronchodilators - after using a spray subject breathes 10-15% better.
ATPS	- Ambient Temperature and Pressure, Saturated - lung function values are read off relative to ambient temperature and pressure, and water vapor saturation.
BTSP	- Body Temperature and Pressure, Saturated - lung function values are adjusted for body temperature and water vapor saturation.
Cl_x	- Chlorine ($\mu g/m^3$), total chlorine analyzed on particles.
COHb	- Carboxyhemoglobin (in per cent of hemoglobin saturation) - carbon monoxide bound to hemoglobin; CO is more efficiently bound to hemoglobin than oxygen and can therefore cause suffocation.
COLD	- Chronic Obstructive Lung Disease is diagnosed when reduced spirometrical values and/or other clinical findings are not reversible when using local bronchodilators during more than two years.
"Delt"	- Number of participants; used in tables and figures in Chapter 9.
Finite difference	- The difference between the values of a function at two discrete points, used to approximate the derivation of the function.

FVC	- Forced Vital Capacity (liters) - amount of air a person is able to expire from full inhalation to full expiration; given in BTPS-values.
$FEV_{1.0}$	- Forced Expiratory Volume (liters) - measure of airway resistance; the volume of air a person is able to expire as quickly as possible from the lung in the first second from full inhalation. Given in BTPS-values.
Hb	- Hemoglobin (g/100 ml) - concentration in blood is given in "blood per cent" (in colloquial language).
LPER	- Length of one continuous period with response (in hours). Is used for description of periods of uninterrupted reporting of subjective health effect variables (symptoms) in chapter 9.
Mass consistent	- Pollution mass is not added or subtracted from the area as a result of numerical approximations.
Morning	- Indicator variable for the first interval (time block) after a person woke up. Morning=1 in the interval a person has got up, Morning=0 otherwise.
NO	- Nitrogen monoxide ($\mu g/m^3$), gas
NO_2	- Nitrogen dioxide ($\mu g/m^3$), gas
NO_3^-	- Nitrate ($\mu g/m^3$), in the text also NO_3. Is analysed on particles.
NO_x	- Sum of nitrogen oxides ($\mu g/m^3$) (in gaseous form), given as NO_2.
NPER	- Number of periods with uninterrupted reporting of subjective health parameters (symptoms), is used in Chapter 9.

Numerical diffusion	- The pollution concentration is diluted as a result of the numerical approximation of transport and diffusion.
O_3	- Ozone ($\mu g/m^3$), gas
Part-f	- Particles - fine fraction, dust, fine fraction (particles under 2.5 μm in diameter).
Particles	- In the text also dust; particles with diameter less than ca 10 μm.
PM_{10}	- Particles with diameter less than 10μm ($\mu g/m^3$).
$PM_{2.5}$	- Particles with diameter less than 2.5 μm ($\mu g/m^3$), respirable particles.
PEF	- Peak Expiratory Flow rate (l/min), measure of airway resistance. The maximal airflow calculated as liters per minute that a person is able to expire.
Poisson model	- Mathematical model for number of occurrences, based on assumption that the occurrences are consecutive and independent of each other, and that they occur with unchanged rate in time.
SCL-90	- Symptom Check List, psychological test used to classify psychopathological traits in subjects.
SO_2	- Sulfur dioxide ($\mu g/m^3$), gas
SO_4^{2-}	- Sulfate ($\mu g/m^3$), analysed on particles. In the text also as SO_4.
Summer	- Study period 15 April-24 June 1988.
SR	- Sedimentation Rate or sedimentation (mm/h).

Study population	- Adult participants, 18-75 years. They were recruited from 800 persons randomly selected from the Register of Inhabitants. This group contains 312 persons. Also described as "randomly selected study population".
Winter	- Study period 1 January-15 March 1988.

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FORFATTER(E) This report is a collection of articles concerning different phases of the study. Each Chapter has its own authorship list.		TILGJENGELIGHET * A	
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STIKKORD Air pollution	Health	Cohort study	

REFERAT

This report summarizes the different phases of a large cohort study on the short term health effects of air pollution in an industrialized area. The study estimated exposure of each individual on an hourly basis to SO_2, NO_2, CO, O_3, sulfates, nitrates, particles (fine fraction), using information obtained by a diary combined with geographic modelling of air pollution, continuous measurement at 9 stations, and measurements made indoors/outdoors in 15 homes. Health was assessed subjectively using a diary approach hour for hour and objectively with peak expiratory flow measurements four times daily plus complete measurements of lung function, blood and urine parameters every 14 days to 1 month. No changes were found in lung function (PEF) suggestive of an air pollution effect. Associations were found between subjectively reported symptoms of health effects and exposure to nitrates, ozone and possibly sulfate, NO_2 and SO_2.

TITLE Air pollution and short-term health effects in an industrialized area in Norway - Main report

ABSTRACT

Rapporten finnes også på norsk (NILU OR 58/91)

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Kan ikke utleveres C