DEVELOPMENT OF THE METHODOLOGY FOR THE MEASUREMENT OF THE INDOOR POLLUTANTS IN PROBLEM-SOLVING RESEARCH: AS APPLIED TO THE ASSESSMENT OF HEALTH HAZARDS IN OFFICE BUILDINGS

MD NAJIB BIN IBRAHIM

Thesis submitted for the degree of
Doctor of Philosophy in Architecture
University of London
January, 1995

The Bartlett School
University College London

ABSTRACT

This thesis sets out to develop a methodology to monitor indoor pollutants in the assessment of their contribution to building sickness in offices. This methodology was developed in the field during the SERC/LINK Project on Healthy Offices. Within the constraint of allowable intervention time, and allowable number and size of monitoring equipment in the study offices during working hours, there are fifteen controversies and uncertainties which were resolved in this thesis. Some of the most controversial issues which were addressed are whether or not photoacoustic is as good as gas chromatography in assessing the health effect of TVOC, which VOC are most relevant to building sickness, which chemical should be used as the standard for TVOC, and when and where to measure them. In this thesis the monitoring times and locations used by previous researchers were put together in a simplified `statistical sampling model' to assist in selecting a more representative sample. Particular attention was given to reliability and validity of the methodology and estimated errors were proposed to take into account the uncertainties faced in the monitorings.

TABLE OF CONTENTS

CHAPTER 2

BUILDING SICKNESS: DESCRIPTION AND CRITERIA

CHAPTER 3

THE AIRBORNE POLLUTANTS TO BE MONITORED

CHAPTER 9

RESULTS AND THEIR ANALYSIS

CHAPTER 10.

CONCLUSION

LIST OF TABLES

CHAPTER 6

CHAPTER 7

CHAPTER 9

LIST OF FIGURES

CHAPTER 6

CHAPTER 7

CHAPTER 8

ACKNOWLEDGEMENTS

My deepest gratitude goes to Prof. P. O'Sullivan for his care, valuable supervision, and time throughout my research. I would also like to express my gratitude to the University of London for accepting me as one of their doctorate students.

My thanks are due to all of the committee members of SERC/LINK Project on Healthy Offices for allowing me to participate in their research on which this thesis was based. Special thanks are due to Nigel Vaughan and Huw Jenkins of UWCC, Richard Rooley of Rooley Consultants and David Tong of BUS for their assistance at various stages of this thesis. Thanks are also due to the staff of the study buildings for their invaluable assistance during the site visits and field works, and to the staff of Bruer and Kjaer (UK) and BOC for information on research equipment and material.

The author also wishes to acknowledge the Public Services Department, Malaysia for financial support and the Universiti Teknologi Malaysia for granting study leave, financial and moral support.

At UCL, my gratitude goes to Dr. Alan Young, Dr. Tadj Oreszczyn, Dr. Tad Grajewski (now at UWCC), and Ashish Patel for their assistance particularly during SERC/LINK site visits and field works. I have also benefited from valuable discussion with them and Tim Mullany.

Special thanks are due to Sabariah Mohd Rashid for writing advice, Abdul Rashid Embi for word-processing advice, and Yusah Hamuth for his assistance in data processing.

Finally, my heartiest and warm thanks to my wife, Noraini, for her patience and help in uncountable ways especially in editing. My loving thanks to my two daughters, Afina and Atifah, for reminding me to complete my thesis as soon as possible.

Chapter 1
INTRODUCTION

1.1 SUMMARY

Sickness in buildings is a problem in the operation of office buildings. The solution to such a complex problem requires the use of multi disciplinary research techniques. This thesis, using a problem-solving approach, attempts to develop a practical but valid, and reliable methodology to assess the contribution of airborne pollutants within the office building to this problem.

1.2 CHAPTER INTRODUCTION

This chapter consists of two parts: Section 1.3 sets the background from which the thesis problem was formulated and Section 1.4 defines the thesis problem and describes the thesis research itself.

1.3 THE BACKGROUND

1.3.1 Research in Built Environment

The definition of research most suitable for this thesis is given by Emory (1976). According to him, research is any organised inquiry designed and carried out to provide information for solving a problem. Solving real world problems has always been the main objective of research in built environment. For example, one of the reasons for conducting research in architecture is to investigate building failures with a view to improve it (The Commonwealth Foundation, 1972). Phillips and Pugh (1987) call this type of research a problem-solving research.

Problem-solving research is not a type of research traditionally practised. In his comprehensive discussion on research as it is applied in solving real business problems, Emory (1976) divides research which is traditionally practised into two types: pure and applied. He elaborates that pure research generates theories which is then employed by applied research. The theories generated by pure research is normally developed by controlling all other factors except the one to be studied in depth. These theories are developed in a single discipline. As applied research subsequently employs the theories generated by pure research to solve real world problems or needs, it can also be considered as single disciplinary.

However, most of the problems faced in the real world may not be solved by conducting traditional research for three reasons. Firstly, in practice, the real world needs also generate their own research problems and theories rather than depend solely on the theories generated by traditional research (Emory, 1976; Phillips and Pugh, 1987). Secondly, real world problems are governed by many interacting factors and most of them cannot be isolated and controlled. Therefore, the condition under which the research is conducted cannot be replicated. Thirdly, most of these factors cannot be fitted into a single discipline. Consequently, another type of research which uses a multi disciplinary approach is required to solve real world problems. This is the type of research called non- traditional or problem-solving research.

1.3.2 Problem-Solving Research

Basically, problem-solving research begins with a concern to improve the decision-making process in solving real world problems. As stated earlier, many factors generally govern the real world problems. Normally these problems are multi disciplinary. The resources required to solve these problems - for example basic information, background theory, applicable methodology, and related expertise - are scattered in various disciplines.

In solving real world problems, the research can be divided into three steps:

1) to define in what way the decision-making process may be improved. This step is referred to as the research issue.

2) to develop a method of tackling the research issue. This is called the research methodology.

3) to develop a recommendation to improve the decision- making process. This step is referred to as the research conclusion and recommendation.

The improvement to the decision-making process is the key contribution of the problem-solving research. Taking the research undertaken by this thesis as an example, had it not been carried out it may have taken the SERC/LINK Team longer to determine the most appropriate methodology to measure airborne pollutants within the office buildings.

1.3.3 Building Sickness as the Area of Concern in Built Environment, to which the Research is Addressed

According to a survey reported in Environmental Health (1988), more than half of the office buildings in the United Kingdom may be unhealthy; the buildings suffer from building sickness. The World Health Organisation estimated that thirty percent of new or refurbished office buildings in industrialised countries have problems which may cause complaints and impair working performance by office workers (Rollos, 1993). Although building sickness is not medically serious (Burge, 1992), it affects work efficiencies and effectiveness (Casey, 1990). Building sickness is claimed as not a form of infection or the result of toxic pollution (Hedge and Wilson, 1987). But Woods et al (1987) argue that unacceptable indoor air is a factor since the office worker experiences relief immediately after leaving the building.

In finding a solution to this problem, the focus at the moment and indeed in the future should be via a multi disciplinary approach (Garvey, 1994). This approach is elaborated by Raw (1992). Rather than focusing on the concern of each of the related disciplines of the unhealthy building, the concern should be directed toward the building as a whole, its indoor environment (including airborne pollutants), the organisation which occupies the building and the needs of the office workers in the unhealthy building. Taking one area of concern in isolation will distort the problem and thus invalidate the solution to the problem.

1.3.4 The SERC/LINK Project on Healthy Office Environment

The Science and Engineering Research Council (SERC), The Department of Trade and Industry, The Bartlett School, The Welsh School of Architecture, British Gas, Gilberts

(Blackpool) Limited, Building Use Studies, and Rooley Consultants are concerned with the problem of building sickness. SERC is the main funder of academic research relating to built environment in the United Kingdom. Through LINK projects, SERC provides part of the fund for research projects which are aimed at stimulating collaborative research between academia and industry. The rest of the fund comes from the industry. SERC and the above bodies, universities, and firm pooled together their resources in terms of funding and expertise in a SERC/LINK Project entitled The Design of Healthy Office Environment. This SERC/LINK Project is aimed at producing design guidelines for the design and operation of healthy office environment.

This project is steered by a management committee which meets periodically. To ensure multi disciplinary approach the management committee consists of experts from various disciplines. The advantage of multi disciplinary approach is that the research objective, methodology, and findings are not biased to a particular discipline in which a particular research team is more familiar. The relevance of the finding of this project to the industry is ensured by having their representative in the management committee.

For the SERC/LINK project on healthy office environment, the management committee selected several buildings, both healthy and unhealthy, as samples. The selection was based on initial questionnaires sent to the building owners followed by preliminary visits. During the preliminary visits the research team investigated whether or not the building was properly maintained or the faulty design was obvious. The buildings with faulty design or poor maintenance were not selected as building samples. For each of the building samples a thorough assessment was conducted to determine whether or not the building was healthy in terms of psycho social factors and health symptoms, spatial organisation, air ventilation performance, environmental comfort, and airborne pollution.

The author used this SERC/LINK Project as the basis of the field studies in which he made measurements of airborne pollutants. In this thesis the objective of the monitoring is to measure typical concentration of pollutants that the occupant would have been exposed to over the period covered by the social survey (See Appendix VI). The development of the methodology for assessing airborne pollution in the building samples is the research issue of this thesis.

1.4 THE THESIS

1.4.1 Research Issue of The Thesis

The research issue addressed in this thesis is stated in fifteen research questions. Within the constraint of allowable intervention time, and allowable number and size of monitoring instrument in the office, there are fifteen controversies and uncertainties to be resolved in the development of methodology to assess airborne pollution in the building samples of the SERC/LINK Project.

The controversies and uncertainties will be addressed in this thesis but not in equal depth. They are laid out in the following research questions:

1) which terminology is most suitable to describe building sickness;
2) which criteria are appropriate to determine if a building is healthy;
3) which few of the numerous airborne pollutants identified by previous researchers are most relevant to the SERC/LINK research;
4) whether or not a particulate monitor using piezobalance is still appropriate to measure the particulate relevant to building sickness;
5) whether or not inorganic gases should be monitored;
6) which few of the inorganic gases are most relevant to building sickness;
7) which few of the volatile organic compounds in office indoors are most relevant to building sickness;
8) why several standards for volatile organic compounds are used;
9) which standard of volatile organic compounds is most appropriate to the SERC/LINK project;
10) which instrument should be selected to measure gaseous pollutants;
11) in which part of the building should the monitoring be conducted;
12) when should the monitoring be conducted;
13) how reliable and valid is the proposed monitoring methodology;
14) how much is the estimable error;
15) whether short-term, sequential, and mobile monitoring or long-term stationary monitoring is more practical.

1.4.2 The Objective of the Thesis

The above research questions are aimed at meeting the research objective of this thesis which is to recommend the most practical but valid and reliable methodology of monitoring airborne pollutants in the assessment of health hazards in buildings.

In the context of this thesis, the following terms bears the following definitions:

1. `methodology means the identification of the most relevant airborne pollutants, the selection of the most suitable instrumentation to conduct the monitoring, the quality control of the monitoring instrument, and the method of monitoring.
2. `monitoring' means a repetitive or continued measurement of the concentration of airborne pollutants in a predetermined monitoring location, time, and monitoring sequence.

1.4.3 Research Methodology of the Thesis

The development of the methodology for monitoring airborne pollutants required a thorough understanding of the SERC/LINK project on healthy office. To obtain this understanding, the author became a member of the Working Committee of SERC/LINK Project and was directly involved in the preliminary site visits and in the committee meetings for selecting building samples. Thereafter the author was involved mainly in the monitoring of airborne pollutants of the first four building samples selected by the committee. The committee did select other building samples. Nonetheless they are not included in this thesis.

In the development of the methodology, there are several controversies and uncertainties to be resolved. These controversies and uncertainties, stated earlier in this chapter as research questions, are resolved through a literature review; a pilot study in the first building; discussions with the equipment manufacturers and in particular the manufacturer of the gas monitor, and the supplier of standard gases; and the experiments and theoretical analysis conducted during the calibration of gas monitor and the monitoring of the first, second and third buildings. Since the controversies and uncertainties were resolved in the monitoring of the first three buildings, the resulting methodology was used in the monitoring of the fourth building.

1.4.4 The Significance of this Thesis

The significance of this thesis lies in the following improvements to the methodology of assessing airborne pollutants which the author believes he has made:

1) more data may be collected within the same monitoring period using the proposed methodology when compared to other methodologies employed by previous researchers. This improvement was made based on the latest knowledge of health hazards in buildings and the techniques of monitoring;
2) spatial variation of airborne pollutants in the office at a particular time may be studied using the data collected by the proposed methodology;
3) time variation of airborne pollutants at a particular location in the office may be studied using the same data;
4) the information from the spatial variation and time variation studies will aid the Management Committee and Working Committee of the SERC/LINK Project to relate the monitoring of airborne pollutants with the findings of other research teams so that the distribution of the symptoms of building sickness can be explained.

1.4.5 Outline of Remainder of the Thesis

The thesis itself is described earlier on in this chapter. The development of the methodology of monitoring the airborne pollutants is described in Chapters 2 to 6. The pilot test on the methodology is described in Chapter 7. The application of the methodology is described in Chapters 8 and 9. Specifically, Chapter 8 describes the methodology used in the monitoring of the second, third, and fourth study buildings and Chapter 9 describes the results and analysis of the data. Finally, Chapter 10 contains and summarises the conclusions and the discussion on the proposed methodology and suggests further improvements that can be made to it.

The following paragraphs are the summary of the various chapters mentioned above:

Chapter 2 seeks to answer research questions 1 and 2. In this chapter the definition and meanings of health are explained. After justifying the use of the term building sickness, the symptoms and the criteria for determining unhealthy buildings are elaborated. Finally the sources of health hazards relevant to building sickness are identified.

Chapter 3 seeks to answer research question 3. This chapter begins with a review of the factors in the physical environment considered by previous researchers as a threat to health. Then the related terminology, the health effects, and the regulating standards or recommended limits on the relevant hazardous particles and gases are discussed. This chapter ends with a discussion on the units used in the assessment of hazardous particles and gases in buildings.

Chapter 4 seeks to answer research questions 4 to 10. Since the gas monitoring technique used in this research has never been used before and its use in this research is controversial, the main discussion in this chapter focuses on the justification of the selection of the gas monitor and the explanation of the process of selecting the optical filters for the gas monitor. A controversy also exists in selecting the standard for calibration. This is also discussed in this chapter.

Chapter 5 seeks to answer research questions 11 and 12. In this chapter the monitoring location and time used by previous researchers are put into perspective to facilitate the selection of representative samples.

Chapter 6 seeks to answer research questions 13 and 14. Here the reliability and validity of the methodology discussed in the previous four chapters are assessed qualitatively or quantitatively. The assessment shows that the reliability and validity are subject to errors due to limitation of knowledge and equipment. As some of this errors are estimable, an estimated error band is recommended.

Chapter 7 seeks to answer research question 15. The discussion in this chapter focuses on the monitoring of airborne pollutants in the pilot test. The chapter discusses the answers to six test questions which forms the main results of the pilot test. It ends with the recommendation of the monitoring approach and equipment and number of monitoring locations that should be used in the other selected buildings.

Chapter 8 describes the monitoring of the airborne pollutants in the other three buildings, the Royal Insurance Building, Peterborough; The Lakeside Municipal Building, Kendal ; and the Pearl Building, Cardiff.

Chapter 9 discusses the result and analysis of the monitoring. It examines the characteristics of the data collected, its problems and solutions so that reliability, validity, and practicality can be achieved.

Chapter 10 is the conclusion and recommendation of this thesis. In this chapter the author suggests further improvements that could be made on the proposed methodology.

1.5 REFERENCES

1. Burge, P.S. (1992). `The Sick Building Syndrome: Where are We in 1992'. Indoor Environment, 1992, Vol. 1, pp199-203

2. Casey, T. (1990). `Sick Building Syndrome - Fact of Fantasy?', Energy World, Mar. 1990, pp9-10

3. The Commonwealth Foundation. (1972). The Application of Architectural Research To Practice. Occasional Paper No. XVII. Proceedings of The First Seminar on Architectural Research in Commonwealth and United Kingdom Universities at The University of Edinburgh

4. Emory, C.W. (1976). Business Research Methods. Illinois: Richard D. Irwin, Inc.

5. Environmental Health (1988). `Survey Reveals Widespread Sickness in UK Buildings', Environmental Health, Vol. 96, No. 2, pp18-19

6. Garvey, J. (1994). `Developing an Integrated Approach to SBS', Occupational Health, Feb., 1994, pp50-53

7. Hedge, A. and Wilson, S. (1987). The Office Environment Study: A Study of Building Sickness. A Study Sponsored by the Health Promotion Research Trust. London: Building Use Studies

8. Phillips, E. M. and Pugh, D. S. (1987). How to Get a PhD : Managing the Peaks and Troughs of Research. Milton Keynes: Open University Press.

9. Raw, G. J. (1992). Sick Building Syndrome: A Review of the Evidence on Causes and Solutions, HSE Contract Research Report No. 42/1992. HMSO

10. Rollos, M. (1993). `HVAC Systems and Indoor Air Quality'. Indoor Environment, 1993, Vol. 2, pp204-212

11. Woods, J.E. et al (1987). `Resolution of The Sick Building Syndrome', in IAQ87 Practical Control of Indoor Air Problems, Proceedings of The ASHRAE Conference IAQ87, May 18-20, 1987, Arlington, Virginia, pp338-348

Chapter 2
BUILDING SICKNESS: DESCRIPTION AND CRITERIA

2.1 RESEARCH QUESTIONS

This chapter seeks to address the following two research questions:

1) which terminology is most suitable to describe building sickness;
2) which criteria are appropriate to determine if a building is healthy.

2.2 SUMMARY

Health is a subjective rather than a concrete concept. Therefore, the basic terminology have to be used consistently by all of the team members involved in solving the multi disciplinary research problems in office environments. Similarly suitable indices of health and sickness have to be agreed prior to assessing whether or not a building is healthy.

2.3 INTRODUCTION

In this chapter the definition and meanings of health are explained. After justifying the use of the term `building sickness', the symptoms and the criteria for determining unhealthy buildings are elaborated. Finally the sources of health hazards relevant to building sickness are identified.

2.4 THE DEFINITION OF HEALTH

The World Health Organisation's definition of health is the most commonly used. Health is defined in the Preamble of The Constitution of World Health Organisation as a state of not only the absence of disease and infirmity but also complete physical, mental and social well-being. The discussion on the lack of agreement on such a definition is well covered by several authors for example Smith (1988), Hunt (1988), and Basch (1990). But as the most often quoted definition is taken from the Preamble of The Constitution of World Health Organisation, it is the one adopted in this thesis.

2.5 THE MEANINGS OF HEALTH

Literature review of the meanings of health as applied in several disciplines will give a better insight into the concept. An example of the meaning of health as defined by the language experts is given by The Oxford English Dictionary. The dictionary defines health as the perfect condition of spiritual, moral, and mental aspect of a person (Simpson and Weiner, 1989). Under that condition the person will not only have peace of mind but also an ideal condition of body. Therefore, the function of the body of a healthy person is routinely and efficiently conducted. Black's Medical Dictionary also agrees with the concept that health is more than freedom from disease. The dictionary defines good health as the ability to achieve and maintain the highest state of mental and body strength (Harvard, 1990). This concept is further amplified by several authors in the medical field. Herzlich (1972) and Hunt and MacLeod (1987) define health as not only being physically fit and having the ability to discharge everyday routine, but also having energy reserve, feeling good, and enjoying life.

Some of the factors affecting health of office workers - level of civilisation, physical environment, psycho social environment, personal behaviour and medical history - may be explained by Melhuish's model. As stated in the Chapter 1, these factors cannot be isolated. According to Melhuish (1978), health may be considered as the equilibrium state, between upward and downward forces, at a particular time above the threshold of health. The location of the threshold is determined by the level of civilisation. On one hand, emerging health problems tend to raise the threshold level. On the other hand, the rising standard of education enables man to cope better with the health problems (World Health Organisation, 1991), thus it tends to lower the threshold level. Personal behaviour, medical history and physical/psycho social environment are the interacting forces that will move the equilibrium point vertically. Examples of upward forces are routine exercise, balanced diet, work satisfaction, and family moral support. Examples of downward forces are smoking and alcoholic habit, obesity, work problem, and increasing age.

2.6 ILLNESS, SICKNESS, AND DISEASE

Similar to health, ill-health is difficult to describe as illness, sickness, and disease have different meanings (Hunt, 1988; Allsop, 1984). The unhealthy office worker himself, the public with whom the office worker interact and the medical practitioner with whom the office worker seek treatment perceive the person's health condition independently. Illness is the perception of the office worker himself that he is not well. Sickness is the perception of other office workers, his employer, and neighbour of his condition by observing a change in his social behaviour, for example, him being absent from work. When the person's condition is manifested in the form of symptoms or clinical signs, and confirm by a medical practitioner, it is considered a disease.

Illness, sickness, and disease, if exist together, are distributed pyramidally according to clinical iceberg concept (Midwinter and Colley, 1986); with illness at the base, sickness in the middle, and disease on the top. When this concept is applied in the assessment of health hazards in offices two expectations may be made. First, the incidence of health problems in an office is expected to occur more if its assessment is made at the lowest level: the office worker level. However, the assessment should also be made at the middle and top levels because this will result in information from different perspectives which would provide a total picture of the worker's problem. As stated in the last chapter, the multidisciplinary research of unhealthy office should focus on the total picture of the problem and total solution. Second, many people are exposed to health hazards than those that seek medical treatment. Thus, the number of people suffering from building sickness may be higher than reported.

2.7 BUILDING SICKNESS

Based on the above concepts of health, illness, sickness, and disease, building sickness seems to be less controversial. The unhealthy condition of the office worker who suffers from building sickness is beyond the perception of the affected person himself. Therefore, the term illness is not sufficient to describe the unhealthy condition. Change in social behaviour is involved, for example, the neighbouring workers becoming aware of the lethargy or mental fatigue suffered by the affected person. The employer is also aware of the reduction in job effectiveness and an abnormally high rate of absenteeism among the office workers suffering from building sickness. However, building sickness is not serious to the health of the office worker who suffers from it. By medical standards, the symptoms of building sickness are relatively trivial (Burge, 1992). The office worker who suffers from building sickness may or may not seek medical treatment from a medical practitioner. Hence, the term disease is also not appropriate to describe building sickness.

Building sickness is also known in several synonyms: sick building syndrome, sick office syndrome, tight building syndrome and office eye syndrome (Sykes, 1988), and it is also known as stuffy building syndrome (Stolwijk, 1984). The terminology sick building syndrome is more widely used (Sykes, 1988). Building sickness can also be partially described by mucosal irritation syndrome or general symptom syndrome. According to Rollos (1993), it was suggested that the symptoms of building sickness related to environment be named mucosal irritation syndrome, and those related to personal and job characteristic be named general symptom syndrome.

The word syndrome is used by several researchers to describe building sickness because it involves a consistent pattern of several medical symptoms. `Syndrome' comes from the Greek words, syn and dromos (Jablonski, 1991). `Syn' means together. Hence, `Syndrome' is a group of symptoms which, occurring together, produce a pattern or symptom complex typical of a particular disease (Roper, 1978).

The literature review shows that the use of the term `syndrome' is controversial for two reasons:

1) building sickness is not a serious health threat but more of a perception such as the perception of discomfort. Several consultants disagreed with the use of `syndrome' in describing the above building sickness (LaBar, 1992) mainly because the public generally associate `syndrome' with serious health threat such as cancer. Therefore, the term building related symptoms was considered to be more appropriate by the consultants.

2) `syndrome' suggests an unhealthy condition confirmed by medical procedure. Jarvholm (1993) argues that medical diagnoses and syndromes based on pathological changes do not occur in the case of building sickness.

For the reasons described above, the term `building sickness' is used for the purpose of this thesis.

2.8 THE SYMPTOMS OF BUILDING SICKNESS

Building sickness can manifest itself in several symptoms. `Symptom', as it is used here, means a change in health condition of the office worker. The symptom is the evidence of the worker suffering from building sickness. The symptoms are also known as complaints.

Several researchers, for example Hedge and Wilson (1987), Stolwijk (1984), and Jablonski (1991), identify the symptoms of building sickness. The symptoms identified by Hedge and Wilson (1987) was initially adopted by the SERC/LINK Project on healthy office environment. The ten symptoms used in this project are tightness of the chest, dryness of the eyes, itching eyes, runny nose, lethargy and/or tiredness, dry throat, blocked or stuffy nose, headaches, flu-like symptom but not flu, and difficulty in breathing.

There are some differences in the symptoms used in the SERC/LINK Project when compared to those identified by some researches.

Firstly, the SERC/LINK Project is more specific than Stolwijk (1984) in describing eye, nose and throat irritations. The specific terms are dryness of eyes and itching eyes for eye irritations, runny and blocked or stuffy nose for nose irritations, and dry throat and difficulty in breathing for throat irritations.

Secondly, some of the symptoms identified in the SERC/LINK Project are described in a less serious manner than those described by other researchers. According to Jablonski (1991) the symptoms of building sickness are more than dry throat. They also include cough and hoarseness. He also states the symptoms of building sickness as more than chest tightness and breathing difficulty but also wheezing.

Thirdly, several symptoms identified by Stolwijk (1984), Burge (1992), Bluyssen (1992), and Jablonski (1991) are not included in the SERC/LINK Project. According to Stolwijk (1984), dry and itching skin, dizziness, and nausea are also symptoms of building sickness. The other symptoms quoted by Jablonski (1991) are dry mucous, membrane, and skin, high frequency of airway infection, erythema, and mental fatigue. According to Burge (1992) and Bluyssen (1992), asthma is also a symptom of building sickness.

2.9 UNHEALTHY OFFICE BUILDING AND AREA

An office building or area where the symptoms of building sickness are present can be described as an unhealthy building or area. The description of unhealthy office building is given by several researchers, for example Sykes (1988), Stolwijk (1984), Stolwijk (1987), and Hedge and Wilson (1987). Sykes (1988) considers the unhealthy building as that in which symptoms of building sickness are more common than might reasonably be expected. According to Stolwijk (1984) building sickness occurs temporarily but consistently to the affected office workers while they are in the building. It is reasonable to expect between fifteen to twenty percent of office workers in any office building to experience one or more of the building sickness symptoms within the past two weeks (Stolwijk, 1987). The symptoms disappear immediately to most of the affected office workers when they leave the unhealthy office building (Stolwijk, 1987). Hedge and Wilson (1987) used two indices - Building Sickness Score (BSS) and Person Symptom Index (PSI) - to describe quantitatively healthy and unhealthy offices.

The SERC/LINK Project initially adopted the above health indices, mean PSI and BSS, to decide symptomatic (unhealthy) area and asymptomatic (healthy) area in the building samples. In symptomatic areas the PSI was 3.3 or greater. In asymptomatic areas it was 2.6 or below.

PSI is the index for individual office workers by aggregating the ten symptoms of building sickness: tightness of the chest, dryness of the eyes, itching eyes, a runny nose, lethargy and/or tiredness, a dry throat, blocked or stuffy nose, headaches, flu-like symptom but not flu, and a difficulty in breathing. From these symptoms, the scale of PSI is determined to be from zero to ten. For example, in the analysis of the total respondents of the questionnaires sent to the study building at least one office worker had reported suffering from all of the ten symptoms of building sickness. Therefore, his PSI was ten. Similarly at least one office worker had reported suffering none of the ten symptoms of building sickness. Therefore, his PSI was zero. That means the PSI of the office workers in the building varies from 0 to 10.

The average value of PSI of all office workers in the study building is the BSS. In other words, BSS is derived by dividing the total reported number of building sickness symptoms by the total questionnaire respondents in the study building. For example, at the Royal Insurance Building, Peterborough, the mean BSS is 2.9, the minimum is zero, the maximum is 10, and the standard deviation is 2.4. But the average symptom of building sickness reported by all of the 160 office workers in the building is 2.9 with a standard deviation of 2.4.

Once the symptomatic and asymptomatic areas were selected using both PSI and BSS, airborne pollutants monitoring was required to determine the contribution of the pollutants to building sickness. This monitoring was carried out by the author.

2.10 HEALTH HAZARDS IN OFFICE BUILDINGS

Airborne pollutants are not the only health hazards in office buildings. Anything which threatens an office worker's health in office buildings is a health hazard. `Hazard' is defined as a substance, process or activity with potential to cause harm (Health and Safety Executive, 1990). As can be seen from earlier discussions on factors affecting health, the threat does not only exist in the physical environment but also in the psycho social environment.

The health hazards in the physical environment which are relevant to building sickness include thermal, acoustical, and luminous environment as well as air quality. The comfort range for thermal, acoustical, and luminous environment is well established. Any conditions beyond the comfort range causes discomfort and consequently stress which contributes towards building sickness.

The health hazards affecting air quality include airborne pollutants and combustion generated contaminants. Some of the airborne pollutants relevant to building sickness are bioaerosols, asbestos, man-made mineral fibres, and volatile organic compounds. Bioaerosol are air-borne microbiological particulates derived from viruses, bacteria, fungi, protozoa, mites, pollen, and their cellular or cell mass components. Bioaerosols are everywhere in indoor and outdoor. The presence of abundant moisture and nutrient amplifies the growth of some of the bioaerosols. Bioaerosol samples for the SERC/LINK Project for healthy office environment were taken from the seat and the armrest of clothed chairs. Asbestos is not considered relevant to the SERC/LINK Project because it is banned in new buildings. The man-made mineral fibres which are relevant to the project are porous insulation materials used in air-conditioning duct liner and filters. When certain conditions - temperature, humidity, and nutrient - exist there, the fibres amplify the population of some microbial agent which produces specific products, such as aldehydes, one of the volatile organic compounds described earlier. Like asbestos, combustion-generated contaminants are not considered relevant because primarily they are generated from environmental tobacco smoke.

Health hazards in psycho social environment may arise from poor spatial organisation and personal interaction in the office. Expert estimates showed that fifty percent of cases of reported building sickness are manifestation of psycho social factors (LaBar, 1992).

Both physical and psycho social environments may cause psychological factors such as depression, anxiety, stress, and boredom and consequently building sickness.

Other than the factors of physical and psycho social environments, personal and medical factors may also cause health problems. Personal factors include personal behaviour, physical conditions, psychological conditions, and recent activities. The office worker may suffer from insomnia, indigestion, hunger, post-coital or menstruation- related headache or fatigue. The headache and fatigue may be due to nutrient excesses or deficiencies. Personal behaviour includes smoking and drinking habit and exercise routine. Medical factors include their recent illness, existing disease or early stage of a disease. These health problems, although may be manifested in symptoms similar to those of building sickness, will persist even after the office worker leaves the offices. Therefore, personal and medical factors are not considered as health hazards in office buildings and subsequently, are not relevant to building sickness.

2.11 CONCLUSION

Building sickness is the most suitable way of describing symptoms associated with health hazards in office buildings. The extent of building sickness may be measured by distributing symptoms questionnaire and the result may for example be expressed in terms of the indices of PSI and BSS, or indeed in terms of individual symptom terms of the indices of PSI and BSS, or indeed in terms of individual symptom themselves.

2.12 REFERENCES

1. Allsop, J. (1984). Health Policy and The National Health Service. London: Longman, p145

2. ASHRAE (1993). ASHRAE Handbook: Fundamentals. Chap. 37. Atlanta: ASHRAE, Inc.

3. Basch, P.F. (1990). Textboook of International Health. New York: Oxford University Press

4. Bluyssen, P.M. (1992). `Indoor Air Quality Management'. Indoor Environment, 1992, Vol. 1, pp326-334

5. Burge, P.S. (1992). `The Sick Building Syndrome: Where are We in 1992'. Indoor Environment, 1992, Vol. 1, pp199-203

6. Harvard, C.W.H. (1990). Black's Medical Dictionary. 36th ed. London: A & C Black.

7. Health and Safety Executive (1990). `Hazard and risk explained', Leaflet, in Fairman, R. and Parkinson, N. (1992), `Risk Assessment', Environmental Health, June 1992, pp156-159

8. Hedge, A. and Wilson, S. (1987). The Office Environment Study: A Study of Building Sickness. A Study Sponsored by the Health Promotion Research Trust. London: Building Use Studies

9. Herzlich, C. (1972). 'Health and Illness: A sosio- psychological Approach'. New York: Academic Press in Smith, G.T. (1988). Measuring Health: A Practical Approach. New York: John Wiley and Sons

10. Hunt, S.(1988). 'Measuring Health in Clinical Care and Clinical Trials' in Smith, G.T. (ed.). Measuring Health: A Practical Approach. New York: John Wiley and Sons, pp7-9

11. Hunt, S. M. and MacLeod, M. (1987). "Health and Behaviour Change: Some Lay Perspective'. Community Medicine, 9, pp68-76 in Smith, G.T. (1988). Measuring Health: A Practical Approach. New York: John Wiley and Sons

12. Jablonski, S. (1991). Jablonski's Dictionary of Syndromes & Eponymic Diseases. Florida: Krieger Publishing Co.

13. Jarvholm, B. (1993).'Is It Time to Change the Terminology of Sick Building Syndrome'. Indoor Environment, 1993, Vol. 2, pp186-188

14. LaBar, G. (1992). `Putting Indoor Air Quality in Its Place', Occupational Hazards, Oct. 1992, pp105-108

15. Melhuish, A. (1978). Executive Health. London: Business Book Ltd.

16. Midwinter, R.E. and Colley, J.R.T. (1986). 'Health and Disease' in Read, A.E., Barritt, D.W. and Hewer, R.L. (ed.). Modern Medicine, 3rd Ed., London: Churchill Livingstone

17. Rollos, M. (1993). `HVAC Systems and Indoor Air Quality'. Indoor Environment, 1993, Vol. 2, pp204-212

18. Roper, N. (1990). Pocket Medical Dictionary. 14th ed. London: Churchill Livingstone

19. Simpson, J.A. and Weiner, E.S.C. (1989). The Oxford English Dictionary. 2nd Ed. Vol. VIII. Oxford: Clarendon Press.

20. Smith, G.T. (1988). Measuring Health: A Practical Approach. New York: John Wiley and Sons

21. Stolwijk, J.A.J. (1984) `The Sick Building Syndrome', in Berglund, B. et al. (ed). Indoor Air. Vol. 1., Recent Advances in The Health Sciences and Technology, Swedish Council for Building Research, Stockholm, Sweden, 1984, p23- 29

22. Stolwijk, J.A.J. (1987). `The Sick Building Syndrome', in ASHRAE. IAQ87. Practical Control of Indoor Air Problems. Proceeding of ASHRAE Conference IAQ87. May 18-20, 1987, Arlington, Virginia.

23. Sykes, J.M. (1988). Sick Building Syndrome: A Review. Specialist Inspector Reports. Health and Safety Executive Technology Division. Report No. 10, June 1988

24. World Health Organisation (1991). Environmental Health in Urban Development. WHO Technical Report Series 807. Geneva: WHO

Chapter 3
THE AIRBORNE POLLUTANTS TO BE MONITORED

3.1 RESEARCH QUESTION

This chapter seeks to address this research question:

Which of the numerous airborne pollutants identified by previous researchers are most relevant to the SERC/LINK Project and to this thesis

3.2 SUMMARY

Literature review shows that medically the most important airborne pollutants to be studied in this research are the indicator gases, carbon dioxide and carbon monoxide, plus the volatile organic compounds (VOCs). Many previous researchers have also included thermal, aural, and visual environment in their assessment of health problems in buildings. Due to a large number of VOCs existing in the indoor the determination of a representative VOC for assessing the total composition of VOCs is a major problem. For that reason as well as different techniques and representative VOC used, cross-comparison between the work of previous researchers, particularly the recommended limit, is difficult.

3.3 INTRODUCTION

This chapter begins with a review of the environmental factors considered by previous researchers as a threat to the health of office workers. Then the related terminology, the health effects, and the regulating standards or recommended limits on the relevant hazardous particles and gases are discussed. This chapter ends with a discussion on the units used in the assessment of hazardous particles and gases in buildings.

Anything which threatens occupants' health in buildings is a health hazard. As can be seen in the health model described in Chapter 2, the threat do not only exist in physical environment but also in social and occupational environments. This research is concerned with the health hazards in the physical environment.

Literature reviews showed that the important factors affecting health in physical environment of office buildings are hazardous particles and hazardous gases. A comprehensive check-list of all the factors affecting human health was proposed by Foort de Roo (1988). Most of them are not medically important. Roe (1990) and Hansen (1991) suggested the airborne pollutants which are considered medically important. Many researchers also included thermal, aural, and visual comfort in their assessment of health problems in buildings.

In proposing the master-plan for investigation into health problem in buildings, Foort de Roo (1988) considered surface temperature, air temperature, air velocity, composition of air including oxygen, carbon dioxide, moisture, noxious gases, irritating gases, dust, ion and biological, static electric fields, electromagnetic radiation, and noise as important factors to be monitored. Other studies showed electric and magnetic fields and ion were not important factors. Epidemiological research showed that there is no hard evidence of the harmful effects of the exposure to electric or magnetic fields (Everley, 1991). Another study showed that the use of negative ion in improving the indoor air quality is not conclusive (Daniell et al, 1991). There is still debate about the impact electric fields have on health. See, for example, an article on the effect of electric/magnetic field on cancer (Bennett, 1994) and the response letters (Physics Today, 1995).

Roe (1990) identified respirable particles, house dust, mite excreta, biological including fungal spores, bacteria and allergen, radon, carbon monoxide, ozone and nitrogen dioxide gases, formaldehyde, VOCs, nicotine, and aldehydes as medically important pollutants in homes and offices.

Major airborne pollutants that affect health according to Hansen (1991) may be divided into two groups: particles and vapour/gases. The particles include respirable particles of sizes not greater than 10 microns, tobacco smoke, asbestos fibres, allergen, and pathogen. The allergen are pollen, fungi, mould spores, insects parts, and faeces. The pathogen are bacteria and viruses. Vapour and gases that affect health are carbon monoxide, formaldehyde, VOCs, nitrogen oxide, nitrogen dioxide, and radon. In the United Kingdom average radon levels are low in comparison with estimated world standard. The average indoor radon level in England is 21 becquerel per square metre and the estimated world average is 40 becquerel per square metre (Occupational Safety and Health, 1992).

Although the effect of traditional parameters in physical environment such as thermal, visual, and aural comfort are well understood the parameters are sometimes monitored in the assessment of health problems in buildings. The reason is to know if the problems are caused by those parameters rather than the factors to be uncovered by the building sickness research. Besides monitoring hazardous gases and particles, Yeung et al (1991), in assessing health problem in buildings, also monitored noise, illumination, and thermal levels.

Since this is a problem-solving research, the relevant factors should be selected from existing medical evidence which shows that the factors do cause health problems. Physical measurements should be conducted in the problem areas to assess whether or not any of the above factors cause the complaint.

The subsequent discussion of these factors consists of four sections:

1) hazardous particles (Section 3.4);
2) hazardous gases (Section 3.5);
3) unit and standard conditions in the measurement of health hazards (Section 3.6);
4) conclusion (Section 3.7).

3.4 HAZARDOUS PARTICLES

This section begins with a description of the terminology associated with particulates. The way the particulate become health hazards is explained followed by a description of the effect of particulates on the lung and its defence mechanism. This section ends with a discussion on the current standards regulating hazardous particles.

According to Hansen (1991) the hazardous particles include respirable particles of sizes not greater than 10 micron, tobacco smoke, asbestos fibres, allergen, and pathogen. The allergen are pollen, fungi, mould spores, insects parts, and faeces. The pathogen are bacteria and viruses.

The subsequent discussion of hazardous particles consists of three sections:

1) definition and terminology (Section 3.4.1);
2) health hazards of particles (Section 3.4.2);
3) standards on hazardous particles (Section 3.4.3).

3.4.1 Definition and Terminology

In describing the hazardous particles in buildings the terms `particulate', `viable' and `non-viable particulate', `aerosols', `respirable particulate matter' (RPM), and `total suspended particulate matter' (TPM) are commonly used. `Particulate' is defined by Stoker and Seager (1976) as small solid particles and liquid droplets except pure water. Living particulate is called `viable' and the non- living particulate is called `non-viable'. Particulate in air is known as `aerosol' which is defined by Stoker and Seager (1976) as dispersions of solids or liquids in a gaseous medium.

Particle size may refer to its equivalent aerodynamic diameter in free-fall or its cut-off size in impaction. According to Calvert and Englund (1984) particle is normally assumed to be spherical in shape and its size normally refers to its diameter. According to the United Nations (1979) particle size normally refers to its aerodynamic equivalent diameter. In other words, a particle having any shape is assigned a diameter equal to the diameter of a spherical particle having the same weight. Size sometimes refers to specific unit such as 50 percent cut-off impaction size. The concept of 50 percent impaction cut-off size is elaborated in Chapter 4.

The particulate of medical concern is generally within the RPM's size range. This includes small dust, environmental tobacco smoke, and bioaerosols. According to World Health Organisation, particles that have the greatest effect on human health are of sizes between 0.01 to 10 micron (United Nations, 1979). `Dust' is solid particles smaller than 100 micron projected into air by natural forces, such as wind, or mechanical forces such as sweeping (ASHRAE, 1993). The RPM of sizes less than 3 micron is produced principally by vapour condensation and agglomeration of Aitken nuclei of sizes less than 0.1 micron (Yocom and McCarthy, 1991). `Environmental tobacco smoke' is a suspension of small liquid particles of sizes between 0.01 to 1.0 micron that formed as the superheated vapours leaving the burning tobacco condense (ASHRAE, 1993). `Bioaerosols' are airborne viruses, bacteria, pollen, and fungus spores. Viruses range in size from 0.003 to 0.06 micron. Normally they form colonies or are attached to other particles. Most bacteria range in sizes from 0.4 to 5 micron and also are usually attached to large particles. Fungus spores are usually from 10 to 30 micron in size. Most common pollen grains are from 20 to 40 micron in size.

In terms of size, RPM refers to particulate matter less than 10 micron. PM10 is the RPM with 50 percent cut-off size of 10 micron. `Total suspended particulate matter' (TSP) refers to particulates with a broader size range than RPM. Under most conditions the 50 percent cut-off size of TSP is 30 micron. Dust refers to particulates with a broader size range than TSP; its size is up to 100 micron.

The physical characteristics of RPM and TSP are different. RPM exists in suspension or behaves like gas molecules. Small RPM of sizes less than 0.1 micron travels in Brownian Movement and therefore behaves quite similar to gas molecules. Medium RPM between 0.1 to 1 micron has but negligible settling velocity due to natural air current. Large RPM between 1 to 10 micron settles in still air but normal air currents keep it in suspension for appreciable periods. The particles exceeding RPM sizes, greater than 10 micron, settles fairly rapidly. Therefore, it is found near its source or under strong wind.

3.4.2 Health Hazards of Particles

Particles become a hazard in three ways (Fisk et al, 1987). Firstly, it may be intrinsically a hazard due to its chemical or physical characteristics. Secondly, it may be a carrier of an adsorbed hazardous substance. Thirdly, it may be a highly efficient adsorbers of hazardous organic and inorganic compounds. Although the concentration of VOCs in the air is very low, carbon particles, as an example, may carry a relatively dangerous concentration of the VOCs deep into the lungs.

Particles of sizes larger than between 8 to 10 micron is believed to be retained in the upper respiratory tract which consists of nasal cavity, pharynx, and trachea. Smaller particles of sizes between 2 to 8 or 10 micron is believed to be swallowed or coughed out. In their description on the nature of cough, Lippold and Cogdell (1991) mentions that cough occurs when sensory endings in the respiratory tract, especially in the larynx and bifurcation of the trachea, are irritated chemically or mechanically. The cough sends a rapid blast of expired air which sweeps the particles out of the respiratory tract. Therefore, industrial hygienists are concerned with particles of sizes less than 2 micron (ASHRAE, 1993). Particles of that size may enter the lower respiratory tract which consists of bronchi and lung. However, Duffus (1980) believes that smaller particles up to 5 micron may pass beyond the upper respiratory tract. The particles between 0.5 to 5 micron is believed to reach the bronchioles. In the bronchioles it will be removed by the ciliary action of the pharynx and then be eliminated through the gastrointestinal tract by swallowing. This will cause the ciliary beat to become slow and inhibit the removal of harmful substance in the mucous flow. Consequently illness such as bronchitis may occur. Meanwhile the particles smaller than 0.5 micron will reach the alveoli. Since alveoli does not have cilia, the particles will be retained for several years. But Ariens et al (1976) argue that finer particles is trapped in turbulent air and therefore is exhaled.

3.4.3 Standards on Hazardous Particles

The Health and Safety Executive Standard is 10 milligram per cubic metre for total inhalable dust and 5 milligram per cubic metre for respirable dust (Health and Safety Executive, 1990). Purnell and IRS Staff (1987) elaborates the meaning of total inhalable dust and respirable dust used by the Health and Safety Executive. Also known as inspirable, inhalable and total, the total inhalable dust is the acutely toxic dust which can enter through the nose and mouth. Respirable dust is the dust, between 0.5 to 7 micron, fine enough to reach the deepest parts of the respiratory system, be deposited and have biological effect there. Respirable and inhalable dust are not defined consistently by different researchers. Yocom and McCarthy (1991) refer to particulates smaller than 10 micron as inhalable and those smaller than 3 micron as respirable. Collison and Baum (1992) refer to the total inhalable particle as dust smaller than 100 micron and the respirable particle as dust smaller than 7 micron.

Other researchers have taken a limit of about one-tenth of the limit set by the Health and Safety Executive. The Japanese standard for dust is 0.15 milligram per cubic metre (150 microgram per cubic metre)(Potter, 1988). The Canadian guidelines for residential indoor is 0.10 milligram per cubic metre (ASHRAE Standard 62-1989).

Microbial contamination is rarely the cause of office building problems; if it occurs, it is due to water damage to carpet or due to standing water in heating, ventilating, and air conditioning system (Godish, 1989).

3.5 HAZARDOUS GASES

In terms of health effect, VOCs may be important hazardous gases. Other hazardous gases are carbon dioxide, carbon monoxide, nitrogen oxide, nitrogen dioxide, ozone, and radon. Carbon dioxide although not normally a health problem in building is however a good indicator of dilution level.

The subsequent discussion consists of two sections: organic and inorganic gases.

3.5.1 Organic Gases (VOCs)

This section begins by arguing that VOCs are the most important airborne pollutants relevant to health problems in buildings. Then the synonyms and the chemistry of VOCs are briefly described. The three major works on the identification of VOCs commonly found in the indoor and are medically important are then discussed. The health effects of some individual VOC is first discussed followed by their joint effects. The problem of finding a standard VOC representing the numerous VOCs and cross-checking the recommended limit are highlighted at the end of this section.

VOCs are considered as very important in the assessment of health hazards for two reasons:

1) they cause symptoms commonly associated with building sickness such as mucous membrane irritation, fatigue, and difficulty in concentrating (Girman, 1989).

2) some of the toxic VOCs commonly found in an office environment may cause death at low concentration if their potentiator exists. For example, individually, benzene at a concentration of about 10 ppm may be toxic to blood cell forming tissue in the bone marrow (Ray, 1992). Due to limited knowledge on interaction of VOCs, it cannot be ruled out at this stage that benzene, which exists at a concentration commonly found indoors, may damage the bone marrow and consequently cause anaemia. Theoretically, the existence of a potentiator, even at an extremely low concentration, may enhance drastically the toxicity of a relatively low concentration of benzene.

The subsequent discussion on VOCs consists of six sections:

1) definition and terminology (Section 3.5.1.1);
2) medically important VOCs (Section 3.5.1.2);
3) medical effects of some individual VOCs (Section 3.5.1.3);
4) joint effects of VOCs (Section 3.5.1.4);
5) the standard chemical to be used as a measure of the TVOC (Section 3.5.1.5);
6) recommended concentration (Section 3.5.1.6).

3.5.1.1 Definition and Terminology

In indoor pollution studies, VOCs, hydrocarbon, and organics are synonyms. In its strict definition, organics are the compounds containing carbon and hydrogen only - commonly known as hydrocarbons - but the organics that are commonly referred to in pollution studies may also contain oxygen, nitrogen, chlorine, and fluorine (Warren Spring Laboratory, 1991). The hydrocarbon, as is used in environmental terms, is more precisely called VOCs (Brackley, 1988). The United States Environmental Protection Agency classified the organics as VOCs if at 25 degrees Celsius they have a saturated vapour pressure of not more than 0.1 mm Hg (Yocom and McCarty, 1991).

3.5.1.2 Medically Important VOCs

Numerous VOCs commonly found in the indoors are reported by several researchers. The list may be different from one researcher to the other. Although the link between individual or a combination of VOCs to health are not well understood, Kjaergaard et al (1991) identified twenty-two VOCs (see Appendix I) which they consider as most important to health and used them in their laboratory-type experiment on human being. In two experimental studies on human reaction to VOCs, they blended the twenty-two non-natural VOCs in preparing the artificial indoor air. The VOCs were selected based on those commonly found in the indoor in previous research.

Shah and Singh (1988) identify thirty-five VOCs which they considered as most important based on the Environmental Protection Agency database on natural VOCs in residential and commercial (non-industrial) buildings. (See Appendix II). From 52,810 records in thirty cities and sixteen states in the United States of America, sixty-six VOCs were found in the indoor. About 98 percent of the records were taken from 1981 to 1984. About 90 percent of the records were taken in the State of California and the State of New Jersey. More than 95 percent of the records contained the data of one to twenty-four sampling periods. Based on their known mutagenic and toxic properties, the thirty-five VOCs are identified as important.

The VOCs which are usually detected in all office buildings are toluene, tetrachloroethane, trichloroethane, benzene, methylene chloride, propanol, chloroform, butyl acetate, acetaldehyde, acetone, cyclohexane, ethyl acetate, dioxane, heptane, hexane, methyl cyclohexane, octane, styrene, freon, and 1,1,1-trichloroethane (Bayer and Black, 1987). A more comprehensive list of the VOCs in the indoor was prepared by Dawidowicz et al (1988)(see Appendix III).

Many sources of VOCs exist in offices. They include dry cleaned clothes, cosmetics, air deodorisers, felt markers, detergents, adhesives, particle-board, floor wax, carpets, and carbonless copy paper. Girman (1989) quoted the rate of emission of VOCs from bioeffluents. The rate of emission of acetone is 50.7 milligram per day per person, acetaldehyde 6.2, ethyl acetate 25.4, ethyl alcohol 44.7, methyl alcohol 74.4, and toluene 7.4 milligram per day per person. Otson and Fellin (1992) published the rate of emission of dry clean cloth and glued carpet. Dry cleaned cloth may emit tetracholoethylene at a rate of between 0.5 to 1 milligram per square metre per hour. Glued carpet may emit n-undecane and n-decane each at a rate of between 0.5 milligram per square metre per hour.

3.5.1.3 Medical Effect of Some Individual Organic Compounds

The medical effect of some individual VOCs in the indoor is reviewed in this section. But the discussion is given in the next section when the joint effects of VOCs is discussed. The medical effect of benzene, toluene, ethylene, n-hexane, 2-butanone, and 1,1,1-trichloroethane is discussed by Ray (1992). The medical effect of formaldehyde is discussed by Fisk et al (1987). The meaning of their medical effects may be found in a medical dictionary, for example Harvard (1990).

Threshold Limit Value refers to airborne concentration of a substance and represents conditions under which the American Conference of Governmental Industrial Hygienists believes that nearly all workers may be repeatedly exposed day after day without adverse health effects (Lisella ,1994).

<u>Benzene</u>

The Threshold Limit Value of benzene is set at 10 ppm (32 milligram per cubic metre). At this level unusual toxic action occurs on the tissue in the bone marrow which forms white blood cell. At 20,000 ppm (64,000 milligram per cubic metre) it can cause death to a human being within 5-10 minutes of exposure. Even at a lower level of between 94 to 188 ppm (300 to 600 milligram per cubic metre) benzene can cause death by bone-marrow toxicity. Under this condition the bone marrow could not generate red blood corpuscles. The disease, in which the red blood corpuscles are greatly reduced but the bone marrow do not attempt to generate them, is known as aplastic anaemia.

<u>Toluene</u>

The Threshold Limit Value of toluene is 100 ppm (377 milligram per cubic metre). The existence of toluene is detectable by human beings at 2.65 ppm (10 milligram per cubic metre). At between 50 to 200 ppm (200 to 750 milligram per cubic metre) toluene causes CNS (central nervous system) depression, headache and fatigue. Weakness and confusion occur at between 200 to 300 ppm (750 to 1130 milligram per cubic metre). Reversible encephalopathy and cerebellar atrophy leading to irreversible ataxia occur at between 212 and 663 ppm (800 to 2500 milligram per cubic metre). Ataxia is the loss of co-ordination though the power necessary to make the movements is still present. An injury or irritation to the cerebellum, the part of the brain which is responsible for the refinement and modification of movement, may result in the loss of balance, a staggering gait, and generalised weaknesses. The injury, in this case, is due to atrophy in which the healthy nutrient does not reach the cerebellum. Irritation to the cerebellum is known as encephalopathy. Exposure to a higher concentration of toluene between 1,988 to 3,260 ppm (7,500 to 12,300 milligram per cubic metre) can cause death within one-half of an hour.

Ethylbenzene

The Threshold Limit Value of ethylbenzene is 100 ppm (434 milligram per cubic metre). At 989 ppm (4,300 milligram per cubic metre) ethylbenzene causes irritation to the eye and throat. CNS depression occurs at 2,001 ppm (8,700 milligram per cubic metre).

n-hexane

The Threshold Limit Value of n-hexane is 50 ppm (176 milligram per cubic metre). No irritation occurs at a concentration as high as 511 ppm (1,800 milligram per cubic metre). CNS depression in the form of dizziness begins to occur at 5,112 ppm (18,000 milligram per cubic metre). If a human being is exposed over several months to a concentration between 511 to 2,556 ppm (1,800-9,000 milligram per cubic metre) human neuropathies occur. Human neuropathies also occur at a lower concentration between 241 to 474 ppm (850 to 1,670 milligram per cubic metre) if exposed over several years.

2-butanone

2-butanone has no neuropathic potential itself but it is a potentiator for n-hexane. Slight nose and throat irritation occur at between 300 to 509 ppm (885 to 1,500 milligram per cubic metre). Mild sedation occurs at a concentration between 305 and 610 ppm (900 to 1,800 milligram per cubic metre). Narcosis, a condition of deep insensitivity resembling sleep, occurs at 800 ppm (2,360 milligram per cubic metre).

1,1,1-trichloroethane

The Threshold Limit Value of 1,1,1-trichloroethane is 350 ppm (1,910 milligram per cubic metre). At 494 ppm (2,700 milligram per cubic metre) no adverse effect occurs except transient light headedness and mild sedation. Its unpleasant odour is detected at a concentration of 1,007 ppm (5,500 milligram per cubic metre). Loss of co-ordination occurs at 915 ppm (5,000 milligram per cubic metre)

Formaldehyde

People vary widely in their subjective reaction and response to formaldehyde. The effect of formaldehyde to human being is reviewed by Fisk et al (1987). The odour of formaldehyde may be detectable at 0.05 ppm. Burning of the eyes and irritation of upper respiratory passage occur at between 0.05 to 0.5 ppm. Normally odour threshold occurs at 1 ppm.

The Maximum Exposure Limit, set by Health and Safety Executive, for formaldehyde is 2 ppm (Health and Safety Executive, 1990). This limit is more suitable for industrial environment. The American Conference of Governmental Industrial Hygienists standard is 2 ppm for short-term exposure and 1 ppm for long-term exposure (ASHRAE Standard 62-1989). In some American homes the concentration of formaldehyde is limited to only one-fifth of the limit set by the Health and Safety Executive. The limit for the indoor in Minnesota State and some manufactured homes in the United States of America is 0.4 ppm (ASHRAE Standard 62-1989). However, the American standard is higher than the WHO Concentration of Concern of 0.10 ppm (0.12 milligram per cubic metre) (Potter, 1988). Scandinavian countries set the limit around the WHO Concentration of Concern. The limit in Germany and Netherlands is 0.10 ppm (0.12 milligram per cubic metre) and in Sweden it is 0.08 ppm (0.10 milligram per cubic metre) (Sykes, 1988).

The link between formaldehyde and building sickness is controversial (Sykes, 1988).

3.5.1.4 Joint Effects of VOCs

The symptoms of building sickness are elaborated in Chapter 2. It is unlikely that individual VOCs causes the symptoms of building sickness in offices. The reason is that the concentration of individual VOCs in offices is well below the concentration which causes the symptoms of building sickness. Kjaergaard et al (1991) quoted the highest expected concentration of total volatile organic compounds (TVOC) in new buildings as 25 milligram per cubic metre. As discussed earlier, for the symptom of building sickness to occur, at least 200 milligram per cubic metre of toluene or 18,000 milligram per cubic metre of n-hexane, for example, should exist individually.

According to Feron et al (1992) the health effects of the mixture of VOCs are not only determined by the individual VOC but also by the possible interaction between them. Although knowledge is limited, the basic principles governing the possible joint effect of a mixture of chemicals are discussed at length in many textbooks on clinical toxicology, for example Gossel and Bricker (1990) and Grosselin et al (1984). A particular VOC may not have an adverse effect on health but its existence may potentiate a toxic VOC which exists in an extremely low concentration. Similarly two toxic VOCs may each exists at an extremely low concentration. An example of a potentiator is methylethylketone which potentiates n- hexane, a VOC which may cause dizziness (Ray, 1992). Acting together the VOCs cause symptoms commonly associated with building sickness such as mucous membrane irritation, fatigue, and difficulty in concentrating (Girman, 1989).

According to Weetman (1994), there is virtually no reliable information about the effects on human health of the mixture of VOCs normally found in the indoor. However, Molhave (1986) believes that the building sickness symptoms are more related to the total mixture of VOCs rather than individual VOC (Lunau, 1992). The symptoms are believed to be not reduced by reducing any of the individual components.

3.5.1.5 The Standard Representative Chemical to be Used as a Measure of the Total Volatile Organic Compounds (TVOC)

Three chemicals are used as the standard for TVOC, namely methane (Shaw et al, 1991), toluene (Skov et al, 1990; Lunau, 1992), and pentadecane (Skov et al, 1990). TVOC is a developing concept, therefore there is no standard measurement (Grot, 1991).

Although methane is used earlier (Shaw et al, 1991), it is not based on infra-red spectrometry technique. Methane seemed to be more established than toluene and pentadecane as the standard for VOCs. A calibration curve for converting the concentration of methane to the total concentration of VOCs was prepared by Shaw et al (1991).

The principle by which methane may be used to estimate the total concentration of VOCs in ambient air is discussed by Harrison (1990). In the flame ionisation analyser the air sample becomes the oxidant in air/hydrogen flame ionisation detector. The presence of VOCs enhances the conductivity of the flame. The sensitivity per carbon atom in the VOCs is almost constant. However, the presence of oxygen and halogen atoms in the VOCs reduces this sensitivity.

Methane is used for comparison since it has only one carbon atom. As stated earlier, the sensitivity of VOCs in the air sample to the flame ionisation analyser depends on the number of carbon atoms in those VOCs. The concentration of VOCs is expressed as ppb C (part per billion Carbon). Since methane has only one carbon atom its concentration is taken as unity. The concentration of other VOCs is expressed in this basic unit. For example, 0.5 ppb of ethane is equivalent to 1 ppb C and 0.25 ppb of butane is equivalent to 1 ppb C.

In this thesis the author used methane as the representative chemical of the TVOC. The justification of this chemical is described in detail in Section 4.5.2.9.

3.5.1.6 Recommended Concentration

Due to different standard chemicals used in calibration, the limit recommended for total concentration of VOCs as recommended by different authors may not be compared to each other. Recommended limits reported are 0.3 milligram per cubic metre (Seifert, 1990), 1 milligram per cubic metre (Tucker, 1988), and 5 milligram per cubic metre (Molhave et al, 1986). A study in Australia recommends a limit of 0.5 milligram per cubic metre provided that no single VOC contributes up to fifty percent of the total concentration (Dingle and Murray, 1993).

3.5.2 Inorganic Gases

In this section the inorganic gases contributing to health problems is discussed. The discussion includes the regulating standards and recommended limits of some of them. The gases are carbon dioxide, carbon monoxide, radon, and ozone. Carbon dioxide and carbon monoxide are argued to be the most important in this study.

Carbon Dioxide

Although carbon dioxide in itself is not a hazardous gas, many researchers feel its concentration should be monitored since it is considered as an indicator of dilution of airborne pollutants (Sykes, 1988; Dawidowicz et al, 1988)

The effect of carbon dioxide on human beings is reviewed by Fisk et al (1987). A concentration of less than 5,000 ppm causes no known biochemical or other effects. At a concentration between 5,000 to 30,000 ppm carbon dioxide causes adaptive biochemical changes which may be considered as a mild physiological strain. At greater than 30,000 ppm carbon dioxide can cause pathological changes in basic physiological functions.

Although human beings can tolerate such a high concentration, several authors have recommended lower concentrations because of indirect health issues associated with poor dilution. According to Tong (1991) discomforts begins at 1,000 ppm. A lower concentration is quoted by Potter (1988). At 800 ppm only 95 percent of office occupants and visitors reported it to be acceptable. Potter then suggests a limit between 500 to 600 ppm.

The Occupational Exposure Standard (OES) approved by the Health and Safety Executive is 5,000 ppm for long-term exposure and 15,000 ppm for short-term exposure (Health and Safety Executive, 1990). Although the Health and Safety Executive limit is more strict than the WHO Concentration of Concern, it is far below some standards. The World Health Authority's Concentration of Concern is 6,668 ppm (12,000 milligram per cubic metre) (Potter, 1988). The Canadian guidelines for residential indoor is 3,500 ppm (ASHRAE Standard 62-1989). According to ASHRAE Standard 62-1989, The Japanese standard is 1,000 ppm (1,800 milligram per cubic metre). The limit of 1,000 ppm is also adopted by the Swedish National Board of Health and Welfare (Johnson et al, 1991).

Carbon Monoxide

Although carbon monoxide rarely causes concern, it is also considered as a dilution indicator (Dawidowicz et al, 1988). Other than by smoking, carbon monoxide is rarely generated in offices. However, the carbon monoxide generated by vehicles or boiler at other parts of the buildings may get into office space via lift ducts or service risers due to negative pressures sometimes created by the wind. A relatively high concentration of carbon monoxide may be generated in the carpark area when most office workers arrive in the morning and leave in the evening at about the same time.

Carbon monoxide is a chemical asphyxiant, a material that deprives the body of oxygen. The effect of carbon monoxide on human beings is reviewed by Fisk et al (1987). Since the affinity of haemoglobin for carbon monoxide is more than 200 times that of oxygen, carbon monoxide reduces the oxygen- carrying capacity of the blood. In an experiment, exposure of carbon monoxide to non-smokers at 50 ppm for 90 minutes impaired their discrimination of time intervals. This concentration is equivalent to an exposure of between 10 to 15 ppm for 8 hours.

The Health and Safety Executive approves 50 ppm as the long- term Occupational Exposure Standard (OES) for carbon monoxide (Health and Safety Executive, 1990). For short-term exposure the OES is 300 ppm. The Canadian exposure limit is about one-fifth of this value. The Canadian guidelines for residential indoor is 11 ppm for long-term exposure and 25 ppm for short-term exposure (ASHRAE Standard 62-1989). This limit is higher than the WHO Concentration of Concern which is 4.4 ppm (5.0 milligram per cubic metre)(Potter, 1988).

Radon

Radon is site dependent. None of the buildings studied are in the area known to have high radon emission. It is included only for the sake of completion. A report on radon in dwellings in England shows that the most affected area are Cornwall and Devon followed by Derbyshire, Northamptonshire, and Somerset (Occupational Safety and Health, 1992). However, geological conditions only may not be used in predicting radon gas in the indoor. The reason is that Uranium-238, the major parent element in the uranium decay chain, is not distributed in any simple way with geological condition (Yocom and McCarthy, 1991).

The chemistry of radon is well covered in literature (Berger, 1990; Nazaroff and Teichman, 1990; Yocom and McCarthy, 1991). Radon is an inert gas (boiling point -61.8 degree Celsius). Not generated by the occupants, indoor radon is a naturally occurring product in the uranium decay chain. Uranium-238 and Radium-226, two of the isotopes in the uranium decay chain, exist in most soils and rocks.

It is generally accepted that soil gas is the predominant source of radon in the indoor although earth-based building materials may also be its sources. Granite, shales and phosphates containing soils in the United States of America and alum shale in Sweden are reported as sources of radon.

The effect of indoor radon on human beings is reviewed by Yocom and McCarthy (1991) and Berger (1990). The most important decay product to human health in the uranium decay chain is Radon-222. As stated previously, radon itself is not a health hazard but the first four of its decay products, Polonium-218, Lead-214, Bismuth-214, and Polonium- 214, are important sources of human cancer.

The lungs, especially at the tracheo-bronchial tree, are considered as the primary target organ of radon. During the decay process the radon decay products become electrically charged. They become attached to water molecules, gas molecules such as oxygen, and aerosol particles. The airborne dust particles then stick to the moist epithelial lining of the bronchi and remain there until the lung clearance mechanism removes them.

The most significant dose of radon comes from Polonium-218 isotopes which has a half-life of 3 minutes. The duration is long enough for the electrically charged Polonium-218 atoms to become attached to airborne dust particles, gases, and water vapour and be inhaled. However, the half-life is not long enough for the lung clearance mechanism to remove them. At the bronchi the Polonium-218 emits alpha radiation which may cause cancer.

In comparison with the unattached, the attached decay products are more dangerous. First, being attached to the inhalable aerosol and gases, the decay products are more efficiently deposited in the lungs than those unattached. Second, they are more concentrated in the relatively small volume of bronchial epithelium. Therefore, a relatively large radiation doses per unit volume are emitted there.

Ozone

Although it is highly unstable and easily reverts back to oxygen, ozone is important to the study of office buildings because it is generated by high voltage equipment, fluorescent lamps, photocopier, and laser printers which are commonly found and continuously used in office buildings. Ozone is also important to the study of building sickness because, according to Smith (1992), high ozone levels are associated with increase asthmatic attack. Some researchers argue that ozone is not important (Potter, 1988) because it is highly reactive and decays very rapidly, half-life in the order of minutes.

Tong (1991) recommends a limit of 0.1 ppm for 8 hours exposure and 0.3 ppm for 15 minutes exposure be used. The WHO Concentration of Concern is 0.08 milligram per cubic metre (Potter, 1988).

Nitrogen Oxide and Nitrogen Dioxide.

Although normally there is no indoor combustion which contributes nitrogen dioxide in offices except smoking, like carbon monoxide, it may get into office spaces via cross-contamination.

3.6 UNITS AND STANDARD CONDITIONS IN THE MEASUREMENT OF HEALTH HAZARDS

Toxic gases are normally expressed in ppm as well as milligram per cubic metre. The former is independent of temperature and air pressure but the latter is dependent. The standard conditions for the toxic gases measurement used by the Health and Safety Executive, are 25 degrees Celsius and 1 bar (Health and Safety Executive, 1990). Most of the measurements use the standard atmospheric pressure at sea level (760 millimetre

Hg) as the standard atmospheric pressure (ASHRAE Standard 62-1989). Dust is normally expressed in milligram per cubic metre.

3.7 CONCLUSION

Respirable particulate, TVOC, carbon dioxide and carbon monoxide are the four important pollutants to be investigated. It is unlikely that any of the individual VOCs causes building sickness symptoms. The net concentration of VOCs is more relevant to the assessment than the concentration of individual VOCs. The major problem in the assessment of VOCs is in finding a suitable representative VOC for cross-checking with the findings of other researchers.

3.8 REFERENCES

1. Ariens, E. J. et al (1976) Introduction to General Toxicology. London: Academic Press

2. ASHRAE (1993). ASHRAE Handbook 1993 Fundamentals. Chapter 11, `Air Contaminants'. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.

3. ASHRAE Standard 62-1989. Ventilation for Acceptable Indoor Air Quality. Atlanta, Georgia: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.

4. Bayer, C. W. and Black, M. S. (1988). `IAQ Evaluations of Three Office Buildings', ASHRAE Journal, Jul. 1988, pp48- 53

5. Berger, R. S. (1990). `The Carcinogenicity of Radon'. Environmental Science Technology, Vol. 24, No.1, 1990, p30.

6. Brackley, P. (1988). Energy and Environmental Terms: A Glossary.. Aldershot, Gower

7. Calvert, J. and Englund, H. M. (ed.) (1984). Handbook of Air Pollution Technology. Chichester: John Wiley & Sons.

8. Collison, J. and Baum J. (1992). `Taking the air', Occupational Safety & Health, 1991, pp37

9. Daniell, W. et al (1991). 'Trial of a Negative Ion Generator Device in Remediating Problems Related to Indoor Air Quality', Journal of Occupational Medicine, Vol. 33, No. 6, June 1991, pp681-687

10. Dawidowicz, N. et al (1988) The Healthy Building. Swedish Council for Building Research, Stockholm, 1988

11. Dingle, P. and Murray, F. (1993). `Control and Regulation of Indoor Air: An Australian Perspective', Indoor Environment, 1993, Vol. 2, pp217-220.

12. Duffus, J. H. (1980) Environmental Toxicology. London: Edward Arnold, 1980

13. Everley, M. (1991).'Electric and Magnetic Fields and Cancer'. Occupational Health Review. No. 31, pp17-20

14. Feron, V. J. et al (1992). `Toxicology of Volatile Organic Compounds in Indoor Air and Strategy for Further Research', Indoor Environment, Vol. 1, 1992, pp69-81

15. Fisk et al (1987). Indoor Air Quality Control Techniques. New Jersey, USA: Noyes Data Corporation

16. Foort de Roo (1988). `Master plan of interrelations between indoor environmental parameters'. in Berglund, B. & Lindvall, T. Healthy Buildings. Vol. 2. Planning Physical & Climate Technology for Healthier Buildings. Swedish Council for Building Research, Stockholm, Sweden

17. Girman, J. R. (1989). Occupational Medicine: State of Art Review. in Cone, J.E. and Hodgson, M.J. (eds.) 4:695- 712. Philadelphia, USA: Hanley and Belfus, Inc.

18. Godish, T. (1989). Indoor Air Pollution Control. Michigan: Lewis Publishers Inc., 1989

19. Gossel, T. A. and Bricker, J. D.(1990) Principles of Clinical Toxicology. 2nd Ed. New York: Raven Press, 1990

20. Grosselin, R. E. et al (1984). Clinical Toxicology of Commercial Products. 5th Ed. London: Williams & Wilkins, 1984

21. Grot, R. A. et al (1991). `Indoor Air Quality Evaluation of A New Office Building'. ASHRAE Journal, Sep. 1991, pp16- 25

22. Hansen, S. J. (1991). Managing Indoor Air Quality. Georgia, USA: The Fairmont Press, Inc.

23. Harrison, R. M. (1990). `Important Air Pollutants and Their Chemical Analysis', in Harrison, R. M. (ed.) Pollution: Causes, Effects and Control, Royal Society of Chemistry, Second Edition, pp127-155.

24. Harvard, C. W. H. (1990). Black's Medical Dictionary. 36th ed. London: A & C Black, 1990

25. Health and Safety Executive (1990). Occupational Exposure Limits. Guidance Note EH 40/90.

26. Hesketh, H. E. (1974). Understanding and Controlling Air Pollution. Ann Arbor: Ann Arbor Science.

27. Johnson, B. G. et al (1991). Buildings and Health: Indoor Climate and Effective Energy Use. Stockholm: Swedish Council for Building Research

28. Kjaergaard, S. K. et al (1991). 'Human Reactions to a Mixture of Indoor Air Volatile Organic Compounds in Atmospheric Environment', in Atmospheric Environment, Vol. 25A, No. 8, pp1417-1426

29. Lippold, O. and Cogdell, B. (1991). Physiology Illustrated. London: Edward Arnold.

30. Lunau, F. W. (1992). `The Perception of Indoor Air Quality' in Leslie, G. B. and Lunau, F. W. Indoor Air Pollution: Problems and Priorities. Cambridge University Press

31. Molhave, L. et al (1986). `Human reactions to Low Concentrations of Volatile Organic Compounds.' Environ. Int. 12:167-175. in Godish, T. (1989). Indoor Air Pollution Control, Michigan: Lewis Publishers, Inc.

32. Nazaroff, W. W. and Teichman, K. (1990). `Indoor Radon'. Environmental Science Technology, Vol. 24, No. 6, pp774-782.

33. Occupational Safety and Health (1992). `Radon Report', Aug. 1992, p25

34. Otson, R. and Felin, P. (1992). `Volatile Organics in the Indoor Environment: Sources and Occurrence', in Nriagu, J. O. (ed.). Gaseous Pollutants: Characterization and Cycling. Chichester: John Wiley & Sons, Inc. pp335-421.

35. Potter, I. N. (1988). The Sick Building Syndrome. BSRIA Technical Note 4/88. Berkshire: The Building Services Research and Information Association

36. Potter, I. N. and Potter, P. D. R. (1991). Courtauld Galleries, The Strand: Measurement of Respirable Mass Concentrations. Report No. 67580 No. 1. Berkshire: The Building Services Research and Information Association

37. Purnell, C.J. and IRS Staff (1987). Occupational Health Review. No. 9, pp17-19

38. Ray, D. E. (1992). `Hazards from Solvents, Pesticides and PCBs' in Leslie, G. B. and Lunau, F. W. (ed.) Indoor Air Pollution: Problems and Priorities. Cambridge: Cambridge University Press

39. Roe, F. J. C. (1990). `Medical Aspects of Indoor Air Quality', in Lunau, F. and Reynolds, G. L. (ed.) Indoor Air Quality and Ventilation, London: Selper Ltd.

40. Seifert, B. (1990). 'Regulating indoor air'. Proceedings of Fifth International Conference on Indoor Air Quality and Climate. Vol. 5, pp. 35-49. Toronto, Canada in Grot, R. A. et al `Indoor air quality evaluation of a new office building'. ASHRAE Journal, Sep. 1991, p16-25

41. Shah, J. J. and Singh, H. B. (1988). `Distribution of Volatile Organic Chemicals in Outdoor and Indoor Air'. Environmental Science Technology, Vol. 22, No. 12, pp1381-1388.

42. Shaw, C. Y. et al (1991). `Indoor Air Quality Assessment in An Office-Library Building. Part I: Test Methods'. in ASHRAE Transaction 1991, Part 2, Vol. 97, pp129-135.

43. Skov et al (1990). `Influence of indoor climate on sick building syndrome in an office environment', Scan J Work Environ Health, 1990, Vol. 16, No. 5, pp363-371.

44. Smith, S. (1992). `Ecological and Health Effects of Chemical Pollution', in Harrison, R. M. (1992). (ed.). Understanding Our Environment: An Introduction to Environmental Chemistry and Pollution. Cambridge: Royal Society of Chemistry

45. Stoker, H. S. and Seager, S. L. (1976). Environmental Chemistry: Air and Water Pollution. 2nd Ed. Brighton, England: Scott Forman & Co.

46. Sykes, J. M. (1988). Sick Building Syndrome: A Review. Specialist Inspector Reports. Health and Safety Executive Technology Division. Report No. 10, June 1988

47. Tong, D. (1991). `Sick Buildings: What are They and What is Their Cause'. Facilities, Vol. 9, No. 7, 1991, pp9-17.

48. Tucker, G. (1988). 'Factors influencing indoor air pollutants originating from surface materials. In pre-prints of 'Healthy Buildings 88' Conference. Stockholm, Sweden: Swedish Council for Building Research. Grot, R.A. et al 'Indoor air quality evaluation of a new office building'. ASHRAE Journal, Sep. 1991, p16-25

49. United Nations (1979). Fine Particulate Pollution. Oxford: Pergamon Press.

50. Warner, P.O. (1976). Analysis of Air Pollutants. London: John Wiley & Sons

51. Warren Spring Laboratory (1991). Volatile Organic Compounds and Smells. Centre for Exploitation of Science and Technology.

52. Weetman, D. F. (1994). `Volatile Organic Chemicals in the Environment', Indoor Environment, 1994, Vol. 3, pp55-57.

53. Yeung, A. Y. N. et al (1991). 'Sick Building Syndrome - A Case Study'. Building And Environment, Vol. 26, No. 4, 1991, pp319-330

54. Yocom, J. E. and McCarthy, S. M. (1991). Measuring Indoor Air Quality: A Practical Guide. New York: John Wiley & Sons

Chapter 4
THE INSTRUMENTS FOR MONITORING

4.1 RESEARCH QUESTIONS

This chapter seeks to address the following seven research questions:

1) whether or not a particulate monitor using piezobalance is still appropriate to measure the particulate relevant to building sickness;
2) whether or not inorganic gases should be monitored;
3) which few of the inorganic gases are most relevant to building sickness;
4) which few of the VOCs in office indoors is most relevant to building sickness;
5) why several standards for VOCs are used;
6) which standard of VOCs is most appropriate to SERC/LINK project;
7) which instrument should be selected to measure gaseous pollutants.

4.2 SUMMARY

Two conclusions are made from the literature reviews on current development and trends to measure airborne pollutants. Firstly, light scattering is the latest technique for monitoring particulates. Secondly, although infra-red spectroscopy is the latest technique in monitoring hazardous gases, its application is limited to inorganic gases. For this research piezobalance is selected and justified instead of light scattering technique. Additionally infra-red spectroscopy is selected for monitoring VOCs despite controversies in justifying the selection, selecting the optical filter, and calibration standard.

4.3 INTRODUCTION

This chapter consists of three sections:

1) terminology and definitions (Section 4.4);

2) the instruments (Section 4.5); and
3) conclusion (Section 4.6).

This chapter begins by clarifying the meaning of terminology and definitions as they are used here. It is divided into two parts: how to measure particulates and VOCs. Part one begins with a literature review on current development in particulate monitoring technique, in which the limitation of the latest technique is identified. Then the selection of particulate monitor for this research is described. This is followed by a description on the working principle and a justification of the selection of the particulate monitor. Part two begins with a literature review on current developments and trends in monitoring hazardous gases followed by a discussion on the selection of the gas monitor for this research. This is followed by a description of the working principle of the gas monitor. Since the gas monitoring technique used in this research has never been used before and its use in this research is full of controversies, the main discussions in this chapter are devoted to justifying the selection of the monitor and explaining the process of selecting its optical filters. Besides the controversy in selecting the gas monitor and optical filters, there is also a controversy in the selection of a standard for calibration. The discussion on standard also begins with a literature review on existing standards and ends with a justification on the selected standard.

4.4 TERMINOLOGY AND DEFINITIONS

`Instrumentation', as it is used here, refers to both the technique and equipment involved in the monitoring. Based on the definition of World Health Organisation (1980), `monitoring', as it is used here, is defined as the repetitive and continued measurements of environmental data, such as the concentration of gases, in space and time using comparable methods for data collection. `Monitoring technique', as it is used here, refers to both the sampling and analytical techniques. In the monitoring of gases and particulates, `monitor' is the equipment which provides direct reading of the concentration of gases or particulates. `Sampler' is the equipment which collects a gas sample, for example Tenax sample, which must be analysed, for instance by gas chromatography.

4.5 THE INSTRUMENTS

The discussion on instruments is divided into two sections: the particulate monitor and the gas monitor.

4.5.1 The Particulate Monitor

This discussion is divided into four sub-sections:

1) literature review of particulate monitoring techniques (Section 4.5.1.1);
2) the particulate monitor for this research (Section 4.5.1.2);
3) working principle (Section 4.5.1.3); and
4) justification of selection (Section 4.5.1.4).

4.5.1.1 Literature Review of Particulate Monitoring Techniques

This literature review is aimed at finding the most up-to- date and practical instrumentation for monitoring particulates. Vesilind et al (1988) divide the development of monitoring instrumentation into three generations. The first-generation instrumentation is abandoned since they are no longer considered accurate. The limitation of second- generation instrumentation is that they could not provide continuous data. Although the third-generation instrumentation are capable of providing continuous data, the duration of continuous monitoring is limited since the particulate deposit has to be removed frequently.

Light scattering is probably the only practical technique used in the third-generation particulate monitors. Grot et al (1991) used a light-scattering particle counter in monitoring an office building. Here the concentration of the solid particulate is determined from the scattering of infra-red radiation when radiated onto the particulate. The major difficulty in continuous monitoring of solid particulate is to frequently clean the particulate deposit. Woskie et al (1994) reported their experience in using Miniran, a light-scattering particle counter, for a one calendar year environmental monitoring of a mine site. The monitor was cleaned, zero-checked and downloaded daily.

In this paragraph, the techniques used in the second- generation particulate monitors are described briefly. Two of the monitoring techniques used in the second-generation instrumentation are gravimetric and piezobalance. In both types of particulate monitoring, a known volume of air is passed through a sampling head by means of a pump. In the gravimetric technique, the sampling head consists of a filter. To determine the concentration of particulates in air, the filter is weighed before and after the air monitoring. The filter is normally made from a material which is stable in weight (Collison and Baum, 1992). Cellulose ester (Grimaldi et al, 1990), polyvinyl chloride (Goyer, 1990), glass fibre (Purnell and IRS Staff, 1987) and silver membrane (Purnell and IRS Staff, 1987) are some of the examples of the air monitor filters.

In the gravimetric technique, the particulate monitor monitors total suspended particulate instead of instantaneous concentration of the particulate. The concept of total suspended particulate is used in this case since the rate of the particulate deposited decreases with time. The decrease is due to the increasing thickness of particulates on the filter which consequently reduces air flow through the filter. For example, if the particulate monitor is left running for fifty minutes, the particulate collected over the first five minutes is less than that collected over the last five minutes. Therefore the total particulate collected during the entire fifty minutes of monitoring is less than ten times that collected during the first five minutes. Based on the same argument the total particulate collected during the entire fifty minutes of monitoring is more than ten times that collected during the last five minutes. A problem with all gravimetric technique is that it does not distinguish between particle sizes or number nor does it identify the nature of the particles.

In the piezobalance technique, the particulate is collected electrostatically onto a vibrating piezoelectric quartz crystal. The concentration of the particulate is determined from the change in the resonant frequency of the crystal. For accuracy, the piezobalance particulate monitor should not be used beyond the resonant frequency limit, the frequency at which the piezoelectric quartz crystal is recommended for cleaning.

This literature review suggests that for long monitoring duration, the scattering technique is no better than the piezobalance technique. Both techniques require periodic cleaning of the monitor.

4.5.1.2 The Particulate Monitor for This Research

As suggested in the above literature review, the piezobalance technique is selected for particulate monitoring. The particulate monitor is Model 8510 Piezobalance Respirable Aerosol Mass Monitor manufactured by TSI Inc. USA. The monitor, which carry a serial number 151 6-90, was installed with the piezoelectric quartz crystal number 3347.

4.5.1.3 Working Principle

The particulate monitor consists of two main components: the impactor and the precipitator. Particulate separation occurs at both components. Air from the inlet of the monitor is initially passed through the impactor which filters out the larger particulates. This is the first stage separation. The air containing smaller particulates is then passed through the precipitator which separates and collects the solid particulate remaining in the air. The solid particulate collected in this second stage separation is weighed by the piezobalance technique. The air then leaves the particulate monitor. The movement of air over the impactor and precipitator is maintained by means of a pump.

The impactor and the precipitator are described in detail below.

<u>a. Impactor</u>

An impactor consists of a nozzle and an impaction plate. The principle is that if a stream of air containing particulates is directed perpendicular to a plane, in this case the impaction plate, a partial separation due to centrifugal force will occur. Due to its relatively large centrifugal force, the larger particulate will collide with the impaction plate and remains there. The smaller particulate will be able to follow the air streamline.

The concept of fifty percent cut-off size (sometimes called cut-off diameter) is required to understand the separation of particulates at the impactor. The fifty percent cut-off size of the impactor of the monitor used in this research is 3.5 micron. Ideally all particulates above 3.5 micron will be collected on the impactor plane and all particulates below the cut-off diameter will follow the air stream to the precipitator. Practically only fifty percent of the particulate of 3.5 micron in diameter will be collected on the impactor and the other fifty percent will pass through the impactor, polarised, collected, and affect the resonant frequency of the quartz crystal.

b. Precipitator

The particulate that passed through the impactor is polarised for collection on a vibrating quartz crystal. The air containing particulates from the impactor is passed through a nozzle. In the centre of the nozzle, a needle is placed axially to the air stream. The needle is supplied with a high voltage so that a negative-polarity corona passes from its tip to the sensing crystal plate. Under this electrical condition the particulate are charged. The electric field causes the particulate to be collected on the quartz crystal. The particulate collected changes the resonant frequency of the crystal. From the change in resonant frequency the concentration for the particulate is determined.

4.5.1.4 Justification of Selection

The first consideration in using this particulate monitor is its availability. The second consideration is the compatibility between the size range of the monitor and the size range of the particulate to be measured. The range of the particles size that the above particulate monitor could measure is between 0.01 to 10 micron. In an investigation of health hazard problems in office buildings this range is considered justified for three reasons. Firstly, as noted in Chapter 3, this is the range considered by the World Health Organisation as having the greatest effect on human beings (United Nations, 1979). Secondly, the indoor concentration in a large number of buildings, including offices, in previous researches are reported to be between 0.1 to 0.5 mg/m3 (ASHRAE, 1993). Thirdly, the use of third-generation instrumentation seems to be no better than this particulate monitor. In principle, the third generation is preferred over the second-generation because the former is capable of providing continuous reading. This may not be true in this case. The monitoring period involved is relatively long during which time particulate removal may be required.

4.5.2 The Gas Monitor

The subsequent discussion is divided into nine sections:

1) literature review of gaseous monitoring techniques (Section 4.5.2.1);
2) the gas monitor for this research (Section 4.5.2.2);
3) working principle (Section 4.5.2.3);
4) justification of the selection of gas monitor (Section 4.5.2.4);
5) the selected optical filters (Section 4.5.2.5);
6) justification of the optical filters (Section 4.5.2.6);
7) selection method (Section 4.5.2.7);
8) summary of judgement (Section 4.5.2.8); and
9) the standard for TVOC (Section 4.5.2.9).

4.5.2.1 Literature Review of Gaseous Monitoring Techniques

As described in the last section, Vesilind et al (1988) reviewed the development of air monitoring instrumentation. The analytical technique specifically used in indoor air quality studies is reviewed by Otson and Fellin (1992). The air monitoring instrumentation are divided into three generations. The first-generation instrumentation are considered obsolete. The second generation instrumentation are more established than the third-generation. The difference between the third and the second generation instrumentation is the third generation instrumentation are capable of producing continuous readout. In this research an instrument capable of producing continuous readout is a priority.

Second-generation instrumentation are widely used in monitoring hazardous gases in buildings. As described earlier, the limitation of second-generation instrumentation is they could not provide continuous reading. The most commonly used technique for monitoring VOCs in buildings is to collect the sample in the field and conduct the subsequent analysis in the laboratory (Yocom and McCarthy, 1991).

The VOCs in offices may be collected in inert gas bag, absorbed in a sorbent or bubbler. Tedlar bag may be used to collect the compounds (Yocom and McCarthy, 1991) and activated charcoal, silica gel, and porous polymer may be used as the sorbent or bubbler (Collison and Baum, 1992). Charcoal is used as the sorbent for VOCs by several researchers, for example Goyer (1990), Grot et al (1991), Molhave and Thorsen (1991), and Norback et al (1990). Wolkoff (1988), Skov et al (1990), and Weschler at al (1990) are some of the researchers who used Tenax as the sorbent for VOCs. Tenax is a porous polymeric resin 2,4-diphenyl-p- phenylene oxide (Clements and Lewis, 1988). The VOCs absorbed by the sorbent is taken to the laboratory where they are desorbed thermally or with a solvent and their identity and concentration determined.

As reported by Yocom and McCarthy (1991), the identity and concentration of VOCs may be determined by analytical techniques such as gas-chromatography with mass spectrometry (GC/MS), flame ionisation detection (FID), and electron capture detection (ECD). Flame ionisation detection was used by Wolkoff (1988). Mass spectrometry with flame ionisation detection was used by Rohbock et al(1988). GC/FID was used by several researchers, for example Norback et al (1990). The other analytical technique, GC/MS, was used by many researchers in this field including Morey and Jenkins (1989), Molhave and Thorsen (1991), Weschler et al (1990), and Grot et al (1987). But according to Harrison (1990) in determining TVOC, the analytical technique FID is the universal choice.

As can be seen from the above paragraphs, the use of second- generation instrumentation are well established in the monitoring of indoor air. The United States Department of Energy recommended gas chromatography for large buildings and steady state environment, and mass spectrometry for small buildings and dynamic environment (Hansen, 1991). Not only widely used and recommended for application in this field, according to Vesilind et al (1990), FID was also used as the Standard Environmental Protection Agency Reference Methods for Air Quality Measurement for TVOC.

Although less established, infra-red spectroscopy, the third-generation analytical technique, used in this research is sensitive and reliable. The US Environmental Protection Agency adopted it as one of the reference measurements for carbon monoxide (Yocom and McCarthy, 1991). Non-dispersive infra-red spectroscopy, the technique which is capable of producing continuous reading, is used by several researchers, for example Rohbock et al (1988) and Shaw et al (1991), in their measurement of carbon dioxide and carbon monoxide in buildings.

Two distinct trends could be seen from this literature review. First, despite the inconvenience, only laboratory- type analysis technique is used in sampling of VOCs in indoors. Second, in spite of its proven reliability and its ability for real-time analysis, infra-red spectroscopy is never used in monitoring VOCs.

4.5.2.2 The Gas Monitor for This Research

Although it seems to be less established in this research the application of infra-red spectroscopy technique for monitoring VOCs is tested. The Multi-Gas Monitor, Model 1302, serial number 1666685, manufactured by Bruer and Kjaer was selected for this study. The gas monitor uses infra-red spectroscopy and has a dimension of 175 mm X 395 mm X 300 mm. The gas monitor sampler has a memory of 64,000 bytes. In monitoring four gases at an interval of six minutes the monitor can store data up to eight and a half days.

4.5.2.3 Working Principle

The gas monitor is based on the principle of photoacoustic and infra-red spectroscopy. Infra-red spectroscopy is used to analyse the content of air sample. The gases in the air sample absorbs the infra-red radiation in proportion to their concentration. The radiation is transformed into heat and the heat generated is detected by means of a photo acoustic technique.

The air sample at the inlet is drawn by means of a pump to flush out all of the previous air in the system and to replace the previously used air sample in the measurement chamber cell a with new sample. Two air-filters are placed in the sampling line to remove particulates. The pumping time should be set properly to ensure only new air is in the system. Then both of the inlet and outlet valves to the analysis cell are hermetically sealed and the measurement chamber is irradiated with pulsed narrow-band infra- red radiation. The gases in the air sample absorbs the infra-red radiation in proportion to their concentration. The radiation is transformed into heat. As the radiation source is chopped the sampled air is heated and cooled sequentially. The temperature fluctuation causes expansion and contraction in the concealed gas chamber resulting in a sound wave which is detected by a microphone. Since the microphone used in the gas sampler is very sensitive, pressure in the analysis cell should not be more than 0.1 bar above the ambient.

Optical filters are automatically placed between the chopper and the measurement chamber. Only radiation of specified wavelengths is transmitted beyond the filter. The selection of the filters depend on the gas to be detected. The selection of the optical filter for VOCs is not straight forward but judgmental.

4.5.2.4 Justification of Selection of Gas Monitor

The gas monitor was selected for four reasons:

1) the selected gas monitor, measuring only 175 mm X 395 mm X 300 mm, is considered small and therefore suitable for this research. Since this research is part of the SERC/LINK research on the design of healthy office environment, many teams worked in the buildings. The mere existence of research workers of different teams is an intervention which may result in misleading findings. Therefore the use of small instrumentation is crucial to minimise further disturbance to office workers, office space and activities.

2) the selected monitor is capable of self-recording for a relatively long time. For example, if the monitoring interval is set at five minutes, the gas monitor can store the data of five monitored gases up to seven days and four hours. Again to minimise intervention, the equipment can be left unattended for a long time. If necessary the whole working days can be avoided. The researcher can set up the instrumentation on one weekend and download the data on the next weekend.

3) it was felt that the use of other common but more established techniques is more cumbersome and prone to human and technical error. Although it is more established, reliable, and widely used in indoor air quality studies, the gas chromatography technique was rejected since it requires off-the site laboratory analysis. Human and technical errors can occur during sampling, and moving and keeping the sample before the sample is analysed in the laboratory. Extra

precaution is necessary. The first precaution is during sample collection. The volume of air that passes through the sorbent should not exceed the breakthrough volume of the sorbent. As defined by Yocom and McCarthy (1991), breakthrough volume in this case refers to the volume of air sampled at which fifty percent of the VOCs entering the sampling sorbent is stripped off and is lost in the exit stream. This may be overcome by having more than one sorbent container connected in series. The second precaution is when the sample is in transit to the laboratory. Norback et al (1990) reported that to avoid desorption, the charcoal sorbent used for sampling air is kept below freezing, at -20 degrees Celsius, until the sample is analysed in the laboratory.

4) the specificity and the individual concentration of each of the VOCs, which can only be found by the gas chromatography technique, are not considered critical. Some researchers, for example Feron et al (1992), believe that the health effects of a mixture of VOCs is not only determined by the individual compounds but also by the possible interaction between them. Consequently some researchers, suggests that the perceived air quality is determined by the total content of the VOCs (Lunau, 1992).

4.5.2.5 The Selected Optical Filters

From Chapter 3, it can be seen that the VOCs and the dilution indicators, carbon dioxide and monoxide, are the hazardous gases to be monitored in the indoor. The selection of optical filters UA 0983 and UA 0984 for carbon dioxide and carbon monoxide, respectively, is straight forward because these filters are specific for the gas to be monitored. However the selection of a filter for monitoring VOCs is judgmental.

Despite a controversy in knowing which VOCs may be taken as representative, optical filter UA 0987 was selected since it could monitor four of the six most important VOCs commonly found in buildings. The filter could monitor toluene, ethylbenzene, n-hexane, and 2- butanone. The controversy is resolved in the discussion on calibration for optical filter UA 0987.

4.5.2.6 Justification of Optical Filter

None of the optical filters currently available is capable of monitoring all of the VOCs. However optical filter UA 0987 could monitor more number of VOCs than other optical filters. Six of the thirty-five VOCs identified by Shah and Singh (1988) could be monitored by optical filter UA 0987. The VOCs are acetone, methyl ethylketon, ethylbenzene, toluene, cyclohexane, and octane. Eleven of the sixty-eight VOCs identified by Dawidowicz et al (1988) may be monitored by optical filter UA 0987. The compounds are n-hexane, n- heptane, cyclohexane, methanol, ethanol, 2-butanone, ethylacetate, n-butylacetate, toluene, ethylbenzene, and naphthalene. Five of twenty-two VOCs used by Kjaergaard et al (1991) in the experiment to determine the human reaction to VOCs commonly found in buildings could be monitored by filter UA 0987 alone. The compounds are n-hexane, 1-decene, ethylbenzene, 2-butanone, and n-butylacetate.

Therefore, comparison between TVOCs measured with optical filter UA 0987 will not be comparable with TVOCs level measured by other means. There has been no direct comparison between TVOCs levels measured in offices by different means, yet this could result in significant differences. This is a proposed area of future work (See Section 10.3).

4.5.2.7 Selection Method

As previously stated, the selection of an optical filter for the VOCs is judgmental. The selection of the filters for sampling VOCs was based on two criteria. The first criterion, the optical filter should be able to monitor as many VOCs as possible commonly found in a typical indoor air. The second criterion, the optical filter should be able to monitor as many VOCs as possible known to be medically important. In selecting the optical filters based on the first criterion, the VOCs identified by Shah and Singh (1988), Dawidowicz et al (1988), and Kjaergaard et al (1991) were used.

In selecting the optical filters based on the second criterion, Shah and Singh's VOCs and Kjaergaard's VOCs were used. These compounds are reported as the VOCs which are medically important.

(1) Based on Shah and Singh's List

As described in Chapter 3, Shah and Singh (1988) identified the thirty-five VOCs (Appendix II) in the indoor which are considered important to health. The compounds were selected based on their known mutagenic and toxic properties from the American Environmental Protection Agency's database on natural VOCs. Twenty of the thirty-five VOCs could not be monitored by any of the optical filters. They are alpha- pinene, trimethylbenzene (two isomers), ethenylbenzene, benzaldehyde, dimethylbenzene (two isomers), nonane, decane, tetrachloroethene, decamethylcyclopentasil-oxane, tridecane, tetradecane, pentadecane, undecane, trichlorobenzene, trichloroethane, and dichlorobenzene (three isomers).

Six of the VOCs could be monitored by optical filter UA 0987. They are acetone, methyl ethylketon, ethylbenzene, toluene, cyclohexane, and octane. Four VOCs, acetone, trichloroethene, cyclohexane, and 1,4-(dioxane), could be monitored by the filter UA 0977. Three VOCs, benzene, 1,1,2,2 - tetrachloroethane, and ethylbenzene, could be monitored by the optical filter UA 0936.

Each of the optical filters UA 0972, UA 0976 and UA 0980 could monitor two volatile organic compounds. The optical filter UA 0972 could monitor 2-butoxyethanol and 1,4-(dioxane), UA 0976 could monitor benzene and methyl ethylketon and UA 0980 could monitor carbon tetrachloride and chloroform.

Each of the optical filters UA 0970, UA 0971, UA 0973, UA 0978, UA 0981, and UA 0986 could monitor only one volatile organic compound. UA 0970 could monitor acetone, UA 0971 could monitor methyl ethylketon, and filter UA 0973 could monitor 2 -butoxyethanol. The optical filter UA 0978 could monitor trichloroethene. The optical filter UA 0981 could monitor toluene and UA 0986 could monitor formaldehyde.

Therefore, when the work of Shah and Singh (1988) is used as a base, the optical filter UA 0987, which could monitor the highest number of volatile organic compounds, is the best choice.

(2) Based on Dawidowicz's List

Sixty percent (forty-five of sixty-eight) of the volatile organic compounds in the indoor as listed by Dawidowicz et al (1988) in Appendix III could not be monitored by any of the available optical filters. The compounds are n-octane, n-nonane, n-decane, n-undecane, n-dodecane, n-tridecane, n- tetradecane, 2-methylpentane, 2-methylhexane, 3-methylheptane, methylcyclopentane, 1-octene, 1-decene, trichlorofluoromethane, dibromochloromethane, trichloroethene, tetrachloroethene, 1,4-dichlorobenzene, 2-propanol, 2-methyl-1-propanol, 1-pentanol, 2-ethyl- cyclobutanol, butanal, pentanal, hexanal, benzaldehyde, nonanal, 2-propanone, 3-methyl-2-butanone, 2-ethoxy-ethanolacetate, 1,3-dimethylbenzene, 1,4-dimethylbenzene, 1,2-dimethylbenzene, n-propylbenzene, 1,3,5- trimethylbenzene, 1,2,4-trimethylbenzene, C(3)-alkylbenzene, 1-methylethenylbenzene, 1-ethenyl-3-ethylbenzene, 1-ethenyl- 4-ethylbenzene, biphenyl, alpha-pinene, beta-pinene, (delta- 3)- carene, and limonene.

Eleven VOCs may be monitored by optical filter UA 0987. The compounds are n-hexane, n-heptane, cyclohexane, methanol, ethanol, 2-butanone, ethylacetate, n-butylacetate, toluene, ethylbenzene, and naphthalene.

Each of the other filters could monitor not more than five VOCs Optical filters UA 0936 and UA 0974 could monitor five VOCs each. UA 0936 could monitor chlorobenzene, methanol, 1- butanol, benzene, and ethylbenzene while UA 0974 could monitor methanol, ethanol, 1-butanol, ethylacetate and n- butylacetate. The optical filter UA 0973 could monitor four VOCs: 1,1,1-trichloroethane, chlorobenzene, acetaldehyde, and 3-heptanone.

Both of the optical filters UA 0980 and UA 0981 could monitor three VOCs. UA 0980 could monitor dichloromethane, trichloromethane, and tetrachloromethane while UA 0981 could monitor 1,2-dichloroethane, 1,1,2-trichloroethane and toluene. Each of the optical filters UA 0969, UA 0970, UA 0976, UA 0977, and UA 986 could monitor up to two species. UA 0969 could monitor dichloromethane and ethylacetate, UA 0970 could monitor 1,2-dichloroethane and n-butylacetate, and UA 0976 could monitor 2-butanone and benzene. The optical filter UA 0977 could monitor cyclohexane and 1,2-dichloroethane, and UA 0986 could monitor formaldehyde and acetaldehyde. The optical filter UA 0971 could monitor only 2-butanone.

Again, even when the work of Dawidowicz et al (1988) is used as a basis, the optical filter UA 0987 is the best choice.

(3) Based on Kjaergaard's List

The twenty-two VOCs selected by Kjaergaard et al (1991) (Appendix I) for their experimental studies on human reaction to indoor VOCs was also used for the first criterion. Thirteen of the twenty-two VOCs could not be monitored by any of the twenty-two filters of the gas monitor. The compounds are n-nonane, n-decane, n-undecane, 1-octene, 1-decene, 3-xylene, 1,2,4-trimethylbenzene, n- propyl-benzene, alpha-pinene, n-pentanal, n-hexanal, n- butanol, and 3-methyl-3-butanone.

Of the nine VOCs that are left, five volatile organic compounds could be monitored by the optical filter UA 0987 alone. They are n-hexane, 1-decene, ethylbenzene, 2-butanone, and n-butylacetate. Other filters could monitor either one or two VOCs.

Each of the optical filters UA 0936, UA 0971, UA 0976 and UA 0981 could monitor two VOCs only. Optical filter UA 0936 could monitor ethylbenzene and iso-propanol, and UA 0977 could monitor cyclohexane and 1,2-dichlor-ethane. Both of the VOCs, 2-butanone and 4-methyl-2-pentanone, could be monitored by either UA 0971 or UA 0976.

Each of the optical filters UA 0970, UA 0972, UA 0973, UA 0974, and UA 0981 could monitor only one VOC. The optical filter UA 0974 could monitor iso-propanol and UA 0981 could monitor 1,2-dichlor-ethane. Ethoxyethyl-acetate could be monitored by either UA 0972 or UA 0973. The optical filter UA 0970 could monitor 1,2-dichlor-ethane. Therefore, when based on the work of Kjaergaard et al (1991) the optical filter UA 0987 is again the best choice.

4.5.2.8 Summary of the Judgement

Based on the three major works in this field, undoubtedly if the first criterion is used, optical filter UA 0987 could monitor more VOCs than other optical filters and therefore the best selection.

The optical filter UA 0987 is also the best selection when it is based on the second criterion. The gas monitor could not monitor all of the VOCs simultaneously since it could only be fixed with three optical filters for monitoring the compounds, in addition to the specific optical filters UA 983 for carbon dioxide and UA 984 for carbon monoxide.

4.5.2.9 The Standard for TVOC

Methane was selected as the standard. Therefore the concentration of TVOC should be expressed as ppm with reference to methane. For example a concentration of 0.7 ppm should be written as 0.7 ppm (ref. methane).

The selection of the standard for VOCs is also judgmental. `Standard', as it is used here, refers to a chemical of known concentration for calibrating optical filter UA 0987. The chemical should be sensitive to the optical filter. However the chemical may not be one of the VOCs to be measured. Through calibration the measures of total concentration of VOCs at different calibration settings could be compared to each other.

The subsequent discussion is divided into three sub- sections:

1) literature review of the standard for TVOC;
2) justification of the standard; and
3) limitation of the standard.

<u>Literature Review of the Standard for TVOC</u>

The literature review showed no single chemical is used consistently as the standard. Three chemicals are used, namely methane (Shaw et al, 1991), toluene (Skov et al, 1990; Lunau, 1992), and pentadecane (Skov et al, 1990). Although methane is used earlier (Shaw et al, 1991), it is not based on infra-red spectrometry technique. Methane seems to be more established than toluene and pentadecane as the standard for VOCs. A calibration curve for converting the concentration of methane to the total concentration of VOCs was prepared by Shaw et al (1991).

The principle by which methane may be used to estimate the total concentration of VOCs in ambient air is discussed by Harrison (1990). In the flame ionisation analyser the air sample becomes the oxidant in air/hydrogen flame ionisation detector. The presence of VOCs enhances the conductivity of the flame. The sensitivity per carbon atom in the VOCs is almost constant. However the presence of oxygen and halogen atoms in the compounds reduce this sensitivity.

Methane is used for comparison since it has only one carbon atom. As stated earlier, the sensitivity of the VOCs in the air sample to the flame ionisation analyser depends on the number of carbon atoms in those compounds. The concentration of VOCs is expressed as ppb C (part per billion Carbon). Since methane has only one carbon atom, the concentration of methane is taken as unity. The concentration of other VOCs is thus expressed in this basic unit. For example, 0.5 ppb of ethane is equivalent to 1 ppb C and 0.25 ppb of butane is equivalent to 1 ppb C.

This literature review showed that none of the standards used by previous researchers is based on infra-red spectroscopy and can be used in this research. Consequently the calibration curve for converting the concentration of methane into the equivalent concentration of VOCs is also not relevant to the instrumentation in this research.

Justification of the Standard

First, methane is sensitive to UA 0987 filter. Second, methane is the standard gas which is common in the market and therefore it is relatively cheap. Third, the use of any of the VOCs which commonly exist in indoor air is not practical because it has to be specially prepared.

Limitation of the Standard

No previous use of infra-red spectroscopy in the monitoring of VOCs is reported. There is also no report on any calibration curve for converting the concentration of methane monitored by infra-red spectroscopy into the total concentration of VOCs.

4.6 CONCLUSION

The TSI 8510 particulate monitor using piezobalance technique is sufficient to fulfil the monitoring requirement and is available from Bartlett. Theoretically, light scattering technique is better than piezobalance technique because the light scattering technique can monitor particulates continuously. However, in field conditions, both techniques require frequent cleaning. Practically, this makes neither of the technique better than the other. Therefore, since the TSI 8510 particulate monitor is available, the author decided to use this particulate monitor.

The B&K 1302 gas monitor using infra-red spectroscopy is the best selection to monitor gaseous pollutants. Infra-red spectroscopy technique is better than gas-chromatography technique because the former can monitor continuously. The gas chromatography technique requires laboratory analysis which makes continuous monitoring impossible. In the SERC/LINK Project, continuous monitoring is the more important criterion than other advantages that can be attributed to this technique. For this reason, the author chose the B&K 1302 gas monitor.

4.7 REFERENCES

1. ASHRAE (1993). ASHRAE Handbook 1993 Fundamentals. Chapter 11, `Air Contaminants', Table 5. Atlanta: American Society of Heating Refrigerating and Air-Conditioning Engineers, Inc.

2. Clements, J. B. and Lewis, R. G. (1988). `Sampling for organic compounds', in Keith, L. H. (ed.). Principles of Environmental Sampling, ACS, pp287-296

3. Collison, J. and Baum J. (1992). `Taking the air', Occupational Safety & Health, 1991, pp37

4. Dawidowicz, N. et al (1988) The Healthy Building. Swedish Council for Building Research, Stockholm, 1988

5. Feron, V. J. et al (1992). `Toxicology of Volatile Organic Compounds in Indoor Air and Strategy for Further Research', Indoor Environment Vol. 1, 1992, pp69-81

6. Goyer, N. (1990). `Chemical contaminants in office buildings'. American Industrial Hygiene Association Journal, Vol. 51, No. 12, pp615-619

7. Grimaldi, F. et al (1990). 'Marseilles's Experience of Indoor Air Pollutants' in Lunau F and Reynolds, G.L. (ed.) Indoor Air Quality and Ventilation. London: Selper Ltd, pp377-386

8. Grot, R. A. et al (1991). `Indoor Air Quality Evaluation of A New Office Building'. ASHRAE Journal, Sep. 1991, pp16-25

9. Hansen, S. J. (1991). Managing Indoor Air Quality. Georgia, USA: The Fairmont Press, Inc.

10. Harrison, R. M. (1990). `Important Air Pollutants and Their Chemical Analysis', in Harrison, R. M. (ed.) Pollution: Causes, Effects and Control, Royal Society of Chemistry, Second Edition, pp127-155.

11. Kjaergaard, S. K. et al (1991). `Human Reactions to a Mixture of Indoor Air Volatile Organic Compounds in Atmospheric Environment', in Atmospheric Environment, Vol. 25A, No. 8, pp1417-1426

12. Lunau, F. W. (1992). `The Perception of Indoor Air Quality' in Leslie, G. B. and Lunau, F. W. Indoor Air Pollution: Problems and Priorities. Cambridge University Press

13. Molhave, L. and Thorsen, M. (1991). `A Model for Investigations of Ventilation Systems as Sources for Volatile Organic Compounds in Indoor Climate'. Atmospheric Environment, Vol. 25A, No. 2, pp241-249.

14. Morey, P. R. and Jenkins, B. A. (1989). `What are typical concentration of fungi, VOC, and NO2 in office environment', in Proceedings of IAQ '89. The Human Equation: Health and Comfort. ASHRAE, Atlanta, pp67-71.

15. Norback, D. et al (1990). `Indoor air quality and personal factors related to the sick building syndrome'. Scandinavian Journal of Work Environment Health, Vol. 16, pp121-128.

16. Otson, R. and Fellin, P. (1992). `Volatile Organics in the Indoor Environment: Sources and Occurrence', in Nriagu (ed.). Gaseous Pollutants: Characterization and Cycling. Chichester: John Wiley & Sons, Inc. pp335-421.

17. Purnell, C. J. and IRS Staff (1987). Occupational Health Review. No. 9, pp17-19

18. Rohbock, E. et al (1988). `Indoor air composition in office rooms with central air supply'. in Perry, R. and Kirk, P. W. (eds.). Indoor and Ambient Air Quality, London: Selper Ltd., pp503-511.

19. Shaw, C. Y. et al (1991). `Indoor Air Quality Assessment in An Office-Library Building. Part I: Test Methods'. in ASHRAE Transaction 1991, Part 2, Vol. 97, pp129-135.

20. Shah, J.J. and Singh, H. B. (1988) 'Distribution of volatile organic chemicals in outdoor and indoor air' Environmental Science Technology, Vol. 22, No. 12, 1988, pp1381-1388

21. Skov et al (1990). `Influence of indoor climate on sick building syndrome in an office environment', Scan J Work Environ Health, 1990, Vol. 16, No. 5, pp363-371.

22. United Nations (1979). Fine Particulate Pollution. Oxford: Pergamon Press.

23. Vesilind, P. A. et al (1988). Environmental Engineering, Second Edition, London: Butterworth Publishers.

24. Weschler, C. J. et al (1990). `Concentrations of volatile organic compounds at a building with health and comfort complaints'. American Industrial Hygiene Association Journal, Vol. 51, No. 5, May 1990, pp261-268

25. World Health Organisation (1980). Glossary on air Pollution. Copenhagen, WHO Regional Office Publications, European Series No. 9

26. Wolkoff, P. (1988). `Salient factors influencing the level of volatile organic compounds indoors', in Perry, R. and Kirk, P. W. (eds.). Indoor and Ambient Air Quality, London: Selper Ltd., pp526-329.

27. Woskie, P. et al (1994). `The real-time dust exposures of sodium borate workers: examination of exposure variability'. American Industrial Hygiene Association Journal, Vol. 55, Mar. 1994, pp207-217

28. Yocom, J. E. and McCarthy, S. M. (1991). Measuring Indoor Air Quality: A Practical Guide. New York: John Wiley & Sons

Chapter 5
MONITORING APPROACH, LOCATION, AND TIME (METHODOLOGY 1)

5.1 RESEARCH QUESTIONS

This chapter seeks to address the following research questions:

1) which part of the building the monitoring should be conducted;
2) when should the monitoring be conducted

5.2 SUMMARY

The monitoring approaches, locations, and time used by past researchers are reported in many literature. The monitoring approaches are either monitoring sequentially in several locations for a relatively short period or monitoring at a few locations for a relatively long period. The monitoring locations and time may be viewed in terms of two models which may be used as an aid to select representative monitoring locations and times.

5.3 INTRODUCTION

Once the health hazards to be monitored are determined, the monitoring approach most suitable for this research has to be selected. The process of selecting the monitoring approach is discussed in this and subsequent chapters. This chapter consists of five sections. The first section describes the terminology and definition related to this chapter. The second section sets the objective of the monitoring and the third section explores the monitoring method which is reported in the literature. The fourth section puts together the literature review into a statistical perspective of sampling. Two simplified statistical models are proposed. These models are used in the fifth section to translate the monitoring objective set in the second section into three monitoring requirement. Only two of the requirement are discussed in this section. The third monitoring requirement is discussed separately in Chapter 6.

5.4 TERMINOLOGY AND DEFINITION

`Methodology' of monitoring airborne pollutants in the context of this thesis means the identification of the most relevant airborne pollutants, the selection of the most suitable instrumentation to conduct the monitoring, the quality control of the instrument, and the method of monitoring the pollutants.

Quality control of the instrument includes the calibration of the monitoring instrument and the estimation of its reliability as well as the reliability of the monitoring time interval.

`Method of monitoring' means the selection of monitoring type and the determination of monitoring location, time, and interval.

`Monitoring', in this chapter, means repetitive or continued measurement of the concentration of airborne pollutants in a predetermined monitoring elements - monitoring location and time - in the study building. The measurements should use a common comparable technique. For example, in the monitoring of particulates in this research, all of the measurements were taken using Model 8510 Piezobalance Respirable Aerosol Mass Monitor, serial number 151 6-90, installed with the piezoelectric quartz crystal of number 3347. The use of other technique or instrument in the measurement should be considered as another piece of evidence, but it is not part of the monitoring unless the result can be compared to those used by this particulate monitor.

`Monitoring location' is where the inlet of the gas monitor or the end of the Teflon tube, the other end of which is inserted to the inlet of the gas monitor or of the particulate monitor, is placed.

`Monitoring time' is the time when the air is sampled for airborne pollutants. The time intervals between two monitoring times are referred to in this thesis as the `monitoring intervals'. The whole period during which the monitoring times occur is referred to as the `monitoring period'. For example, if the monitoring times are at 10:05 a.m., 10:10 a.m., and 10:17 a.m., the monitoring period is from 10:05 a.m. to 10:17 a.m. The earlier monitoring interval is five minutes and the later interval is seven minutes.

`Measurement', as it is used in this thesis, is a two level process of comparison. In the first level, the concentration of airborne pollutants detected by the gas or particulate monitor is compared to a calibration standard such as methane. The concentration is then expressed in a multiple of the calibration standard. For example, the concentration of a VOC can be expressed as 65 parts per million of methane. If the calibration standard is expressed in other units then the concentration of airborne pollutants should be expressed in those units. In the second level, the concentration of airborne pollutants measured at the monitoring location is compared with those at the control monitoring locations.

`Representative' means the measurement accurately and precisely represents the measurement which is characteristic of the population or sub-populations being measured. Representative can only be approximated.

A `symptomatic area' is an area identified by the SERC/LINK Project as unhealthy.

5.5 OBJECTIVE OF MONITORING

The objective of monitoring in the SERC/LINK Project is four folds:

1) to determine the concentration of airborne pollutants in the symptomatic areas so that it can be correlated with the symptoms of building sickness.

2) to determine the overall concentration of airborne pollutants in the building so that it can be compared with that in the other buildings. Here the concentration for airborne pollutants refers to that which is relevant to the symptoms of building sickness.

3) the monitoring methodology should meet the scientific requirement: reliable and valid.

4) the monitoring methodology should meet the operational requirements. Operationally the methodology should be practical.

5.6 LITERATURE REVIEW ON MONITORING OF AIRBORNE POLLUTANTS

The objective of this section is to examine how the monitoring approach, location, time, and time intervals are determined and the way the representative is handled by previous researchers. In general, the discussion on the decision process involved is very limited in the literature. This section consists of five parts: monitoring approach (Section 5.6.1), monitoring location (Section 5.6.2), monitoring time (Section 5.6.3), monitoring time intervals (Section 5.6.4), and representative (Section 5.6.5).

5.6.1 Monitoring Approach

The literature review suggests that the monitoring approach of airborne pollutants may be divided into three types:

1) by frequency of monitoring: once or continuous

`Continuous monitoring' is monitoring conducted at frequent monitoring intervals (Otson and Fellin, 1992). `Once is the monitoring conducted once.

2) by monitoring location: sequential mobile or stationary.

`Sequential mobile' is monitoring sequentially over a relatively short monitoring period at a number of monitoring locations. `Stationary' is monitoring at fixed monitoring location over a significant monitoring period. Both of these approaches were recommended by Yocom and McCarthy (1991).

3) by instantaneity of the monitoring result: direct reading or integrative

`Direct reading monitoring' is the monitoring which gives instantaneous result. This approach is also called as short- term monitoring, grab, and snap sampling. Purnell and IRS Staff (1988) refer to short-term monitoring as the monitoring which used direct reading instrument and is of monitoring time up to ten minutes. The synonyms for short- term monitoring are grab and snap samplings

(Purnell and IRS Staff, 1988). Grab sampling, according to Otson and Fellin (1992), is the measurement which provides instantaneous result. `Integrative monitoring' is a single measurement over a period of time (Otson and Fellin, 1992).

5.6.2 Monitoring Location

The discussion on monitoring location consist of three topics: monitoring area (Section 5.6.2.1), monitoring location within monitoring area (Section 5.6.2.2), and monitoring height (Section 5.6.2.3).

5.6.2.1 Monitoring Area

Since the objective of monitoring the airborne pollutants is to determine their health hazards to office workers, occupied areas, workstations, and problem and non problem areas are included as the monitoring areas. The criteria for determining the problem are the symptoms of building sickness and the presence of excessive airborne pollutants. Another criterion which is used to select the monitoring areas is representative. Some literature do not specify the monitoring areas in the study building. The preceding paragraphs elaborate the monitoring areas used by the previous researchers.

Shaw et al (1991) monitored the concentration of carbon dioxide and carbon monoxide at the occupied areas within each of the seven upper floors of an eight storey building. Goyer (1990) reports a thorough measurement of chemical pollutants in seventeen office towers. The measurement was conducted in workstations.

Some literature state that the monitoring areas included problem and non-problem areas. Problem area here refers to an area which has the symptoms of building sickness or in which the airborne pollutants are suspected to be generated excessively. Therefore, non-problem area means an area which neither have the symptoms nor excessive airborne pollutants. The non-problem area is also known as the control area (Quinlan et al, 1989) and the area of least potential problem (Yocom and McCarthy, 1991).

According to Yocom and McCarthy (1991), the problem areas which should be monitored include the areas of lowest ventilation efficiency, highest potential source, and occupied by the most susceptible office workers. The problem areas which were monitored by Goyer (1990) included smoking areas, print shops, workshops using solvents, and wet-process photocopier rooms. In a study on VOCs in a building with health and comfort complaints, the elevator shaft and the elevator machine rooms were found as the problem areas (Weshler et al, 1990).

This paragraph describes the building, area, and location which are used for monitoring control of airborne pollutants. Quinlan et al (1989) recommend another part of the building or similar building in which the occupants do not complain as the control building or area. The control locations for monitoring outdoor air are at the roof and street levels. Outdoor air was sampled by Grot et al (1991) at both roof and street levels. However, in a study on office-library building, Shaw et al (1991) sampled carbon monoxide, carbon dioxide, and TVOC at roof level only but under different heating, ventilating, and air-conditioning mode. The control locations for monitoring air in the heating, ventilating, and air-conditioning systems are reported at downstream and upstream of the intake fan and at the return fan. Air in the heating, ventilating, and air- conditioning systems was sampled by Grot et al (1991) at downstream and upstream of the intake fan and at the return fan. In a study on an office-library building, Shaw et al (1991) sampled carbon monoxide, carbon dioxide, and TVOC at the return duct only but under different heating, ventilating, and air-conditioning mode.

Some literature state that the monitoring areas are or should be based on building sickness symptoms or representative. Representative is based on the physical characteristics of the building and the activity of the office workers. Quinlan et al (1989) recommend the monitoring location to be in the area where the office workers, who are experiencing the symptoms of building sickness, work. In a study on fourteen buildings, Skov et al (1990) selected one representative office in each of the buildings. The criteria of representative are building material, equipment, size, and activity. The exact monitoring location within the representative office is not stated.

Some literature do not specify the monitoring areas in the study building. Weschler et al (1990) report a comprehensive investigation of VOCs in buildings. But in the report, the determination of monitoring areas is not stated. Grot et al (1991) monitored airborne pollutants at more than 100 monitoring locations in an office building including interior spaces. However, the exact monitoring areas in the interior spaces is not stated.

5.6.2.2 Monitoring Location within Monitoring Area

Some literature report that the middle of the monitoring area is selected or recommended as the monitoring location. Shaw et al (1991) monitored the concentration of carbon dioxide and carbon monoxide at the centre of the occupied area. In discussing the monitoring for enforcement of regulation, Kagawa (1993) states that indoor monitoring should be conducted in the centre of the room. But some literature, for example Goyer (1990), do not specify the exact location of the monitoring location in the monitoring area.

5.6.2.3 Monitoring Height

A monitoring height of between 1.1 to 1.5 metre from floor is used in the monitoring of airborne pollutants. However, a monitoring height at a lower level is also possible. ASHRAE Standard 62-1989 defines the occupied zone as the space 75 to 1,800 millimetres above the floor and not closer than 600 millimetres from walls or air-conditioning units. In discussing the monitoring for enforcement of building regulation, Kagawa (1993) states that a monitoring height between 0.75 to 1.2 metre is used. However, past researchers of airborne pollutants used a monitoring height between 1.1 to 1.5 metre from the floor. Skov et al (1990) sampled airborne pollutants at a monitoring height 1.1 metre from the floor. Rohbock et al (1988) sampled air at a working place or a desk in the middle of the room, 1.5 metre above the floor.

5.6.3 Monitoring Time

In determining monitoring time, the criteria for determining problem and representative areas, as discussed above, are used. The problem time, monitored or is recommended to be monitored, is due to air-conditioning system, building interiors and the activities conducted in the building. Therefore, Quinlan et al (1989) recommend the monitoring time for baseline measurement during the monitoring day as early in the day before the air-conditioning is running and the building is occupied. In this case, the baseline probably refers to the representative monitoring time for non-problem time. In this thesis, non problem time is also known as control time.

In this and subsequent paragraphs, the monitoring for problem time is discussed. If heating, ventilating, and air- conditioning systems are suspected, Quinlan et al (1989) recommend that the monitoring be conducted in the indoor before and after the systems are turned on for the first time on a Monday morning. If excessive emission of volatile organic compounds is suspected from the interiors, namely fabric, furnishing, glue, and paints, Quinlan et al (1989) recommend that the monitoring be conducted after the building is closed without ventilation for several days.

The problem time due to indoor activities may be divided into two: the problem time in a week and a day. First, the problem time in a week. If the activities due to building use is suspected to cause the problem, Quinlan et al (1989) recommend that a day later in the week might be more representative of a worst case situation than a day earlier in the week. Second, the problem time in a day. Three reports recommend the monitoring time for problem time in a day. Quinlan et al (1989) recommend the monitoring time for baseline measurement be conducted when the air-conditioning system is running for several hours. In this case, the baseline probably refers to the representative monitoring time for problem time. Skov et al (1990) recommend that carbon dioxide be monitored once in the morning and once in the afternoon. Grot et al (1991) notice that VOCs peak at 11.00 am and 3.00 pm. This suggests that during those times the monitoring time is representative of the problem time.

5.6.4 Monitoring Time Interval

Since the objective of this monitoring is to assess the health hazards, the use of biological half-life of airborne pollutants to determine time interval is more reasonable. However, no published data are found on the biological half- life of TVOC. The reason is elaborated in the next paragraph.

Biological half-life, also known as physiological half-life, is the time during which the concentration of a pollutant in a body is reduced by half. Time interval is the time difference between two consecutive monitorings. Short peaks between the two consecutive monitoring times are not measured. However, if the short peaks occur for a period longer than the biological half-life, a health hazard may occur. That means in this case, the measurement does not measure what it is supposed to measure. A similar phenomenon is raised by Saltzman (1988) in his discussion of the averaging time in outdoor pollution monitoring. If the averaging-time is less than the biological half-life, a significant short-peak may be averaged out and consequently its health hazard is underestimated (Saltzman, 1988). However a shorter time interval of one-tenth of the biological half-life is suggested by Roach (1966) who states that a variation in the concentration of a pollutant, over less than one-tenth of its biological half-life, will have no biological consequence.

5.6.5 Representative

No reports are found on the application of statistical sampling to determine representative monitoring location or time in the monitoring of airborne pollutants. However Smith et al (1988) recommend the use of sampling theory to determine representative monitoring locations. At least one literature suggests the use of the principle of sampling theory in the monitoring of airborne pollutants. Armstrong et al (1989), in monitoring the building sickness in a multi-storey building, selected the floor randomly.

5.7 THE STATISTICAL MODEL OF MONITORING LOCATION AND TIME

This section consists of two parts: the sub-populations of monitoring locations (Section 5.7.1)and the sub-populations of monitoring time (Section 5.6.2). These sections attempt to put the monitoring location and time, identified in the above literature review, into a perspective of statistical sampling theory so that a more representative sample of monitoring location and time could be selected. A separate three strata models, each for monitoring locations and time, are proposed.

The simplified model may be refined by adding more strata. For example, monitoring height as the fourth stratum of monitoring location and running mode of heating, ventilating, and air-conditioning systems as the fourth stratum in monitoring time. Since time and location are mutually exclusive the two four-strata model may be combined into a single sixteen-strata model.

5.7.1 Sub-population of Monitoring Locations

The population of monitoring locations which are found in the literature may be divided into at least six sub- populations in three strata. The outer stratum, based on the occupancy of office workers, consists of two sub- populations: occupied and non-occupied areas. The middle stratum, based on the anticipated concentration of airborne pollutants in the areas of the outer stratum, consists of two sub-populations: areas with normal concentration and excessive anticipated concentration of airborne pollutants. The inner stratum is based on the reported symptoms of building sickness. In this case, the SERC/LINK Project determined whether or not the building sickness symptoms are excessive or normal. Therefore, the inner stratum consists of two sub-populations: the areas identified by the SERC/LINK Project as healthy and unhealthy. This stratification is non-exhaustive. As stated earlier, for a better representative, the location height, may be added as another stratum.

The sub-populations of monitoring locations derived from the above stratification can be divided into six areas:

1. non-occupied areas in which an excessive concentration of airborne pollutants is anticipated;

These areas includes non-occupied areas with lowest ventilation efficiency, highest potential source, the elevator shaft, and the elevator machine room.

2. non-occupied areas in which a normal concentration of airborne pollutants is anticipated;

These areas includes the non-occupied areas other than those listed in the first sub-population.

3. occupied areas in which both the anticipated concentration of airborne pollutants and the reported symptoms of building sickness are excessive. In this case the occupied area in which the reported symptoms of building sickness is

excessive means an occupied area within a cluster identified by the SERC/LINK Project as unhealthy;

These areas includes the areas identified by the SERC/LINK Project as unhealthy and the ventilation efficiency is lowest or the highest potential source exist. Literature review showed that the areas with the highest potential source of airborne pollutants are print shops, workshops using solvents, and wet-process photocopier rooms.

4. occupied areas in which the anticipated concentration of airborne pollutants is excessive but the reported symptoms of building sickness are normal. In this case, normal means the SERC/LINK identified the area as healthy;

These areas include print shops, workshops using solvents, wet-process photocopier rooms and occupied areas in which the ventilation efficiency is lowest as well as those areas identified by the SERC/LINK Project as healthy.

5. occupied areas in which the anticipated concentration of airborne pollutants is normal but the reported symptoms of building sickness are excessive;

These areas includes the occupied areas other than those listed in the fourth sub-population except that these areas were identified by the SERC/LINK Project as unhealthy.

6. occupied areas in which both of the anticipated concentration of airborne pollutants and the reported symptoms of building sickness are excessive.

These areas include occupied areas other than those in the fourth sub-population.

5.7.2 Sub-population of Monitoring Time

The population of monitoring time reported in literature may be divided into at least thirteen sub-populations in three strata:

1) The first stratum, based on the day of the week, consists of three sub-populations: non-working days, Monday, and other working days.

2) The second stratum is based on the running time of the air-conditioning system. It consists of four sub- populations: the time when the air-conditioning system is shut down, the hour before the air-conditioning system is started, the few hours after the air-conditioning system is started, and the time when the air-conditioning system had been running for a few hours.

3) The third stratum is based on the occupancy of the office worker. It consists of two sub-populations: the times occupied and not occupied by office workers. Representative may be refined by adding another stratum: the operation mode of heating, ventilating, and air-conditioning systems.
The detail of the thirteen sub-populations of monitoring time derived from the above stratification is as follows:

1) non-working days of the monitoring week which include Saturday, Sunday and public holidays.

2) the Monday of the monitoring week when the air- conditioning system is shut down.

3) the Monday of the monitoring week a few hours before the air-conditioning system is started

4) the Monday of the monitoring week a few hours after the air-conditioning system is started and the office workers have not yet arrived.

5) the Monday of the monitoring week a few hours after the air-conditioning system is started and the office workers have arrived.

6) the Monday of the monitoring week a few hours after the air-conditioning system is started, the office workers have arrived, and an excessive concentration of airborne pollutants is anticipated. In the above literature review, this occurs around 11:00 a.m. and 3:00 p.m.

7) as in (6) but a normal concentration of airborne pollutants is anticipated.

8) as in (2) except that the time is the Tuesday through Friday of the monitoring week.

9) as in (3) except that the time is the Tuesday through Friday of the monitoring week.

10) as in (4) except that the time is the Tuesday through Friday of the monitoring week.

11) as in (5) except that the time is the Tuesday through Friday of the monitoring week.

12) as in (6) except that the time is the Tuesday through Friday of the monitoring week.

13) as in (7) except that the time is the Tuesday through Friday of the monitoring week.

5.8 THE MONITORING REQUIREMENT

In this section, the statistical perspective of monitoring location and time discussed in the previous sections is applied to translate the monitoring objectives, stated in the second section, into the following three monitoring requirement:

1) To meet the first monitoring objective, the monitoring location should be representative of the symptomatic and asymptomatic areas and control locations. These areas are contained in the third through sixth sub-populations of monitoring locations. Each sub-population may contain several areas. The first and second sub-populations may be included in the monitoring as control areas. Other monitoring location for control includes the outdoor, at roof and street levels, and the heating, ventilating, and air-conditioning systems at downstream and upstream of the intake fan and at the return fan. At each of the monitoring

locations the monitoring should be representative of each of the thirteen sub-populations of monitoring time.

2) To meet the second monitoring objective, the monitoring locations should be representative of all of the six sub- populations of monitoring locations. In this case, the monitoring locations for control are the outdoor, at roof and street levels, and the heating, ventilating, and air- conditioning systems at downstream and upstream of the intake fan and at the return fan.

3) To meet the third and fourth monitoring objectives, the monitoring should be reliable, valid, and practical. This requirement will be discussed in detail in Chapter 6.

5.9 CONCLUSION

The generic theory of monitoring approach, location, and time are identified in this chapter. The monitoring of airborne pollutants may be conducted either once or continuous, using either sequential mobile or stationary monitoring location, by either direct reading or integrative monitor. In theory, the monitoring should be carried out in representative areas and time. Representative requires two conditions which provide the answers to the two research questions addressed in this chapter. Firstly, the monitoring location should be randomly selected from the six sub- populations of monitoring location and secondly, the monitoring time should be randomly selected from the thirteen sub-populations of monitoring time.

5.10 REFERENCES

1. Armstrong, C. W. et al (1989). `Sick Building Syndrome. Traced to Excessive Total Suspended Particles', in ASHRAE. The Human Equation: Health and Comfort.

Proceedings of the ASHRAE/SOEH Conference. IAQ `89, Apr. 17-20, 1989, San Diego, California

2. ASHRAE Standard 62-1989. Ventilation for Acceptable Indoor Air Quality. Atlanta, Georgia: American Society of Heating, Refrigerating and AirConditioning Engineers, Inc.

3. Goyer, N. (1990). `Chemical contaminants in office buildings'. American Industrial Hygiene Association Journal, Vol. 51, No. 12, pp615-619

4. Grot, R. A. et al (1991). `Indoor Air Quality Evaluation of A New Office Building'. ASHRAE Journal, Sep. 1991, pp16- 25

5. Kagawa, J. (1993). `Indoor Air Quality Standards and Regulations in Japan', Indoor Environment, 1993, Vol. 2, pp223-231

6. Otson, R. and Fellin, P. (1992). `Volatile Organics in the Indoor Environment: Sources and Occurence', in Nriagu (ed.). Gaseous Pollutants: Characterization and Cycling. Chichester: John Wiley & Sons, Inc., pp335-421.

7. Purnell, C. J. and IRS Staff (1987). Occupational Health Review. Number 9, pp17-19

8. Quinlan, P. et al (1989). `Protocol for the comprehensive evaluation of building-associated illness', in Cone, J. E. and Hodgson, M. J. (eds.). Problem Buildings: Building Associated Illness and the Sick Building Syndrome, Occupational Medicine: State of the Art Reviews, Oct-Dec 1989, Vol. 4, No. 4, pp771-797

9. Roach, S. A. (1966). `A More Rational Basis for Air Sampling Programs', American Industrial Hygiene Association Journal, Vol. 27, p1-12, in Warner, P. O. (1976). Analysis of Air Pollutants. London: John Wiley & Sons, p200.

10. Rohbock, E. et al (1988). `Indoor air composition in office rooms with central air supply'. in Perry, R. and Kirk, P. W. (eds.). Indoor and Ambient Air Quality, London: Selper Ltd., pp503-511.

11. Saltzman, B. E. (1988). `Basic Factors in Gas and Vapour Sampling and Analysis', in

American Conference of Governmental Industrial Hygienists. Advances in Air Sampling. Michigan, USA: Lewis Publishers

12. Shaw, C. Y. et al (1991). `Indoor Air Quality Assessment in An Office-Library Building. Part I: Test Methods'. in ASHRAE Transaction 1991, Part 2, Vol. 97, pp129-135.

13. Skov et al (1990). `Influence of indoor climate on sick building syndrome in an office environment', Scan J Work Environ Health, 1990, Vol. 16, No. 5, pp363-371.

14. Smith, F. et al (1988). `Evaluating and Presenting Quality Assurance Sampling Data' in Keith, L. H. (ed.) Principles of Environmental Sampling, ACS, pp157-168

15. Weschler, C. J. et al (1990). `Concentrations of volatile organic compounds at a building with health and comfort complaints'. American Industrial Hygiene Association Journal, Vol. 51, No. 5, May 1990, pp261-268

16. Yocom, J. E. and McCarthy, S. M. (1991). Measuring Indoor Air Quality: A Practical Guide. New York: John Wiley & Sons

Chapter 6
RELIABILITY, VALIDITY, AND PRACTICALITY (METHODOLOGY 2)

6.1 RESEARCH QUESTIONS

This chapter seeks to address two research questions:

1) how reliable and valid is the proposed monitoring methodology;
2) how much is the estimable error.

6.2 SUMMARY

The reliability and validity of the methodology of monitoring airborne pollutants are subjected to uncertainties which cause errors. As some of the errors are estimable, an attempt was made to approximate the estimable errors. Furthermore, the monitoring of gaseous airborne pollutants was conducted at four calibration settings. To be valid, the data at the four settings should be first converted to a common calibration setting before a comparison could be made. In this chapter, a conversion formula for that purpose is derived.

6.3 INTRODUCTION

As stated in Chapter 5, reliability, validity, and practicality are the third monitoring requirement. The purpose of this requirement is to ensure a well-grounded research. `Reliability', in this context, means the monitoring gives consistent result. `Validity' means the monitoring monitors what it is supposed to monitor. In this case, the monitoring should use valid particulate and gas monitors. To be valid, the monitors should be calibrated. `Practicality',in this context, means the monitoring is economical and convenient. A trade-off is normally required between reliability, validity, and practicality.

This chapter is divided into four sections. The first section, Section 6.4, discusses the calibration of the gas monitor, calibration history and parameters, and the derivation of the conversion formula. The second section, Section 6.5, discusses reliability in four sub-sections: the reliability in monitoring time, of standard gas, of the concentration measured, and of the population measured. The third section , Section 6.6, discusses the validity of monitoring location, time and instrument. The fourth section, Section 6.7 , is the conclusion.

6.4 CALIBRATION

In this thesis, the gas monitor was calibrated and the conversion formula was derived. The gas monitor was not calibrated when it was delivered. The conversion formula was also not available in the calibration manual.

The calibration of the gas monitor means the calibration of each of its optical filters. Zero point calibration and humidity interference calibration were performed on all of the optical filters. The calibration were performed on site and in the laboratory. The particulate monitor was monitored in the factory. Therefore, in the subsequent discussion only the calibration of gas monitor is discussed.

The subsequent discussion is divided into three parts:

1) the calibration history (Section 6.4.1);
2) the calibration parameters (Section 6.4.2); and
3) the conversion formula (Section 6.4.3).

6.4.1 The Calibration History

Four calibrations were conducted:

1) On 1/4/1992 a static calibration was performed at Wates House. All optical filters except the optical water filter were calibrated. Although the water filter may be used to measure absolute water content, its function in the monitoring of gaseous pollutants was only to measure the relative interference of water.

2) On 31/3/1993, zero-point calibration, humidity-interference calibration and span calibration were performed for the first time on site at Lakeside Municipal Office, Kendal. During the calibration, all of the optical filters were zero-calibrated using a zero gas which was BOC pure nitrogen of grade N5.5. The zero gas contains a small amount of trace gases: total hydrocarbon, carbon dioxide and carbon monoxide. The concentration of each of the trace gases are less than 0.5 ppm. In the calibration, the relative contribution of each of the optical filters due to humidity interference were determined. The optical gas filters UA 0987 and UA 0983 were span calibrated using standard gases. Optical filter UA 0987 was span calibrated using methane of a concentration of 100 ppm, the rest pure nitrogen. Optical filter UA 0983 was calibrated using carbon dioxide of a concentration of 540 ppm, the rest nitrogen.

3) On 30/7/1993, zero point calibration and humidity interference calibration was performed on all of the optical filters for the second time. The same type of zero gas but of a different gas bottle was used. This was conducted in the laboratory at Wates House.

4) On 23/8/1993, optical filter UA 0984 was span calibrated for the first time on site at the Pearl Building, Cardiff. Carbon monoxide of a concentration of 10 ppm, the rest nitrogen, was used as the standard gas.

As the four calibrations were conducted at different settings, a calibration formula is required to convert the concentrations of gaseous pollutants which were monitored in one calibration setting to the equivalent concentrations in the other calibration settings. The calibration formula gives a relationship between the calibration parameters at each calibration setting.

6.4.2 The Calibration Parameters

The calibration parameters at the four calibrations are summarised in the following table:

		1-Apr.-92 @	31-Mar-93	30-Jul.-93	23-Aug.-93
	CF	2.44E+05	3.33E+05	3.33E+05	3.33E+05
UA0987	COF	2.08E-05	2.09E-05	2.01E-05	2.01E-05
	HGF	2.08E-01	2.94E-01	2.58E-01	2.58E-01
	CF	1.91E+04	2.25E+04	2.25E+04	2.25E+04
UA0983	COF	1.29E-06	1.26E-06	1.28E-06	1.28E-06
	HGF	2.43E-02	6.15E-02	7.42E-02	7.42E-02
	CF	5.02E+05	5.02E+05	5.02E+05	5.08E+05
UA0984	COF	5.55E-06	5.17E-06	5.27E-06	5.27E-06
	HGF	3.40E-02	5.32E-02	5.49E-02	5.49E-02

@ This is factory calibrated values.

6.4.3 The Conversion Formula

The concentration of gaseous pollutants monitored at one calibration setting may be converted to its equivalent concentrations at the other settings if the parameters at the corresponding setting is known. As stated earlier, a conversion formula is required.

When the gas monitor is detecting a gaseous pollutant, the detected microphone signal is given by this equation

MSd = MSp + MSw + COF................................(1)

where:

MSd = the total microphone signal detected (microvolt)

MSp = the microphone signal due to the gaseous pollutant (microvolt)

MSw = the microphone signal due to water interference (microvolt)

COF = the concentration offset factor for zero point calibration due to instrument noise (microvolt)

By definition,

$HGF = MSw/MSp$

where:

HGF = humidity gain factor due to humidity interference

Therefore equation (1) becomes

$MSd = (1 + HGF) \times MSp + COF$................................(2)

Since $MGM = MS \times CF$

where:

MGM = concentration of the gaseous pollutant (mg/m3)

CF = conversion factor

Equation (2) then becomes

$MSd = (1 + HGF) \times MGM/CF + COF$................................(3)

The concentration of a gaseous pollutant is normally expressed in PPM. The expression for converting PPM to MGM is:

$MGM = PPM \times MW / 24.45$

where:

MW = molecular weight of the gaseous pollutant

Thus equation(3) becomes

$MSd = (1 + HGF) \times PPM \times MW / (24.45 \times CF) + COF$.....................(4)

By rearranging equation (4),

$PPM = 24.45 \times CF \times (MSd - COF) / (MW \times (1 + HGF))$....................(5)

When the calibration of the gas monitor is changed from setting 1 to setting 2, the calibration parameter which remains constant is MSd . The detected microphone signal is independent of setting parameters.

At calibration setting 2, expression (5) becomes

PPM2 = 24.45 x CF2 x (MSd - COF2) / (MW x (1 + HGF2))........(6)

where :
2 refers to the corresponding parameter at calibration setting 2.

In converting PPM1 to PPM2 the MSd to be used in equation (6) is that which was detected in calibration setting 1.

Therefore,

MSd = (1 + HGF1) x PPM1x MW / (24.45 X CF1) + COF1.............(7)

where:
1 refers to the corresponding parameter at the calibration setting 1

Using equations (6) and (7) , it can be derived that the relationship between the corresponding PPM is

PPM2 = a x PPM1 + b..(8)

where:
a = (CF2/CF1) x (1 + HGF1) / (1 + HGF2)
b = CF2 x (COF1 - COF2) / (MWA x (1 + HGF2))
MWA = MW/24.45

In this thesis, equation (8) was used to convert the concentration of gaseous pollutants at different calibration settings

6.5 RELIABILITY

In this research, the monitoring time and the concentration measured should be reliable. This means the instrument should measure at the time it is supposed to measure. This also means the measurement should give the correct reading of the concentration of the airborne pollutants being measured.

Hence, reliability, in this case, requires three conditions:

1) reliability in monitoring time

the monitoring should occur at the intended sub population of monitoring time.

2) reliability of the standard gases

the instrument calibrated with the same standard for the second time should give the same calibration parameters as those given in the first calibration.

3) reliability in the concentration measured

the instrument measuring the same airborne pollutants at the same concentration for the second time should display the same reading of the concentration as the first measurement.

Each of the three conditions are discussed separately in the following paragraphs.

6.5.1 Reliability in Monitoring Time

This test is aimed at checking whether or not the gas monitor meets the first condition. In this case, reliability means the gas monitor monitors at a consistent monitoring time intervals.

The reliability of monitoring time of the gas monitor was tested at the Kendal Building. In the SERC/LINK Project, the Kendal Building had the largest number of data monitored.

A total of 13,980 measurements were collected in nine monitoring periods. During that monitoring, the interval time was set at 360 seconds (6 minutes and 0 second). The detail of the monitoring will be elaborated in Chapter 8.

The author found that the interval time was not reproducible. Table 6.1 shows maximum (MAX), average (AVG), minimum (MIN), and the standard deviation (STD) of the interval time and the number of measurements (N) during the test in Kendal Building. In the test, the interval time was not consistent at 6 minutes 0 second as it is supposed to be. The interval time varied from 5 minutes 21 seconds to 6 minutes 37 seconds. However, the average of the interval times was 6 minutes 0 second in each of the nine monitoring periods. The standard deviations of the interval time of the nine monitoring periods were between 2 to 9 seconds. Although the interval time is not reproducible, for the purpose of the SERC/LINK Project, the reliability of the monitoring time is sufficient. This will be elaborated in the section where the validity of monitoring time is discussed.

	MAX	AVG	MIN	STD	N
KEN1	6m 06s	6m 00s	5m 53s	2s	668
KEN2	6m 04s	6m 00s	5m 53s	3s	1,446
KEN3	6m 31s	6m 00s	5m 28s	9s	1,208
KEN4	6m 14s	6m 00s	5m 44s	3s	1,595
KEN5	6m 33s	6m 00s	5m 25s	8s	1,892
KEN6	6m 35s	6m 00s	5m 21s	7s	1,668
KEN7	6m 05s	6m 00s	5m 51s	4s	1,701
KEN8	6m 37s	6m 00s	5m 22s	5s	1,719
KSUM	6m 14s	6m 00s	5m 44s	3s	2,063

Table 6.1
Interval Time of Gas Monitor During the Monitoring in Kendal Building

6.5.2 Reliability of Standard Gas

This section discusses whether or not the second condition is met. It begins by clarifying the meaning of the reliability of standard gas. Next, the conditions to meet the reliability are identified. After discussing whether these conditions were observed, a suggestion to improve reliability is made. Finally the zero point error in the calibration are estimated and the assumptions are stated.

For the standard gas to be reliable, two conditions should be fulfilled:

1) the calibration of the gas monitor using the same standard gas for the second time should give the same calibration setting as the first calibration. In this case the same gas means that the second gas sample is taken from the same gas bottle.

2) the calibration of the gas monitor using the standard gas from the second gas bottle, of the same purity, should give the same calibration setting as the gas taken from the first gas bottle.

The first condition for standard gas is achieved if the gas bottle and the connecting tubes to the gas monitor are made of material inert to the standard gas. In this research, the gas bottle is made of steel and the connecting tube is made of Teflon. Teflon is a type of tetrafluorethylene polymer (Fachinformationszentrum Chemie GmbH, 1992). The properties of tetrafluoroethylene which are relevant to this condition are: non-stick to airborne pollutants, melting point of 327 degrees Celsius, and exceptional resistance to chemical attack (Saunders, 1988).

The second condition for standard gas is achieved if the standard gas of the two gas bottles have the same purity. Purity refers to the types and relative concentration of inteferent gases in the gas bottles. Interferent means any substances, which if exist in the sample cell, contribute to the current detected in the microphone of the gas monitor. Ideally the standard gas should not contain any interferents. However, the standard gas is normally supplied with a known type and concentration of interferents. Thus, to meet the second condition, the standard gas in the two bottles should have the same type and concentration of interferents.

To improve the reliability, as required in the second condition, the two gas bottles should contain the standard gas manufactured in the same batch. In this research the standard gas from more than one bottle was used. It is not known whether the standard gas was manufactured from the same batch. However the uncertainty in the reliability of the standard gas may be estimated if the manufacturer specifies the type and concentration of the interferents.

The uncertainty in the reliability of the standard gas may be estimated in terms of zero point and span calibration errors.

Zero point error, in this case, means the maximum expected uncertainty in determining zero point due to the unreliability of the zero gas used in the calibration. The zero gas used in this research was the BOC pure nitrogen of grade N5.5. Besides nitrogen, the zero gas contained carbon dioxide, carbon monoxide, and total hydrocarbon. The concentration of each of the three impurities was not more than 0.5 ppm. For this reason the zero point error for optical filter UA 0983 specific for carbon dioxide was 0.5 ppm. Similarly the zero point error for optical filter UA 0984 specific for carbon monoxide was 0.5 ppm.

The zero point error for optical filter UA 0987 was assumed to be 0.5 ppm. The assumption in this case was that n- hexane, 1-decene, ethylene, 2-butanone, and n-butylacetate, if existed in the zero gas tested in determining its impurity, would not give a concentration larger than 0.5 ppm if it were to be measured using the gas monitor.

In the above estimation of zero point error, it was assumed that the zero gas was perfectly dry. The concentration of water, which is an interferent for the three filters, in the zero gas is not stated by the manufacturer. Therefore the uncertainty in the reliability of the zero gas due to water cannot be estimated. This unreliability can be avoided by using the zero gas from the same gas bottle or gas bottles from the same manufacturing batch.

Span error in this case means the maximum expected uncertainty in determining two points calibration span. The span error may be estimated as follows:

a) TVOCs

Since the standard gas used was of 100 ppm and an error up to 0.5 ppm may be introduced at zero point by zero gas, the error due to span calibration is 0.5 percent (or 0.5 of 100)

b) carbon dioxide

Since the standard gas used was of 540 ppm and an error up to 0.5 ppm may be introduced at zero point by zero gas, the error due to span calibration is 0.09 percent (or 0.5 of 540)

c) carbon monoxide

Since the standard gas used was of 10 ppm and an error up to 0.5 ppm may be introduced at zero point by zero gas, the error due to span calibration is 5 percent (or 0.5 of 10)

6.5.3 Reliability in the Concentration Measured

This section discusses whether or not the gas monitor meet the third condition of reliability. The subsequent discussion is divided into two sub-sections:

1) reliability of detection (Section 6.5.3.1);
2) reliability of the population measured (Section 6.5.3.2).

6.5.3.1 Reliability of Detection

This sub-section discusses how the reliability test of detection was indirectly conducted, how the reliability was estimated, the test result, and finally the limitation of the test. It divided into three parts: test, result, finding, and limitation.

Test

The reliability of the detection was indirectly tested during zero point calibration in the laboratory at Wates House on 30 July 1993. The detail of the calibration is discussed in Chapter 8.

During calibration, the gas monitor does not display the true value of the microphone signals but it does display the average value (MEAN) and the standard deviation (SD) of the average of the last six microphone signals (See Table 6.2). Therefore, in the test, the variation of the instantaneous concentration of an airborne pollutant, as displayed by the gas monitor, was approximated.

TIME	MEAN (mv)	SD (nv)	DVR
14:22	7.41	95.0	1.3
14:24	7.43	99.5	1.3
14:25	7.44	102.0	1.4
14:27	7.47	42.0	0.6
14:29	7.44	64.9	0.9
14:32	7.45	77.2	1.0
14:34	7.43	105.0	1.4
14:36	7.43	103.0	1.4
14:38	7.40	104.0	1.4
14:41	7.42	112.0	1.5
14:43	7.44	105.0	1.4
14:45	7.39	118.0	1.6
14:47	7.38	121.0	1.6
14:05	7.35	110.0	1.5
14:52	7.35	111.0	1.5
14:54	7.28	107.0	1.5
14:57	7.25	71.1	1.0
14:59	7.28	77.5	1.1
15:01	7.31	95.0	1.3

Table 6.2
The Fluctuation of Signal During Zero Point Calibration When the Gas Monitor was Fitted with Filter SB 0542

During the reliability test, the reliability of detection of the monitor was approximated from its deviation ratio (DVR) (See Table 6.2). For the purpose of this discussion, deviation ratio is defined as the ratio of the standard deviation of the average to the average value of the last six displayed microphone signals. The ratio is expressed in percentage.

Theoretically, if the reliability of the gas monitor is perfect, the monitor which measures the same concentration of an airborne pollutant for the second time will display the same microphone signals as those displayed for the first time. Consequently, under this ideal condition, all of the last six measured signals will have the same reading. Therefore, the standard deviation of the last six microphone signals will be zero. This means if the reliability of the detection of the gas monitor is perfect, the deviation ratio will be zero.

At the reliability suggested by the manufacturer, the deviation ratio should have been not more than 1.0 percent.

Result

During the reliability test, the deviation ratio (DVR) varied from 0.6 to 1.6 percent with an average of 1.3 percent (See Table 6.2 and Figure 6.1).

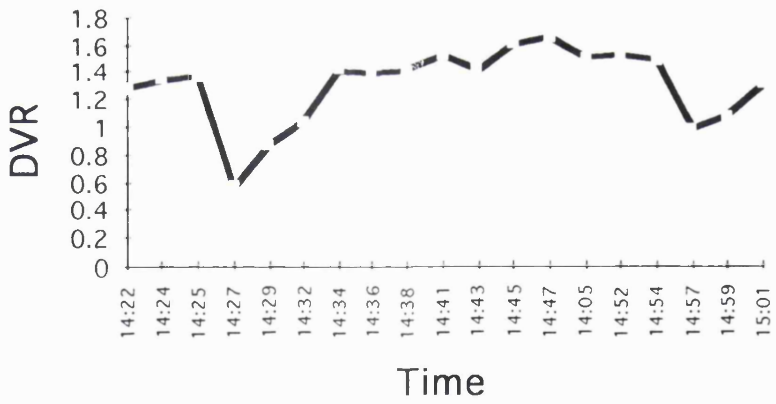


Figure 6.1
Reliability of Microphone Signal During Reliability Test

Finding

This test suggests that DVR up to1.6 percent occur even over short sampling period which is greater than manufacturer's claim of 1 percent. In addition there is a considerable drift (2.96 percent) which occur over a time of 39 minutes.

Limitation

This reliability test on detection is based on two assumptions:

1) the zero gas in the gas bottle used in the calibration is homogenous.

Consequently, the zero gas of the same concentration was assumed to be flowing to the gas monitor during the reliability test. Therefore, the fluctuation of the microphone signals was assumed to be due to instrument noise only.

2) the operation of the gas monitor is in a steady condition.

In this case, steady condition means the steady condition which is practically achievable during field monitoring. The operation of the gas monitor is assumed to be in a steady condition after its minimum warm up time and operating temperature for calibration, as recommended by the manufacturer, are fulfilled. During field monitoring, it is not practical to warm up the gas monitor for more than 3 hours.

The manufacturer suggests that the gas monitor be warmed up for at least 30 minutes and the temperature of the sampling cell be raised at least 15 degrees Celsius above the ambient temperature before the calibration starts.

The test was conducted after the gas monitor was warmed up for 2 hours 37 minutes beyond the minimum recommended and the operating temperature of the sampling cell was at least 6.5 degrees Celsius hotter than the minimum recommended.

During the calibration, the gas monitor was switched on for calibration at 11:15 a.m. but the reliability test was recorded from 2:22 p.m. to 3:01 p.m. During the test, the temperature of sampling cell was between 43.5 and 44.4 degrees Celsius, and the ambient temperature was approximately 22 degrees Celsius.

6.5.3.2 Reliability of the Population Measured

The purpose of the following reliability analysis is to determine if the concentration in any populations of other monitoring time intervals or starting time are reliable representative of those in the population of 5 minute monitoring interval. The population of concentrations measured by the gas monitor was determined by the time interval of monitoring. The shortest and practical time interval in the SERC/LINK Project was 5 minutes. With this time interval, the concentration of airborne pollutants of up to one week can be collected. If a shorter time interval was used, the duration of monitoring would have been shorter than a week.

The above question was theoretically answered in the monitoring at the Trowbridge Building. The answer was inferred from the field data of this monitoring by a theoretical analysis. At the Trowbridge Building, the concentrations of TVOCs, carbon dioxide, and carbon monoxide were monitored from 6:00 a.m. on 22 July 1992 to 2:09 p.m. on 29 July 1992 at 5 minutes time interval. The monitoring was conducted in an area occupied by office workers at location 2P2 (See Chapter 7). During the monitoring, 458 of the total of 1,828 concentrations were recorded during working hours.

The 458 concentrations of the gaseous pollutants are used as the elements of a population. This population is called population 5Mx. 5M refers to the monitoring interval of 5 minutes. x refers to the gaseous pollutants: TV for TVOCs, CD for carbon dioxide, and CM for carbon monoxide. The elements are arranged sequentially according to the monitoring time. In other words, the second element of the population 5MTV is the concentration of the TVOCs monitored approximately 5 minutes after that of the first element and so on.

Reliability analysis of the population measured may be divided into two: A) reliability due to time interval and B)reliability due to sequence.

A) Reliability due to Time Interval

Reliability, in this context, means the monitoring using any time interval will give the same average concentration.

The purpose of this reliability analysis is to have an idea of how much is the error when the average concentration of the gaseous pollutants monitored using a longer time interval is used rather than those monitored using a time interval of 5 minutes. This error is an approximation of the error that should be considered if this monitoring technique is used to decide whether or not a standard is conformed.

In this case the best practical average may be obtained by setting the time interval of the gas monitor at 5 minutes. For the purpose of this reliability test, a field measurement at 5 minutes time interval was conducted in the test building. With this monitoring time interval, the concentration of airborne pollutants up to one week can be collected. If a shorter time interval was used, the duration of monitoring would have been shorter than a week.

However, the time interval actually used in the Kendal and Cardiff Buildings was 48 minutes. For the purpose of this reliability analysis, a time interval of 45 minutes is used to estimate the error, for two reasons. First, 45 minutes interval is a multiple of 5 minutes, thus the field data may be used. Second, 45 minutes is not significantly different from 48 minutes. Therefore, in this analysis the error is estimated by comparing the average at time interval of 45 minutes with those at time interval of 5 minutes.

Result

a) In most of the cases the difference is statistically insignificant. In this case `significant' refers to statistical significance at 0.05. `Difference' refers to the difference between average concentration of the population of 5 minute interval time and those of other interval times. The degree of freedom in all tests are greater than 120. Since the t value for 120 is 1.658 and for infinity is 1.645, a value of t exceeding 1.658 is considered as statistically significant. This suggests that the difference is due to random fluctuations of the data. The insignificant difference is described below:

i) The average concentrations of carbon dioxide in all of the sub populations of 5MCD of different time intervals are not significantly different from that of the population of 5MCD. Table 6.3 shows the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD) and the number of data (N) in the population 5MCD. Tables 6.4 through 6.7 show the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), the number of data (N), the difference (DIFF), the result of the t-test of significance (t), and degree of freedom (DF) of all of the sub populations of 5MCD of different time intervals.

	MAX	AVG	MIN	STD	N
5MCD	761	588	452	54	458

Table 6.3
The characteristic of population 5MTV.

	MAX	AVG	MIN	STD	N	DIFF	t	DF
15MCD1	761	588	452	57	153	0.12	0.02	609
15MCD2	742	589	461	52	153	1.11	0.23	609
15MCD3	756	586	456	52	152	-1.25	-0.25	608

Table 6.4
t-test of significance on the sub-population of 5MCD of 15 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
30MCD1	761	588	455	61	77	0.37	0.05	533
30MCD2	742	587	463	55	77	-0.17	-0.02	533
30MCD3	756	587	456	57	76	-0.77	-0.11	532
30MCD4	743	587	452	53	76	-0.13	-0.02	532
30MCD5	727	590	461	50	76	2.41	0.38	532
30MCD6	722	586	462	47	76	-1.73	-0.29	532

Table 6.5
t-test of significance on the sub-population of 5MCD of 30 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
45MCD1	761	582	455	55	51	-5.93	-0.73	507
45MCD2	727	590	464	50	51	2.27	0.30	507
45MCD3	685	586	462	55	51	-1.17	-0.15	507
45MCD4	723	587	454	51	51	-0.75	-0.10	507
45MCD5	727	583	461	50	51	-4.70	-0.63	507
45MCD6	756	584	483	49	51	-3.31	-0.46	507
45MCD7	751	595	452	64	51	7.05	0.76	507
45MCD8	742	593	463	57	51	5.77	0.69	507
45MCD9	722	588	456	54	50	0.78	0.10	506

Table 6.6
t-test of significance on the sub-population of 5MCD of 45 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
60MCD1	692	587	478	55	39	-0.10	-0.01	495
60MCD2	733	584	465	57	39	-3.45	-0.36	495
60MCD3	701	592	456	57	38	4.56	0.48	494
60MCD4	738	588	454	54	38	0.36	0.04	494
60MCD5	727	594	492	46	38	6.93	0.89	494
60MCD6	722	588	486	52	38	0.42	0.05	494
60MCD7	761	588	455	67	38	0.86	0.08	494
60MCD8	742	591	463	53	38	3.20	0.36	494
60MCD9	756	581	486	58	38	-6.09	-0.62	494
60MCD10	743	587	452	53	38	-0.62	-0.07	494
60MCD11	694	585	461	54	38	-2.10	-0.23	494
60MCD12	665	584	462	41	38	-3.87	-0.55	494

Table 6.7
t-test of significance on the sub-population of 5MCD of 60 minutes interval

ii) Except in the sub population 60MCM2, the average concentrations of carbon monoxide in all of the other sub populations 5MCM of different time intervals are not significantly different from the population 5MCM. Table 6.8 shows the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD) and the number of data (N) in the population 5MCM. Tables 6.9 through 6.12 show the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), the number of data (N), the difference (DIFF), the result of the t-test of significance (t), and degree of freedom (DF) of all of the sub populations 5MCM of different time intervals.

	MAX	AVG	MIN	STD	N
5MCM	2.82	2.24	1.74	0.22	458

Table 6.8
The characteristic of population 5MCM.

	MAX	AVG	MIN	STD	N	DIFF	t	DF
15MCM1	2.72	2.24	1.75	0.21	153	0.01	0.27	609
15MCM2	2.75	2.25	1.74	0.22	153	0.01	0.58	609
15MCM3	2.82	2.22	1.78	0.23	152	-0.02	-0.81	608

Table 6.9
t-test of significance on the sub-population of 5MCM of 15 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
30MCM1	2.66	2.22	1.75	0.18	77	-0.02	-0.88	533
30MCM2	2.75	2.27	1.74	0.21	77	0.03	1.32	533
30MCM3	2.82	2.22	1.78	0.23	76	-0.02	-0.64	532
30MCM4	2.72	2.27	1.78	0.23	76	0.03	1.10	532
30MCM5	2.66	2.22	1.78	0.22	76	-0.01	-0.44	532
30MCM6	2.73	2.22	1.81	0.23	76	-0.02	-0.58	532

Table 6.10
t-test of significance on the sub-population of 5MCM of 30 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
45MCM1	2.64	2.28	1.78	0.21	51	0.04	1.29	507
45MCM2	2.64	2.24	1.86	0.20	51	0.01	0.20	507
45MCM3	2.82	2.23	1.83	0.21	51	-0.01	-0.27	507
45MCM4	2.72	2.22	1.78	0.21	51	-0.02	-0.66	507
45MCM5	2.75	2.25	1.74	0.24	51	0.01	0.32	507
45MCM6	2.73	2.21	1.78	0.24	51	-0.03	-0.90	507
45MCM7	2.71	2.23	1.75	0.20	51	0.00	-0.10	507
45MCM8	2.66	2.25	1.78	0.21	51	0.02	0.56	507
45MCM9	2.70	2.23	1.81	0.24	50	-0.01	-0.32	506

Table 6.11
t-test of significance on the sub-population of 5MCM of 45 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
60MCM1	2.62	2.24	1.80	0.17	39	0.01	0.20	495
60MCM2	2.75	2.30	1.92	0.21	39	0.06	1.83	495
60MCM3	2.58	2.24	1.82	0.19	38	0.01	0.17	494
60MCM4	2.71	2.27	1.78	0.23	38	0.04	0.97	494
60MCM5	2.63	2.23	1.78	0.21	38	-0.01	-0.33	494
60MCM6	2.71	2.26	1.90	0.21	38	0.03	0.77	494
60MCM7	2.66	2.19	1.75	0.19	38	-0.05	-1.47	494
60MCM8	2.70	2.24	1.74	0.22	38	0.01	0.16	494
60MCM9	2.82	2.20	1.78	0.25	38	-0.04	-0.97	494
60MCM10	2.72	2.26	1.78	0.24	38	0.03	0.63	494
60MCM11	2.66	2.22	1.85	0.22	38	-0.01	-0.32	494
60MCM12	2.73	2.18	1.81	0.24	38	-0.06	-1.51	494

Table 6.12
t-test of significance on the sub-population of 5MCM of 60 minutes interval

iii) The average concentrations of TVOCs in the sub populations of 5MTV, other than those will be described in (b), are not significantly different from each other. Table 6.13 shows the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), and the number of data (N) in the population 5MTV. Tables 6.14 through 6.17 show the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), the number of data (N), the difference (DIFF), the result of the t-test of significance (t), and degree of freedom (DF) of all of the sub populations 5MTV of different time intervals.

	MAX	AVG	MIN	STD	N
5MTV	13.04	3.39	2.19	0.96	458

Table 6.13
The characteristic of population 5MTV.

	MAX	AVG	MIN	STD	N	DIFF	t	DF
15MTV1	8.24	3.52	2.19	0.98	153	0.13	1.45	609
15MTV2	13.04	3.46	2.19	1.15	153	0.07	0.72	609
15MTV3	6.78	3.18	2.25	0.68	152	-0.21	-2.92	608

Table 6.14
t-test of significance on the sub-population of 5MTV of 15 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
30MTV1	8.24	3.65	2.29	1.11	77	0.26	1.97	533
30MTV2	6.50	3.44	2.35	0.85	77	0.06	0.53	533
30MTV3	6.78	3.22	2.25	0.76	76	-0.17	-1.76	532
30MTV4	6.71	3.39	2.19	0.81	76	0.00	-0.03	532
30MTV5	13.04	3.48	2.19	1.40	76	0.09	0.56	532
30MTV6	5.85	3.14	2.25	0.59	76	-0.24	-2.99	532

Table 6.15
t-test of significance on the sub-population of 5MTV of 30 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
45MTV1	8.24	3.58	2.55	1.08	51	0.19	1.23	507
45MTV2	6.50	3.38	2.19	0.85	51	-0.01	-0.09	507
45MTV3	5.40	3.16	2.25	0.66	51	-0.22	-2.17	507
45MTV4	5.65	3.42	2.32	0.80	51	0.04	0.30	507
45MTV5	6.46	3.52	2.27	0.95	51	0.13	0.91	507
45MTV6	6.78	3.21	2.26	0.74	51	-0.18	-1.59	507
45MTV7	6.78	3.55	2.19	1.05	51	0.17	1.08	507
45MTV8	13.04	3.50	2.29	1.54	51	0.11	0.49	507
45MTV9	5.85	3.17	2.25	0.63	50	-0.22	-2.18	506

Table 6.16
t-test of significance on the sub-population of 5MTV of 45 minutes interval

	MAX	AVG	MIN	STD	N	DIFF	t	DF
60MTV1	5.65	3.52	2.29	0.91	39	0.14	0.89	495
60MTV2	6.17	3.45	2.47	0.77	39	0.06	0.49	495
60MTV3	5.40	3.26	2.25	0.67	38	-0.12	-1.06	494
60MTV4	5.24	3.39	2.19	0.67	38	0.00	-0.02	494
60MTV5	6.42	3.32	2.30	0.80	38	-0.07	-0.51	494
60MTV6	5.85	3.28	2.30	0.62	38	-0.11	-0.96	494
60MTV7	8.24	3.78	2.40	1.28	38	0.40	1.86	494
60MTV8	6.50	3.43	2.35	0.92	38	0.05	0.30	494
60MTV9	6.78	3.17	2.26	0.84	38	-0.22	-1.52	494
60MTV10	6.71	3.39	2.25	0.94	38	0.00	-0.02	494
60MTV11	13.04	3.64	2.19	1.81	38	0.26	0.87	494
60MTV12	4.26	3.01	2.25	0.53	38	-0.38	-3.92	494

Table 6.17
t-test of significance on the sub-population of 5MTV of 60 minutes interval

b) In some cases the difference is statistically significant:

i) the average concentrations of TVOCs of some sub population of 5MTV namely 15MTV3, 30MTV1, 30MTV3, 30MTV6, 45MTV3, 45MTV9, 60MTV7, and 60MTV12 are significantly different from the population 5MTV. The maximum difference, in the concentration of TVOC, due to interval time at the time interval of 45 minutes is 0.22 ppm. This occurs in the sub population 45MTV9 (see Table 6.16);

ii) the average concentrations of carbon monoxide of sub population of 60MCM2 is significantly different from that of the population 5MCM. The difference is 0.06 ppm (See Table 6.12);

c) there is no consistent pattern of relationship between the maximum difference and time interval. The maximum difference either increases (sub population 15MTV3 in Table 6.14 versus sub population 30MTV1 in Table 6.15) or decreases (sub population 30MTV1 in Table 6.15 versus sub population 45MTV9 in Table 6.16) with increasing time interval.

Interpretation

1) The differences in (b) suggests an error to be considered in interpreting the data. This error should be considered when the monitored data is compared with a standard. The error is of 0.22 ppm, as estimated in b(i), when monitoring TVOCs, using a time interval of 45 minutes.

2) The result (c) suggests that there is no consistent relationship between this type of error with the time interval used.

B) Reliability due to Sequencing

Reliability, in this context, means the average concentration of gaseous pollutants in all monitorings are the same and are independent of starting time as long as the monitorings occur in the same monitoring period and time interval,

The purpose of this reliability analysis is to have an idea of how much is the error in the average concentration of gaseous pollutants when they are monitored at anytime within the same monitoring period and using the same time interval. This type of error should be considered when the average concentration of pollutants monitored sequentially, at different locations, are compared to each other.

In this reliability analysis, only the sub populations of 45 minutes interval time are used. These are the closest sub populations to those used in the field monitoring in terms of interval time. The interval time for field monitoring was 48 minutes.

Result

a) In most of the cases the difference is statistically insignificant. In this case `significant' refers to statistical significance at 0.05. The degree of freedom is either 99 or 100. Since the t value for 60 is 1.671 and for 120 is 1.658, a value of t exceeding 1.66 is considered as statistically significant. This suggests that the difference is due to random fluctuations of the data. The insignificant difference is described below:

i) The average concentrations of carbon dioxide in different sub populations of 5MCD are not significantly different from each other. Table 6.18 shows the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD) and the number of data (N) in all of the sub populations. Tables 6.19 through 6.27 show the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), the number of data (N), the difference (DIFF), the result of the t-test of significance (t), and degree of freedom (DF) when the sub populations are compared to each other.

	MAX	AVG	MIN	STD	N
45MCD1	761	582	455	55	51
45MCD2	727	590	464	50	51
45MCD3	685	586	462	55	51
45MCD4	723	587	454	51	51
45MCD5	727	583	461	50	51
45MCD6	756	584	483	49	51
45MCD7	751	595	452	64	51
45MCD8	742	593	463	57	51
45MCD9	722	588	456	54	50

Table 6.18
Average concentrations, standard deviation of the average and the number of data in sub-population of 5MCD

	DIFF	t	DF
45MCD2	8	0.78	100
45MCD3	5	0.44	100
45MCD4	5	0.49	100
45MCD5	1	0.12	100
45MCD6	3	0.25	100
45MCD7	13	1.09	100
45MCD8	12	1.05	100
45MCD9	7	0.62	99

Table 6.19
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD1

	DIFF	t	DF
45MCD1	-8	-0.78	100
45MCD3	-3	-0.33	100
45MCD4	-3	-0.30	100
45MCD5	-7	-0.70	100
45MCD6	-6	-0.57	100
45MCD7	5	0.42	100
45MCD8	4	0.33	100
45MCD9	-1	-0.14	99

Table 6.20
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD2

	DIFF	t	DF
45MCD1	-5	-0.44	100
45MCD2	3	0.33	100
45MCD4	0	0.04	100
45MCD5	-4	-0.34	100
45MCD6	-2	-0.21	100
45MCD7	8	0.70	100
45MCD8	7	0.63	100
45MCD9	2	0.18	99

Table 6.21
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD3

	DIFF	t	DF
45MCD1	-5	-0.49	100
45MCD2	3	0.30	100
45MCD3	0	-0.04	100
45MCD5	-4	-0.39	100
45MCD6	-3	-0.26	100
45MCD7	8	0.68	100
45MCD8	7	0.61	100
45MCD9	2	0.15	99

Table 6.22
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD4

	DIFF	t	DF
45MCD1	-1	-0.12	100
45MCD2	7	0.70	100
45MCD3	4	0.34	100
45MCD4	4	0.39	100
45MCD6	1	0.14	100
45MCD7	12	1.03	100
45MCD8	10	0.99	100
45MCD9	5	0.53	99

Table 6.23
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD5

	DIFF	t	DF
45MCD1	-3	-0.25	100
45MCD2	6	0.57	100
45MCD3	2	0.21	100
45MCD4	3	0.26	100
45MCD5	-1	-0.14	100
45MCD7	10	0.92	100
45MCD8	9	0.87	100
45MCD9	4	0.40	99

Table 6.24
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD6

	DIFF	t	DF
45MCD1	-13	-1.09	100
45MCD2	-5	-0.42	100
45MCD3	-8	-0.70	100
45MCD4	-8	-0.68	100
45MCD5	-12	-1.03	100
45MCD6	-10	-0.92	100
45MCD8	-1	-0.11	100
45MCD9	-6	-0.53	99

Table 6.25
t-test of significance on the sub-populations of 5MCD in comparison with the sub-popuiation of 45MCD7

	DIFF	t	DF
45MCD1	-12	-1.05	100
45MCD2	-4	-0.33	100
45MCD3	-7	-0.63	100
45MCD4	-7	-0.61	100
45MCD5	-10	-0.99	100
45MCD6	-9	-0.87	100
45MCD7	1	0.11	100
45MCD9	-5	-0.45	99

Table 6.26
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD8

	DIFF	t	DF
45MCD1	-7	-0.62	99
45MCD2	1	0.14	99
45MCD3	-2	-0.18	99
45MCD4	-2	-0.15	99
45MCD5	-5	-0.53	99
45MCD6	-4	-0.40	99
45MCD7	6	0.53	99
45MCD8	5	0.45	99

Table 6.27
t-test of significance on the sub-populations of 5MCD in comparison with the sub-population of 45MCD9

ii) The average concentrations of carbon monoxide in different sub populations of 5MCM are not significantly different from each other. Table 6.28 shows the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD) and the number of data (N) in all of the sub populations. Tables 6.29 through 6.37 show the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), the number of data (N), the difference (DIFF), the result of the t-test of significance (t), and degree of freedom (DF) when the sub populations are compared to each other.

	MAX	AVG	MIN	STD	N
45MCM2	2.64	2.24	1.86	0.20	51
45MCM3	2.82	2.23	1.83	0.21	51
45MCM4	2.72	2.22	1.78	0.21	51
45MCM5	2.75	2.25	1.74	0.24	51
45MCM6	2.73	2.21	1.78	0.24	51
45MCM7	2.71	2.23	1.75	0.20	51
45MCM8	2.66	2.25	1.78	0.21	51
45MCM9	2.70	2.23	1.81	0.24	50

Table 6.28
Average concentrations, standard deviation of the average and the number of data in sub-popuiation of 5MCM

	DIFF	t	DF
45MCM2	-0.03	-0.83	100
45MCM3	-0.05	-1.16	100
45MCM4	-0.06	-1.45	100
45MCM5	-0.03	-0.65	100
45MCM6	-0.07	-1.60	100
45MCM7	-0.04	-1.05	100
45MCM8	-0.02	-0.52	100
45MCM9	-0.05	-1.15	99

Table 6.29
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM1

	DIFF	t	DF
45MCM1	0.03	0.83	100
45MCM3	-0.01	-0.35	100
45MCM4	-0.03	-0.65	100
45MCM5	0.01	0.12	100
45MCM6	-0.04	-0.86	100
45MCM7	-0.01	-0.23	100
45MCM8	0.01	0.29	100
45MCM9	-0.02	-0.39	99

Table 6.30
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM2

	DIFF	t	DF
45MCM1	0.05	1.16	100
45MCM2	0.01	0.35	100
45MCM4	-0.01	-0.30	100
45MCM5	0.02	0.44	100
45MCM6	-0.02	-0.52	100
45MCM7	0.01	0.13	100
45MCM8	0.03	0.62	100
45MCM9	0.00	-0.06	99

Table 6.31
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM3

	DIFF	t	DF
45MCM1	0.06	1.45	100
45MCM2	0.03	0.65	100
45MCM3	0.01	0.30	100
45MCM5	0.03	0.72	100
45MCM6	-0.01	-0.24	100
45MCM7	0.02	0.43	100
45MCM8	0.04	0.91	100
45MCM9	0.01	0.22	99

Table 6.32
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM4

	DIFF	t	DF
45MCM1	0.03	0.65	100
45MCM2	-0.01	-0.12	100
45MCM3	-0.02	-0.44	100
45MCM4	-0.03	-0.72	100
45MCM6	-0.04	-0.91	100
45MCM7	-0.01	-0.33	100
45MCM8	0.01	0.15	100
45MCM9	-0.02	-0.47	99

Table 6.33
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM5

	DIFF	t	DF
45MCM1	0.07	1.60	100
45MCM2	0.04	0.86	100
45MCM3	0.02	0.52	100
45MCM4	0.01	0.24	100
45MCM5	0.04	0.91	100
45MCM7	0.03	0.65	100
45MCM8	0.05	1.10	100
45MCM9	0.02	0.43	99

Table 6.34
t-test of significance on the sub-populations of 5MCM in comparison with the sub-popuiation of 45MCM6

	DIFF	t	DF
45MCM1	0.04	1.05	100
45MCM2	0.01	0.23	100
45MCM3	-0.01	-0.13	100
45MCM4	-0.02	-0.43	100
45MCM5	0.01	0.33	100
45MCM6	-0.03	-0.65	100
45MCM8	0.02	0.51	100
45MCM9	-0.01	-0.18	99

Table 6.35
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM7

	DIFF	t	DF
45MCM1	0.02	0.52	100
45MCM2	-0.01	-0.29	100
45MCM3	-0.03	-0.62	100
45MCM4	-0.04	-0.91	100
45MCM5	-0.01	-0.15	100
45MCM6	-0.05	-1.10	100
45MCM7	-0.02	-0.51	100
45MCM9	-0.03	-0.65	99

Table 6.36
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM8

	DIFF	t	DF
45MCM1	0.05	1.15	99
45MCM2	0.02	0.39	99
45MCM3	0.00	0.06	99
45MCM4	-0.01	-0.22	99
45MCM5	0.02	0.47	99
45MCM6	-0.02	-0.43	99
45MCM7	0.01	0.18	99
45MCM8	0.03	0.65	99

Table 6.37
t-test of significance on the sub-populations of 5MCM in comparison with the sub-population of 45MCM9

iii) The average concentrations of TVOCs in the sub populations of 5MTV, other than those described in (b) below, are not significantly different from each other. Table 6.38 shows the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD) and the number of data (N) in all of the sub populations. Tables 6.39 through 6.47 show the maximum (MAX), average (AVG), minimum (MIN), standard deviation (STD), the number of data (N), the difference (DIFF), the result of the t-test of significance (t), and degree of freedom (DF) when the sub populations are compared to each other.

	AVG	STD	N
45MTV1	3.58	1.08	51
45MTV2	3.38	0.85	51
45MTV3	3.16	0.66	51
45MTV4	3.42	0.80	51
45MTV5	3.52	0.95	51
45MTV6	3.21	0.74	51
45MTV7	3.55	1.05	51
45MTV8	3.50	1.54	51
45MTV9	3.17	0.63	50

Table 6.38
Average concentrations, standard deviation of the average and the number of data in sub-population of 5MTV

	DIFF	t	DF
45MTV2	-0.20	-1.064	100
45MTV3	-0.42	-2.360	100
45MTV4	-0.16	-0.841	100
45MTV5	-0.07	-0.329	100
45MTV6	-0.37	-2.041	100
45MTV7	-0.03	-0.130	100
45MTV8	-0.09	-0.327	100
45MTV9	-0.41	-2.346	99

Table 6.39
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV1

	DIFF	t	DF
45MTV1	0.20	1.064	100
45MTV3	-0.21	-1.407	100
45MTV4	0.05	0.287	100
45MTV5	0.14	0.775	100
45MTV6	-0.17	-1.067	100
45MTV7	0.18	0.936	100
45MTV8	0.12	0.482	100
45MTV9	-0.21	-1.383	99

Table 6.40
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV2

	DIFF	t	DF
45MTV1	0.42	2.360	100
45MTV2	0.21	1.407	100
45MTV4	0.26	1.789	100
45MTV5	0.35	2.169	100
45MTV6	0.04	0.315	100
45MTV7	0.39	2.246	100
45MTV8	0.33	1.415	100
45MTV9	0.01	0.053	99

Table 6.41
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV3

	DIFF	t	DF
45MTV1	0.16	0.841	100
45MTV2	-0.05	-0.287	100
45MTV3	-0.26	-1.789	100
45MTV5	0.09	0.528	100
45MTV6	-0.22	-1.415	100
45MTV7	0.13	0.706	100
45MTV8	0.07	0.296	100
45MTV9	-0.25	-1.771	99

Table 6.42
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV4

	DIFF	t	DF
45MTV1	0.07	0.329	100
45MTV2	-0.14	-0.775	100
45MTV3	-0.35	-2.169	100
45MTV4	-0.09	-0.528	100
45MTV6	-0.31	-1.823	100
45MTV7	0.04	0.196	100
45MTV8	-0.02	-0.078	100
45MTV9	-0.34	-2.155	99

Table 6.43
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV5

	DIFF	t	DF
45MTV1	0.37	2.041	100
45MTV2	0.17	1.067	100
45MTV3	-0.04	-0.315	100
45MTV4	0.22	1.415	100
45MTV5	0.31	1.823	100
45MTV7	0.35	1.924	100
45MTV8	0.29	1.204	100
45MTV9	-0.04	-0.271	99

Table 6.44
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV6

	DIFF	t	DF
45MTV1	0.03	0.130	100
45MTV2	-0.18	-0.936	100
45MTV3	-0.39	-2.246	100
45MTV4	-0.13	-0.706	100
45MTV5	-0.04	-0.196	100
45MTV6	-0.35	-1.924	100
45MTV8	-0.06	-0.224	100
45MTV9	-0.38	-2.232	99

Table 6.45
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV7

	DIFF	t	DF
45MTV1	0.09	0.327	100
45MTV2	-0.12	-0.482	100
45MTV3	-0.33	-1.415	100
45MTV4	-0.07	-0.296	100
45MTV5	0.02	0.078	100
45MTV6	-0.29	-1.204	100
45MTV7	0.06	0.224	100
45MTV9	-0.33	-1.395	99

Table 6.46
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV8

	DIFF	t	DF
45MTV1	0.41	2.346	99
45MTV2	0.21	1.383	99
45MTV3	-0.01	-0.053	99
45MTV4	0.25	1.771	99
45MTV5	0.34	2.155	99
45MTV6	0.04	0.271	99
45MTV7	0.38	2.232	99
45MTV8	0.33	1.395	99

Table 6.47
t-test of significance on the sub-populations of 5MTV in comparison with the sub-population of 45MTV9

b) the average concentrations of TVOCs of some sub population of 5MTV are significantly different from each other:

i) Sub population 45MTV1 is significantly different from sub populations 45MTV3, 45MTV6, and 45MTV9. (See Table 6.39)

ii) Sub population 45MTV3 is significantly different from sub populations 45MTV1, 45MTV4, 45MTV5, and 45MTV7. (See Table 6.41)

iii) Sub population 45MTV4 is significantly different from sub populations 45MTV3 and 45MTV9. (See Table 6.42)

iv) Sub population 45MTV5 is significantly different from sub populations 45MTV3, 45MTV6, and 45MTV9. 45MTV6 is significantly different from 45MTV1, 45MTV5, and 45MTV7. (See Table 6.43)

v) Sub population 45MTV7 is significantly different from sub populations 45MTV3, 45MTV6, and 45MTV9. (See Table 6.45)

vi) Sub population 45MTV9 is significantly different from sub populations 45MTV1, 45MTV4, 45MTV5, and 45MTV7. (See Table 6.47)

c) The maximum difference in (b) occurs between 45MTV1 and 45MTV3. The difference is 0.42 ppm.

Interpretation

Result (c) suggests 0.42 ppm as the error to be considered when the average concentration of TVOCs monitored sequentially at different locations are compared to each other.

6.6 VALIDITY

In this research the monitoring location, the monitoring time, and the instruments should be valid. This means the monitoring is conducted at the location where the monitoring is supposed to be conducted, and at the time when the monitoring is supposed to be conducted. This also means the particulate and gas monitors monitor the airborne pollutants they are supposed to monitor. Each of these validity is discussed separately in the following three sections:

1) validity of monitoring location (Section 6.6.1);
2) validity of monitoring time (Section 6.6.2);
3) validity of the instrument (Section 6.6.3).

6.6.1 Validity of Monitoring Location

This section discusses the validity of monitoring location with special reference to the symptomatic areas in the Kendal Building. The same validity principle should be extended to in selecting the asymptomatic and control areas, as elaborated in the first monitoring requirement, so that a valid comparison between the symptomatic and asymptomatic areas could be made. Valid comparison, in this case, means the comparison compares the measurements in the areas it is supposed to compare. For the same reason, the validity principle should also be extended to the selection of the areas in all of the six sub populations and the control areas described in the second monitoring requirement.

In the preceding paragraphs the validity of monitoring locations at the symptomatic areas is discussed. The discussion begins by identifying the problems in selecting the symptomatic areas and the monitoring locations within the symptomatic areas. Next, the basis of selection used and the meaning of validity in the selection are discussed. Finally, a statistical approach to improve the validity is recommended.

This paragraph describes the selection of monitoring area and location within the selected area at the symptomatic areas in the Kendal Building. For the purpose of this discussion the population of interest is the symptomatic areas only. The selection of monitoring location which affects validity occurred at two stages. The first stage was the selection of four out of five monitoring areas. In this case, the five areas were the symptomatic areas, LOC-2, LOC- 4, LOC-5, LOC-6, and LOC-8, identified by the SERC/LINK Project. For economical reason, only LOC-2, LOC-4, LOC-5, and LOC-6 were selected. (See Chapter 8). The second stage was the selection of the monitoring location within the selected monitoring areas.

This paragraph describes the basis used for the above selections. In the first stage, the selection was based on the location number: the smaller four numbers were selected. In the second stage, the selection was based on practicality: convenience of hanging the monitoring tube and minimum disturbance to the office workers. The location was at the ceiling lamp nearest to the office worker's table.

This paragraph describes the meaning of validity in the above selections. As described earlier, validity means the monitoring monitors what it is supposed to monitor. In the first stage, the selection is valid if the result of the monitoring at the four selected areas is representative of the five symptomatic areas identified in the building. In the second stage, the selection is valid if the result of the monitoring at the lamp is representative of all possible locations of the inlet tube in the selected symptomatic areas.

Finally, in this paragraph, the technique to improve validity is suggested. In the first stage, theoretically, the validity may be improved by giving each of the five symptomatic areas an equal chance of being selected. Again, theoretically, in the second stage, the validity may be improved by giving any location in the symptomatic areas an equal chance of being selected. That means an equal chance is given to the monitoring locations which will give under represented and over represented measures. Therefore, the selection is fair in terms of representative. Consequently, the selection should be based on random sampling.

6.6.2 Validity in Monitoring Time

Validity in monitoring time depends on the interval of monitoring time, the size of the population of the monitoring time, and the reliability of monitoring time. If the reliability of monitoring time is low, validity requires the monitoring of small population of the time be conducted using a small monitoring time interval.

Validity, in this context, means the monitoring monitors the intended sub population of monitoring time. If the reliability of the monitoring time is poor, the true monitoring time may occur in other monitoring sub populations. However, assuming that the gas monitor display the true monitoring time, the monitoring which occurs outside the intended time may be removed during data analysis. The only problem which may arise is that when the monitoring time interval is large such that only two monitorings are expected from the monitoring sub populations. In this case due to poor reliability, both of the monitorings may occur outside the intended sub population of the monitoring time.

For the purpose of discussion, the above problem is elaborated here. For example, the sub population of time is after the air-conditioning system is switched on at 7:30 a.m. and before the office workers arrive at 8:30 a.m. The monitoring time interval is 45 minutes. Due to poor reliability in the monitoring time, the monitoring may occur at anytime between 20 minutes, before and after, the intended monitoring time. The monitoring for 24-hours began at 12:00 midnight the night before. Therefore the intended monitoring time, for this particular sub population of time, is 8:15 a.m. But the monitoring may occur at 8:35 a.m. This monitoring is not valid. Therefore the sub population of the monitoring time is not represented.

However, the reliability test at the Kendal Building shows that the gas monitor was sufficiently reliable such that the problem described above has an extremely small probability of occurring. As stated earlier, the interval monitoring time during the reliability test was 6 minutes and 0 second. It was found that the standard deviation of interval time was between 6 to 9 seconds. That means the longest expected standard deviation of interval time in the above problem is 1.125 minute. From statistical table, the probability of occurrence of the monitoring time, at four standard deviations of the interval time, after the intended monitoring time, is 0.00003. The monitoring time at four standard deviations of interval time before the intended monitoring time is at 8:19:30 a.m. This means, in terms of probability, it is highly unlikely to have the monitoring occurring at 8:35 a.m.

6.6.3 Validity of the Instrument

6.6.3.1 Particulate Monitor

As described in Chapter 3, according to the World Health Organisation, the hazardous particulate has a size between 0.1 to 10 microns. As described in Chapter 4, the particulate monitor which was used in this research could measure the particulates of sizes between 0.01 and 10 micron. Therefore, the particulate monitor is valid for this monitoring.

6.6.3.2 Gas Monitor

The validity of gas monitor occurs at two levels. First, in selecting the optical filter. Second, in selecting the standard gas.

Therefore, the subsequent discussion is divided into two sections:

1) validity of the optical filters;
2) validity of the standard gases.

Validity of the Optical Filters

The discussion under this section mainly refers to the optical filter UA 0987 which was fitted to the gas monitor. Optical filters UA 0983 for carbon dioxide and UA 0984 for carbon monoxide are not discussed since they are valid. As highlighted in Chapter 4, the validity of optical filter UA 0987 for monitoring TVOC is controversial. Therefore, the subsequent discussion is focused on the monitoring technique for VOCs using the infra-red spectroscopy and the optical filter UA 0987.

In this discussion, it is argued that in terms of validity, the infra-red spectroscopy, the technique used in this research, is as good as the more established gas-chromatography technique. The validity of the technique used in this thesis is subject to uncertainty in the selection of the representative VOC. The process involved in the off-site analysis exposes the technique of gas-chromatography to a higher probability of invalidity when compared to the direct-reading infra-red spectroscopy technique.

As described in Chapter 3, the number of VOCs which are relevant to health hazards in office buildings is between twenty-two to sixty-eight. Only up to six VOCs can be selected by the optical filter used by the gas monitor. This technique is valid if the six compounds are representative of the TVOC hazardous to health. The author could not find the answer to this fundamental question in the literature. Therefore, the validity of this technique is subject to an uncertainty.

Will gas-chromatography be more valid than infra-red spectroscopy technique? The discussion in the next paragraphs suggests that a high degree of validity may not be achieved by both techniques. As stated earlier, on one hand, the validity of the technique used in this research is subjected to the uncertainty in the selection of the representative VOCs to represent TVOC. On the other hand, the validity of gas-chromatography technique is subjected to a high probability of human and technical errors involved from collecting the sample of indoor air in the office to analysing the VOCs in the sample at the laboratory.

The gas-chromatography technique is elaborated in Chapter 4. Basically it involves three steps: adsorption of the VOCs in vapour phase in a study office onto a solid sorbent, desorption of the compounds from the solid sorbent in the laboratory, and analysis of the desorbed compounds using gas-chromatography and flame-ionisation detector. Human or technical errors resulting in invalidity may occur at four stages:

1) if the adsorbed and desorbed concentration of the relevant VOCs are not the same;

2) if, for example, the sorbent used in the previous monitoring is not properly cleaned (Yocom and McCarthy, 1991);

3) if during the desorption, the breakthrough volume of a particular VOCs is exceeded (Yocom and McCarthy, 1991);

4) if the VOCs in the sorbent desorbed while being transported to the laboratory. For this reason, Norback (1990) kept the sorbent at minus 20 degrees Celsius until the sorbent was desorbed in the laboratory.

In other words, the process involved in the off-site analysis exposes the technique to a higher probability of invalidity when compared to the direct-reading infra-red spectroscopy technique. For this reason, the author chose the latter for this research.

Validity of the Standard Gases

The discussion under this section is mainly focused on the monitoring technique for VOCs using infra-red spectroscopy and optical filter UA 0987 fitted to the gas monitor as it can measure six VOCs. Optical filter UA 0983 and UA 0984 are not discussed since they are valid for the standard gases, carbon dioxide and carbon monoxide respectively.

In this discussion, it is argued that in terms of validity, in the measurement of TVOC in the indoor of the offices, the use of methane as the standard gas for this gas monitor is as good as the use of methane, propane, or toluene as the standard gas in the more established gas-chromatography technique.

As highlighted in Chapter 4, the validity of methane as the standard gas for calibrating the concentration of TVOC is controversial because it is subject to an uncertainty. The uncertainty is whether or not the relative contribution of the six VOCs, measurable by the filter UA 0987, to the microphone signals of the gas monitor, is the same as the relative contribution of the six compounds to health hazards. This uncertainty cannot be resolved due to knowledge limitation.

The same uncertainty also occurs in the more established flame ionisation detection technique. The conductivity of the flame is enhanced by the presence of the VOCs. The increase in the conductivity results in an increase in the detected current. Different VOCs of the same concentration contribute different amount of detected current. The question remains whether or not the relative contribution of the detected current of the different compounds, also reflect the relative contribution of the compounds to health hazard.

6.7 CONCLUSION

The reliability and validity of the monitoring of airborne pollutants are subject to significant uncertainties. Through test and analysis, some of the errors in the concentrations due to those uncertainties are estimated. The estimable error may be calculated pesimisstically using the following equation:

$E = (a + b)\,x + c + d$ ....(9)

where:

E = estimable error (expressed in ppm)
x = concentration measured (expressed in ppm)
a = error in span calibration due to impurity of standard gas (expressed in a fraction)
b = error in concentration measured due to detection unreliability (expressed in a fraction)
c = error in locating zero point due to impurity of zero gas (expressed in ppm)

d = error in concentration measured due to unreliability of the measured population (expressed in ppm)

Depending on the application of the monitoring, d is equal to e, f or zero. Error e is used when a measurement of TVOCs is used to compare with a standard. Error f is used when a sequential measurement of TVOCs is used to compare the average in any two locations

where:

e = error in the concentration measured due to time interval (expressed in ppm)

f = error in the concentration measured due to sequencing (expressed in ppm)

Table 6.48 shows the values of a, b, c, e, and f.

	a	b	c	e	f
TVOC	0.0050	0.0160	0.5	0.22	0.42
CO2	0.0009	0.0160	0.5	-no-	-no-
CO	0.0500	0.0160	0.5	-no-	-no-

Table 6.48
Summary of Estimable Error in the Monitoring of Gaseous Pollutants

The estimable error is limited by the selection of the standard gases used in dynamic calibration. In this thesis, the error for TVOC is plus or minus 2.1 percent of the measured concentration. The zero point error is 0.5 ppm. The error for carbon dioxide is plus or minus 1.69 percent of the measured concentration. The zero point error is also 0.5 ppm. The error band for carbon monoxide is plus or minus 6.6 percent of the measured concentration. The zero point error is also 0.5 ppm. These errors can be minimised by using standard gases of better quality.

6.8 REFERENCES

1) Fachinformationszentrum Chemie GmbH (1992). Index of Polymer Trade Names, Greatly enlarged edition, second edition. Weinheim: VCH.

2) Saunders, K. J. (1988). Organic Polymer Chemistry. second edition. London: Chapman and Hall

3) Yocom, J. E. and McCarthy, S. M. (1991). Measuring Indoor Air Quality: A Practical Guide. New York: John Wiley and Sons

4) Norback, D. et al (1990). `Indoor air quality and personal factors related to the sick building syndrome'. Scandinavian Journal of Work Environment Health, Vol. 16, pp121-128

Chapter 7
PILOT TEST: TESTING THE METHODOLOGY

7.1 RESEARCH QUESTIONS

This chapter seeks to answer the question of whether short-term, sequential, and mobile monitoring or long-term stationary monitoring is more practical.

7.2 SUMMARY

The pilot test suggests that stationary monitoring is more suitable for this research.

7.3 INTRODUCTION

The pilot test of the methodology was conducted during the pilot study of the SERC/LINK Project at the Wiltshire County Council Building, Trowbridge. During the pilot test, the result of the questionnaire on symptoms of building sickness distributed for the SERC/LINK Project was not yet ready.

This chapter is divided into four sections: aim and test questions, test, results, and conclusion.

7.4 AIM AND TEST QUESTIONS

The aim of the pilot test was to determine if the methodology for the measurement of airborne pollutants in office buildings works in a real office environment.

Specifically, the test was aimed at answering the following six test questions:

1) is the gas monitor, selected in Chapter 4, suitable for monitoring indoor environment of offices;

2) is the particulate monitor, selected in Chapter 4, suitable for monitoring indoor environment of offices;

3) is the first monitoring approach, described in Chapter 5, suitable for application in offices. In this case, the monitoring approach is a mobile monitoring carried out in sequence at several monitoring locations;

4) what is the practical number of monitoring locations to be monitored;

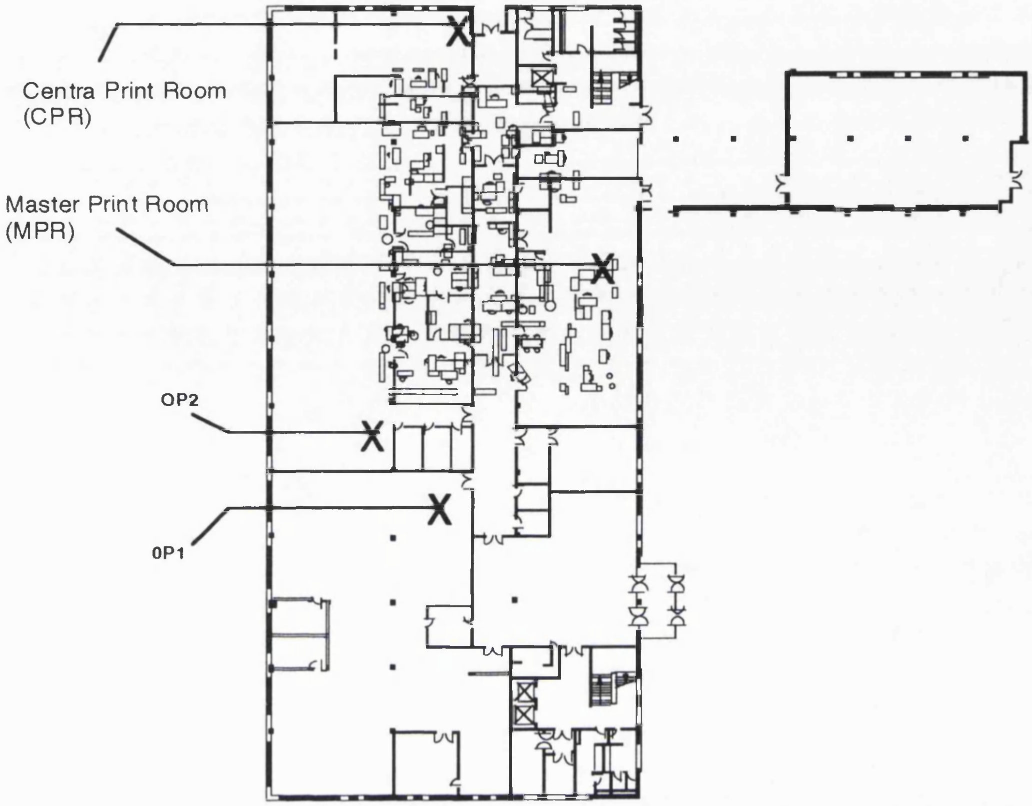
5) are the locations identified by the Personnel Department sufficient to be used as symptomatic areas;

6) since the particulate monitor is not a real time monitor, at what time of the day should the measurement of particulates be conducted.

7.5 TEST

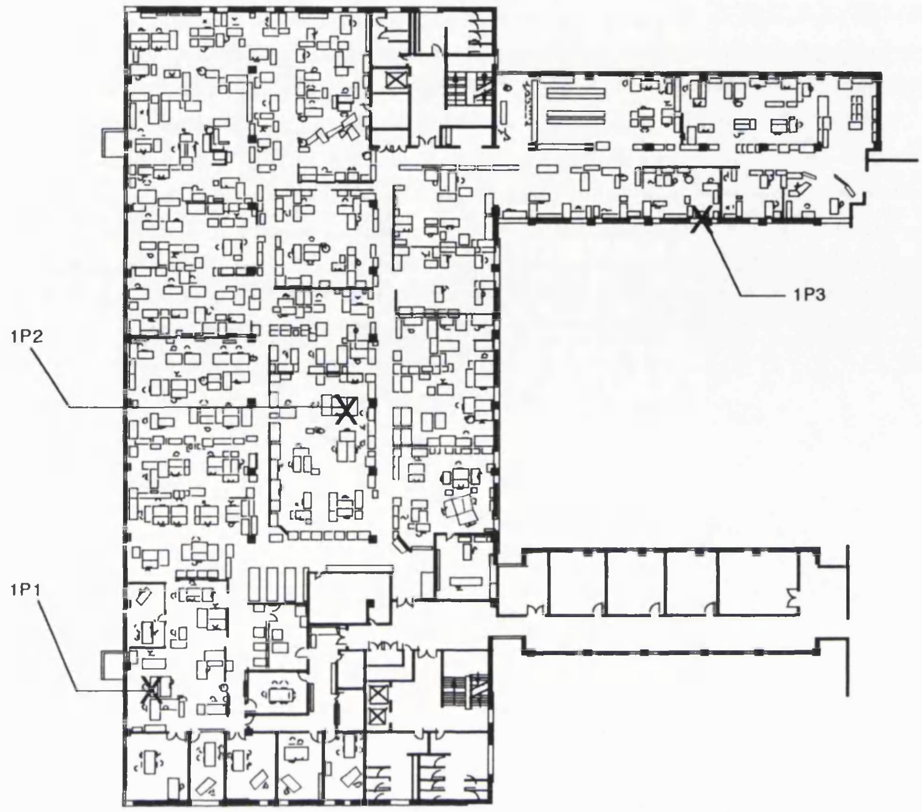
This section describes the methodology that was tested. Both of the two types of monitoring approaches identified in Chapter 5 were tested. First, sequential mobile monitoring over a relatively short monitoring period was conducted at as many monitoring locations as possible on the following dates: 8/7, 9/7, 10/7, 13/7, and 14/7/1992. Second, stationary long term monitoring was conducted at selected locations: one in the indoor and the other one in the outdoor.

An attempt was made to include all of the monitoring locations, described in Chapter 5, in the sequential mobile monitoring. Since the result of the SERC/LINK Project's questionnaire on symptoms of building sickness was not yet ready at this time, the selection of the symptomatic areas was based on the recommendation of the Personnel Department and maintenance engineer. The symptomatic areas recommended by the Personnel Department were in locations 0P1 on the ground floor, 1P1 and 1P3 on the first floor, 2P3, 2P4, 2P5, 2P6, and 2P7 on the second floor, and locations 3P1 and 3P2 on the third floor. (See Figs. 7.1, 7.2, 7.3, 7.4).



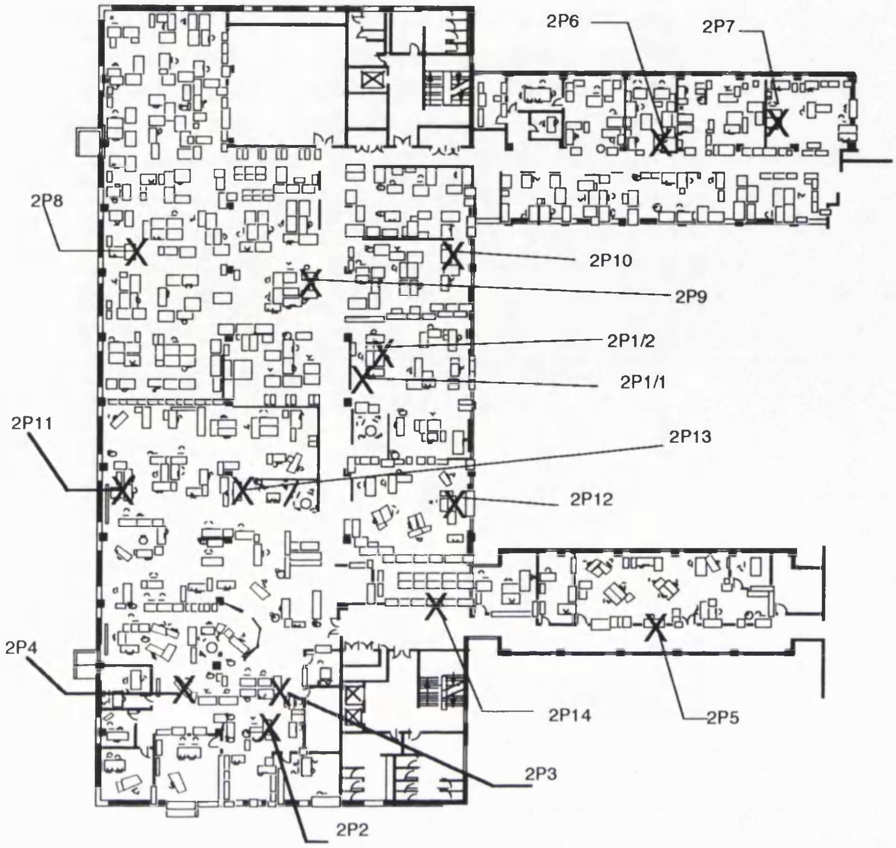
X Mobile Monitoring Locations

Figure 7.1
Monitoring Locations in Trowbridge Building, Ground Floor



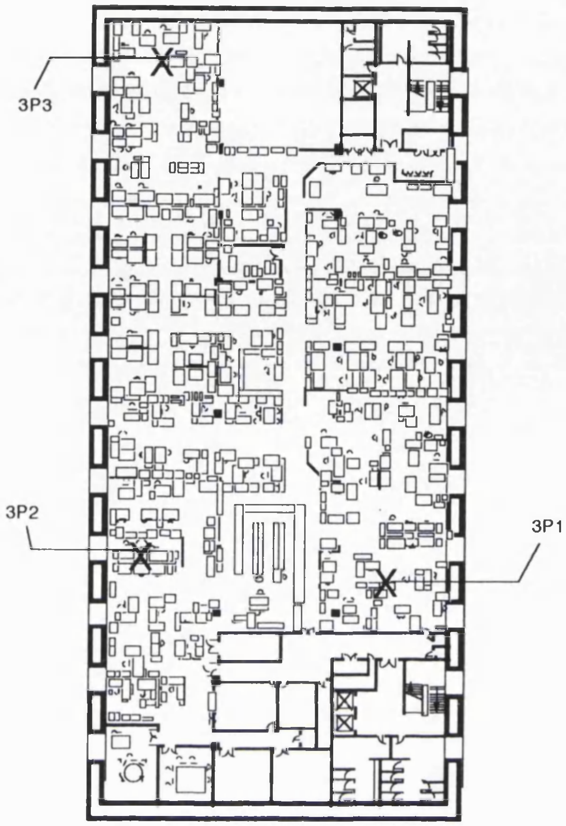
X Mobile Monitoring Locations

Figure 7.2
Monitoring Locations in Trowbridge Building, First Floor



X Mobile Monitoring Locations

Figure 7.3
Monitoring Locations in Trowbridge Building, Second Floor



X Mobile Monitoring Locations

Figure 7.4
Monitoring Locations in Trowbridge Building, Third Floor

The control and suspected problems areas were identified by walking through all of the areas in the building with the maintenance engineer. The suspected problem areas were the area in the open plan with extensive open shelves, coded 2P14 (see Fig. 7.3), and the print rooms called CPR and MPR (see Fig. 7.4). The print rooms were also reported by the Personnel Department as symptomatic areas. It was thought that at this stage a relatively large monitoring locations selected in one floor may be required for the other research team in the SERC/LINK Project: Spatial Analysis. Therefore, the monitoring locations 2P1, 2P2, 2P8, 2P9, 2P10, 2P11, 2P12, and 2P13 were selected as the control areas. (See Fig 7.3)

The stationary long term monitoring was conducted in the indoor at location 2P2 and in the outdoor on the roof. The concentration of airborne pollutants at 2P2 was monitored at the monitoring time interval of 5 minutes from 06:00 a.m. on 22/7/1992 to 2:09 p.m. on 29/7/1992. The concentration of airborne pollutants at the roof top was monitored at the monitoring time inte-val of 2 minutes from 12:18 a.m. on 31/8/1992 to 2:00 p.m. on 3/9/1992.

The outdoor was monitored on the roof top at the parapet wall facing the main air intake. To protect against rain, the gas monitor was placed in the mechanical room and a simple water trap was designed for the gas monitor. The water trap was a glass flask with a stopper. Two Teflon tubes were inserted into the stopper with one end of the first tube just below the stopper and one end of the second tube almost reaching the bottom of the flask. The other end of the first tube was connected to the inlet of the gas monitor while the other end of the second tube was placed at the parapet wall.

The particulate and gas monitors, selected in Chapter 4, were used in the monitoring. Since the particulate monitor is an integrated type, it measures total concentration of particulate in the sampled air. The particulate monitor was calibrated in the factory before it was used. Since the gas monitor is a real-time type, it measures the instantaneous concentration of TVOC, carbon dioxide, and carbon monoxide.

7.6 RESULTS

The result of this test may be divided into two headings: main result and other findings. The main result describes the result of the methodology test. The other findings are the findings that can be used by the SERC/LINK Project or that can be incorporated to improve the methodology

7.6.1 The Main Result

The main results are presented by restating the six test questions this test was supposed to answer.

1) Is the gas monitor suitable for monitoring the indoor environment in offices? As defined in Chapter 1, `monitoring' means repeated measurements. Repeated measurement may not be possible because the office is sometimes

used for discussion and the power socket is not always available. Interruption to office activities is sometimes not acceptable. The monitoring area which is accessible in one measurement may not be accessible in the next measurement. For example, in the next monitoring time, the area may be used for discussion or the office worker may be answering an important call and referring to several files. The gas monitor requires mains. Unused power sockets are not always available. The power socket which is available during a monitoring may not be available in the next monitoring. Although the gas monitor may be equipped with a battery power pack, the power pack is heavy. The gas monitor itself weighs 9 kilograms. When it is equipped with the battery power pact, it weighs 16 kilograms. It should be noted this monitoring involves two pieces of instruments: the gas and particulate monitors. The particulate monitor weighs 4.5 kilograms. In other words, with the battery power pack the gas monitoring instrumentation is no longer portable.

2) Is the particulate monitor suitable for monitoring the indoor environment in offices? Since it does not require the use of power socket and weighs only 4.5 kilogram, the particulate monitor is suitable for monitoring. However, the problem of inaccessibility due to office activities, as described in the first finding, also occurs here.

3) Is the first monitoring approach suitable for application in an office? The proper sequencing was meant to improve validity due to time variability of the airborne pollutants by reducing the differences in concentration. However, the location in the sequence may not be monitored due to office activities as elaborated in the first finding.

4) What is the practical number of monitoring locations to be monitored? In practice, during the monitoring, the questions from the office workers regarding the research were entertained. For this reason, the time spent per monitoring location was more than what was anticipated. This pilot study suggests that about four and one-half days was required to cover the monitoring at twenty-five monitoring locations. Under the learning curve concept, the monitoring in the subsequent buildings will take less time per monitoring location. Therefore, a

realistic monitoring location to cover per day is between five to six. This estimation is based on mobile monitoring in two complete sequences: once in the morning and once in the afternoon.

5) Are the locations identified by the Personnel Department sufficient to be used as symptomatic areas? It was found that only location 3P2 was the symptomatic area. (See Fig 7.4 and 7.5). Therefore, the monitoring in the future should be conducted only after the result of the questionnaire on the symptoms of building sickness is ready.

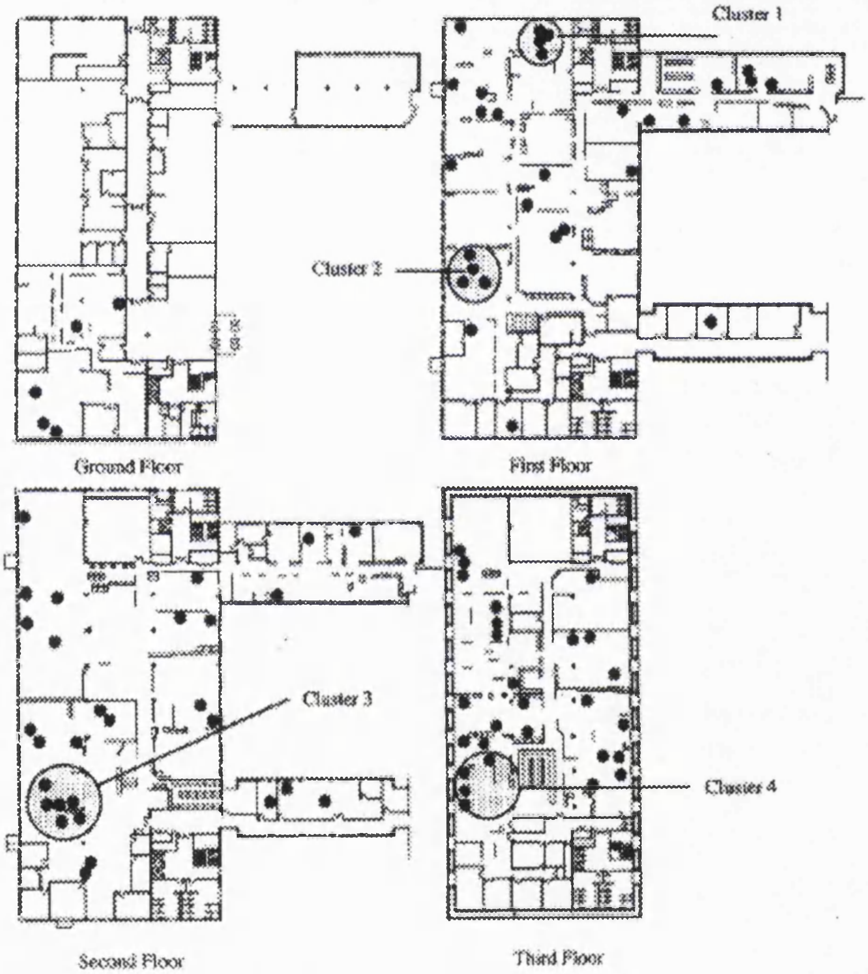


Figure 7.5
Symptomatic Clusters in Trowbridge Building

6) Since the particulate monitor is not a real time monitor, at what time of the day should the measurement of particulates be conducted? Grot et al (1991)

observed that the concentration of particulates between 0.3 to 0.5 micron is fairly constant in the office indoor irrespective of time. However, the particulate monitor monitors the particulate between 0.01 to 10 microns. An attempt was made to monitor the variation of the particulate at a workstation during working hours. The monitoring was only possible at the unoccupied workstation 2P2. Therefore, the data was limited in use as it could not be generalised for all workstations. Fig 7.6 shows the average concentration of the particulate at location 2P2 measured at an interval of approximately one hour. The particulate peaks twice, firstly, from 9:00 a.m. to 11:00 a.m. and secondly, at around 3:00 p.m.

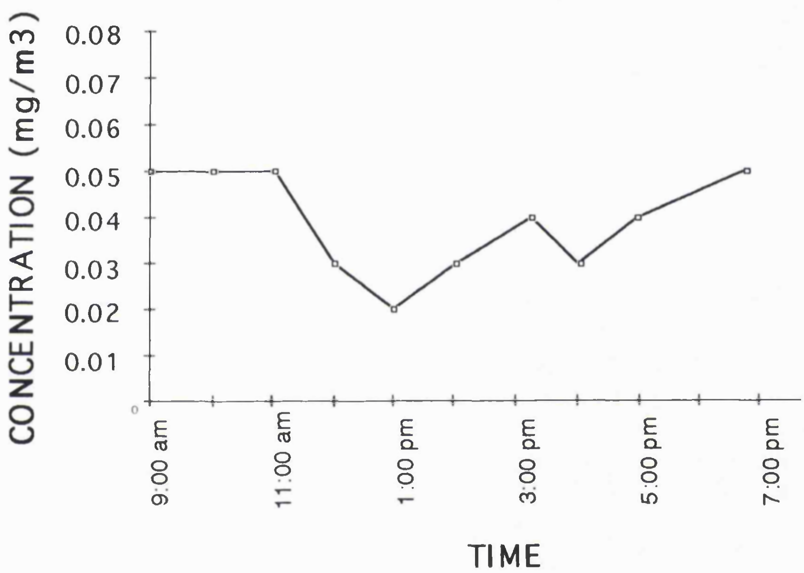


Figure 7.6
Profile of Respirable Particulates at 2P2 (mg/m3)

7.6.2 Other Findings

The measurements discussed in Section 7.6.2.1 to Section 7.6.2.4 were used for five specific purposes:

1) the measurements were grouped together to see the variation of the airborne

pollutants in the indoor during the mobile monitoring period. In this case, the indoor did not include print rooms;

2) the stationary indoor measurement was analysed to see the variation of the airborne pollutants in a typical office indoor;

3) the stationary outdoor measurement was analysed to see the variation of the airborne pollutants for a typical office outdoor;

4) the measurements of the indoor, both mobile and stationary, were grouped together to see the variation of the airborne pollutants in the indoor in the study building. In this case, the indoor did not include print rooms;

5) the measurements during the stationary monitoring at location 2P2 were used to estimate the reliability of measurements at other monitoring time intervals. The estimation is not repeated here since it is elaborated in Chapter 6.

No attempt was made to compare the measurements taken in the indoor with those taken in the outdoor or to see the spatial variation in the indoor. The reason was that the mobile and stationary measurements, of both indoor and outdoor, were not conducted simultaneously. Therefore, the measurements in the outdoor could not be compared with those in the indoor. Furthermore, the monitoring locations in the mobile monitoring were covered over five days, instead of one day. Additionally, during the mobile monitoring sequencing was not possible. Therefore, large variations in concentration due to time between monitoring locations should be expected. For those reasons, the mobile monitoring cannot be used to study spatial variation.

7.6.2.1 Airborne Pollutants During Mobile Monitoring

The mobile monitoring was conducted at various locations in five working days: on 8/7, 9/7, 10/7, 13/7, and 14/7/1992. The data of the monitoring are shown in Tables 7.1 to 7.4. Table 7.1 shows the measurements of TVOC, Table 7.2 shows the measurements of carbon dioxide, Table 7.3 shows the measurements of carbon monoxide, and Table 7.4 shows the measurements of particulates.

	MAX	AVG	MIN	STD	N
0P1	3.75	3.46	3.14	0.25	5
0P2	4.43	4.30	4.17	0.19	2
1P1	3.19	2.79	2.42	0.28	5
1P2	4.24	4.24	4.24		1
2P01/1	3.32	2.40	2.13	0.42	8
2P01/2	2.61	2.45	2.26	0.12	6
2P02	9.76	6.32	2.76	2.55	11
2P03	3.35	3.03	2.64	0.24	6
2P04	3.90	3.23	2.74	0.44	5
2P05	4.52	4.52	4.52		1
2P06	8.82	8.75	8.66	0.08	3
2P07	11.16	10.86	10.71	0.22	4
2P08	11.20	10.82	10.53	0.34	3
2P09	10.51	10.24	9.98	0.22	4
2P10	10.99	10.78	10.60	0.20	3
2P11	9.25	9.10	9.02	0.13	3
2P12	9.91	9.50	8.92	0.51	3
2P13	11.26	11.03	10.90	0.20	3
2P13	7.98	7.75	7.63	0.20	3
2P14	8.85	8.15	7.42	0.61	4
3P1	3.46	3.22	3.01	0.22	4
3P2	3.20	2.99	2.81	0.17	4
3P3	12.59	12.09	11.41	0.48	5
central copy room	16.75	14.16	11.20	2.79	3
copier/1	9.63	9.31	9.02	0.20	6
copier/2	8.44	7.37	7.01	0.33	18
copier/3	7.39	7.17	6.89	0.15	9
main prt rm	63.90	47.35	37.05	14.47	3

Table 7.1
Mobile Measurement of TVOC at Trowbridge Building (ppm)

	MAX	AVG	MIN	STD	N
0P1	619	531	499	50	5
0P2	644	643	643	1	2
1P1	624	564	538	35	5
1P2	625	625	625		1
2P01/1	624	597	579	17	8
2P01/2	583	575	569	5	6
2P02	995	783	489	173	11
2P03	844	680	626	82	6
2P04	800	684	626	70	5
2P05	578	578	578		1
2P06	658	652	642	9	3
2P07	754	749	746	4	4
2P08	951	924	891	30	3
2P09	931	909	876	23	4
2P10	914	880	861	29	3
2P11	1015	1004	985	17	3
2P12	979	954	937	22	3
2P13	943	933	915	16	3
2P13	863	856	846	9	3
2P14	867	828	806	28	4
3P1	699	678	655	21	4
3P2	638	624	616	10	4
3P3	743	676	650	39	5
central copy room	573	539	516	30	3
copier/1	967	879	859	43	6
copier/2	906	866	839	19	18
copier/3	886	811	776	36	9
main prt rm	598	566	533	33	3

Table 7.2
Mobile Measurement of Carbon Dioxide at Trowbridge Building (ppm)

	MAX	AVG	MIN	STD	N
0P1	2.62	2.56	2.49	0.06	5
0P2	2.21	2.16	2.12	0.06	2
1P1	2.65	2.63	2.61	0.02	5
1P2	2.04	2.04	2.04		1
2P01/1	1.96	1.81	1.66	0.10	8
2P01/2	2.11	2.04	1.98	0.06	6
2P02	2.93	2.53	2.18	0.24	11
2P03	2.57	2.39	2.19	0.13	6
2P04	2.65	2.54	2.48	0.07	5
2P05	2.14	2.14	2.14		1
2P06	2.40	2.38	2.36	0.03	3
2P07	2.36	2.27	2.21	0.07	4
2P08	2.24	2.19	2.17	0.04	3
2P09	2.25	2.20	2.17	0.04	4
2P10	2.37	2.36	2.36	0.01	3
2P11	2.38	2.27	2.17	0.10	3
2P12	2.40	2.28	2.18	0.11	3
2P13	2.33	2.28	2.26	0.04	3
2P13	1.78	1.76	1.71	0.04	3
2P14	1.83	1.68	1.61	0.10	4
3P1	2.31	2.20	2.16	0.07	4
3P2	2.43	2.38	2.34	0.04	4
3P3	2.93	2.88	2.79	0.06	5
central copy room	3.07	2.76	2.58	0.27	3
copier/1	2.00	1.90	1.82	0.08	6
copier/2	2.33	2.09	1.61	0.19	18
copier/3	2.79	2.61	2.26	0.18	9
main prt rm	2.65	2.53	2.46	0.11	3

Table 7.3
Mobile Measurement of Carbon Monoxide at Trowbridge Building (ppm)

LOCATION	MAX	AVG	MIN	STD	N	N
0P1	0.05	0.05	0.04	0	5	5
0P2	0.03	0.03	0.03	NA	1	1
1P1	0.04	0.04	0.04	0	4	4
2P1/1	0	0	0	0	2	2
2P1/2	0.04	0.04	0.04	0	9	9
2P2/2	0.05	0.04	0.02	0.01	10	10
2P3	0.05	0.04	0.04	0	6	6
2P4	0.04	0.04	0.04	0	5	5
2P5	0.03	0.03	0.02	0.01	2	2
2P6	0.02	0.02	0.01	0.01	2	2
2P7	0.03	0.03	0.02	0	4	4
2P8	0.02	0.02	0.02	0	3	3
2P9	0.03	0.03	0.02	0.01	3	3
2P10	0.03	0.03	0.02	0.01	3	3
2P11	0.02	0.02	0.01	0.01	3	3
2P12	0.02	0.01	0.01	0.01	3	3
2P13	0.01	0.01	0.01	0	3	3
2P14	0.02	0.01	0	0.01	3	3
3P1	0.04	0.04	0.03	0.01	4	4
3P2	0.04	0.04	0.04	0	4	4
3P3	0.02	0.02	0.02	0	3	3
CPR	0.04	0.03	0.02	0.01	3	3
MPR	0.04	0.04	0.03	0	5	5
RA/1	0.02	0.02	0.02	NA	1	1
RA/2	0.08	0.06	0.05	0.02	3	3
RA/3	0.03	0.03	0.03	NA	1	1
RC	0.13	0.11	0.09	0.03	2	2
RE	0.03	0.02	0.01	0.01	3	3

Table 7.4
Respirable Particulates Concentration in Trowbridge Building (mg/m3)

A total of ninety-six measurements were made in the indoor: seventy-three during working hours and twenty-three during non-working hours of working days. Here, indoor means typical office spaces excluding print rooms. For this purpose, the measurements at the copier were also excluded.

During working hours, the concentration of TVOC in the indoor varied between 2.13 to 12.59 ppm. The average was 6.47 ppm and the standard deviation was 3.57 ppm. The concentration of carbon dioxide varied from 569 to 1,015 ppm. The average was 740 ppm and the standard deviation was 136 ppm. The concentration of carbon monoxide varied from 1.61 to 2.93 ppm. The average was 2.24 ppm and the standard deviation was 0.34 ppm.

During non-working hours of working days, the concentration of TVOC in the indoor varied between 2.42 to 11.26 ppm. The average was 5.21 ppm and the standard deviation was 3.29 ppm. The concentration of carbon dioxide varied from 489 to 995 ppm. The average was 671 ppm and the standard deviation was 176 ppm. The concentration of carbon monoxide varied from 2.14 to 2.65 ppm. The average was 2.45 ppm and the standard deviation was 0.16 ppm.

The 2-minute average concentration of particulates in the indoor, except at print rooms MPR and CPR, varied between 0.00 to 0.05 milligram per cubic metre. The average was 0.3 milligram per cubic metre and the standard deviation was 0.01 milligram per cubic metre. This analysis was based on eighty-two measurements.

7.6.2.2 Airborne Pollutants at 2P2

As stated earlier, the indoor was monitored at 2P2 from Wednesday 22/7/1992 at 06:00 a.m. to Tuesday 29/7/1992 at 2:09 p.m. During that period 1,828 measurements were made: 458 measurements during working hours, 794 measurements during non working hours of working days, and 1,252 measurements during non working days. These measurements are presented in standard weeks and analysed. A standard week means a 7-day week beginning 12:00 midnight on a Monday to 12:00 midnight the next Monday. The analysis is divided into three: working hours, non working hours of working day, and non working days.

Fig. 7.7 shows the measurements of the TVOC at 2P2 in the standard week from 20/7/1992 to 27/7/1992. The vertical axis displays the concentration in ppm and the horizontal axis displays the time. Fig. 7.8 shows the measurements of the TVOC in the standard week from 27/7/1992 to 3/8/1992. Fig. 7.9 shows the measurements of the carbon dioxide in the standard week from 20/7/1992 to 27/7/1992. Fig. 7.10 shows the measurements of the carbon dioxide in the standard week from 27/7/1992 to 3/8/1992. Fig. 7.11 shows the measurements of the carbon monoxide in the standard week from 20/7/1992 to 27/7/1992 and Fig. 7.12 shows the measurements of the carbon monoxide in the standard week from 27/7/1992 to 3/8/1992.

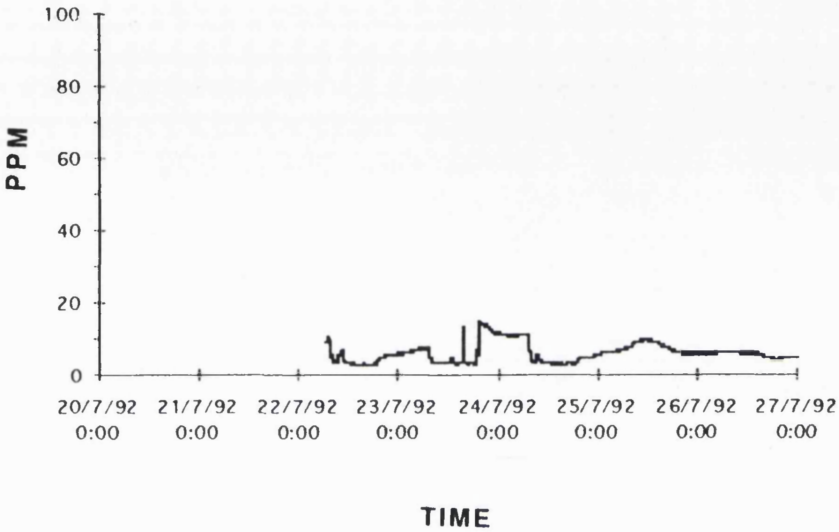


Figure 7.7
Profile of TVOC in the indoor of Trowbridge Building from 20/7/92 to 27/7/92 (ppm)

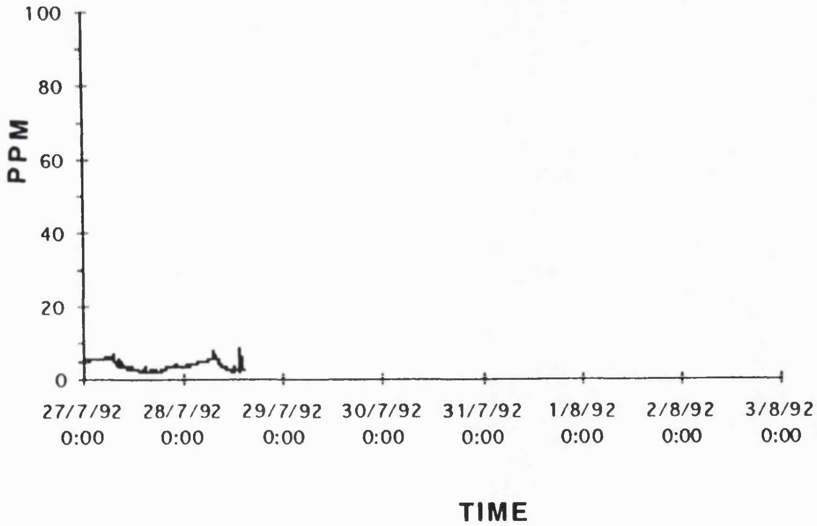


Fig 7.8
Profile of TVOC in the indoor of Trowbridge Building from 27/7/92 to 3/8/92 (ppm)

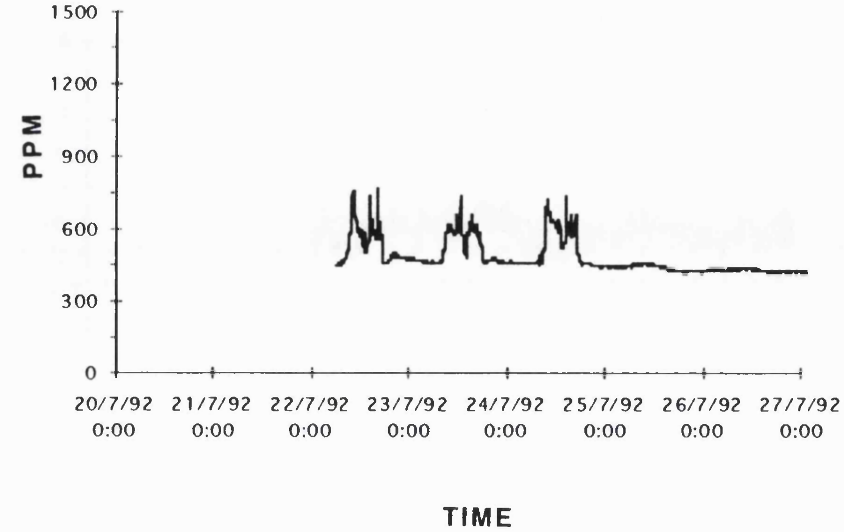


Fig 7.9
Profile of Carbon Dioxide in the indoor of Trowbridge Building from 20/7/92 to 27/7/92 (ppm)

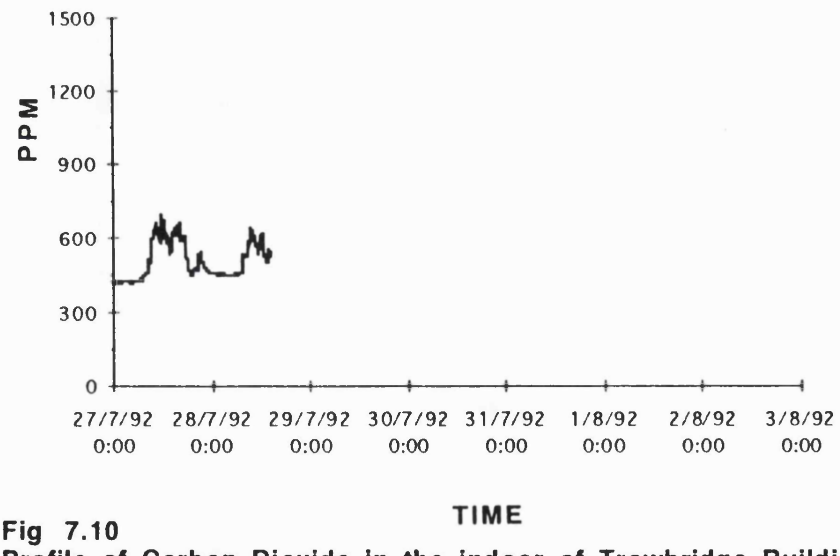


Fig 7.10
Profile of Carbon Dioxide in the indoor of Trowbridge Building from 27/7/92 to 3/8/92 (ppm)

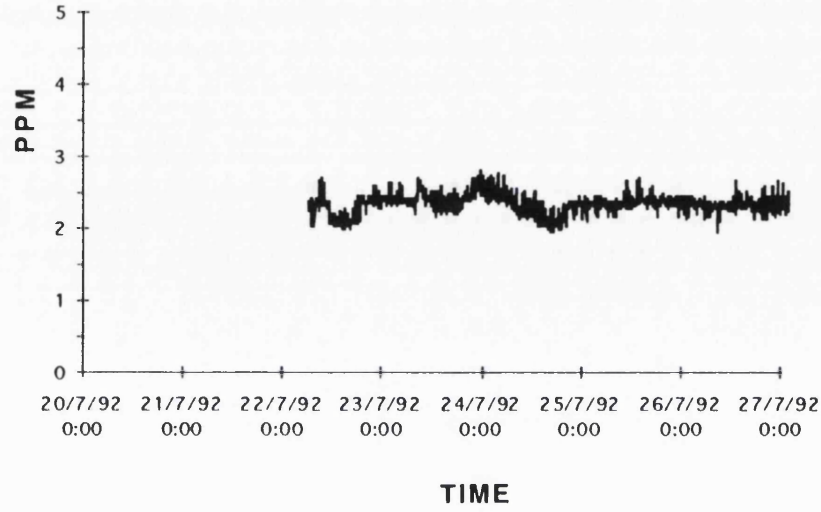


Fig 7.11
Profile of Carbon Monoxide in the indoor of Trowbridge Building from 20/7/92 to 27/7/92 (ppm)

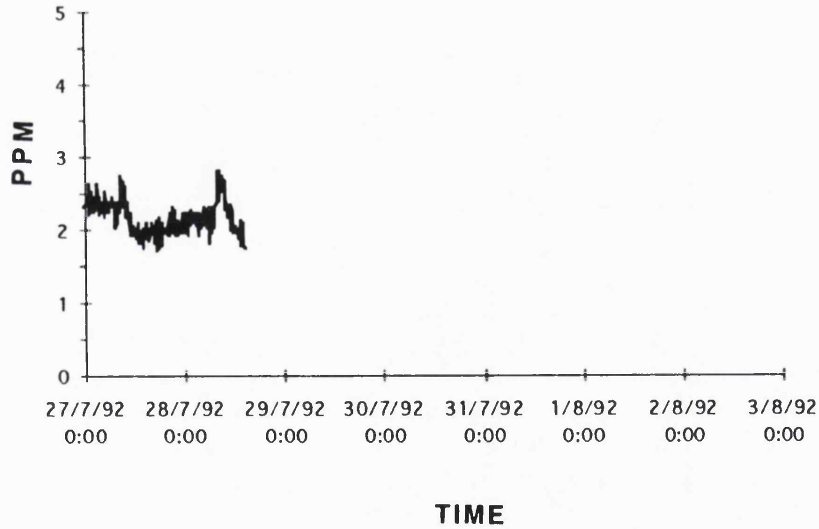


Fig 7.12
Profile of Carbon Monoxide in the indoor of Trowbridge Building from 27/7/92 to 3/8/92 (ppm)

During working hours, the concentration of TVOC varied between 2.19 to 13.04 ppm. The average was 3.39 ppm and the standard deviation was 2.19 ppm. The concentration of carbon dioxide varied from 452 to 761 ppm. The average was 588 ppm and the standard deviation was 54 ppm. The concentration of carbon monoxide varied from 1.74 to 2.82 ppm. The average was 2.24 ppm and the standard deviation was 0.22 ppm. This analysis was based on 458 measurements.

During non-working hours of working days, the concentration of TVOC varied between 2.11 to 15.05 ppm. The average was 6.15 ppm and the standard deviation was 3.09 ppm. The concentration of carbon dioxide varied from 417 to 769 ppm. The average was 469 ppm and the standard deviation was 38 ppm. The concentration of carbon monoxide varied from 1.72 to 2.82 ppm. The average was 2.30 ppm and the standard deviation was 0.18 ppm. This analysis was based on 794 measurements.

During non-working days, the concentration of TVOC varied between 4.25 to 9.88 ppm. The average was 6.43 ppm and the standard deviation was 1.40 ppm. The concentration of carbon dioxide varied from 416 to 456 ppm. The average was 433 ppm and the standard deviation was 10 ppm. The concentration of carbon monoxide varied from 1.97 to 2.70 ppm. The average was 2.35 ppm and the standard deviation was 0.09 ppm. This analysis was based on 1,252 measurements.

7.6.2.3 Airborne Pollutants in the Outdoor

As stated earlier, the outdoor was monitored from Monday 31/8/1992 at 12:18 p.m. to Thursday 3/9/1992 at 2:00 p.m. During those working days, a total of 2,063 measurements were made: 720 measurements during working hours and 1,323 during non-working hours. These measurements are presented in a standard monitoring week and analysed. The analysis is divided into two: working hours and non working hours.

Fig. 7.13 shows the measurements of TVOC in the outdoor in a standard monitoring week from 31/8/1992 to 7/9/1992. The vertical axis displays the concentration in ppm and the horizontal axis displays the time. Fig. 7.14 shows the measurements of the carbon dioxide and Fig. 7.15 shows the measurements of the carbon monoxide.

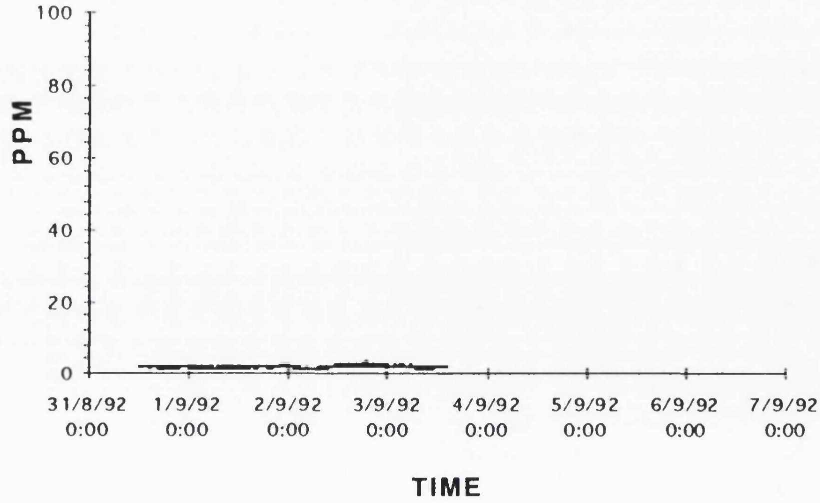


Fig 7.13
Profile of TVOC in the outdoor of Trowbridge Building from 31/8/92 to 7/9/92 (ppm)

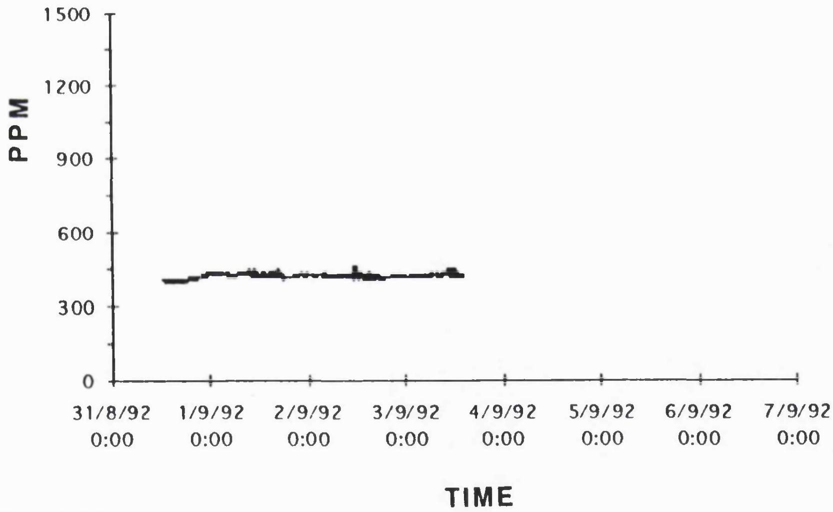


Fig 7.14
Profile of Carbon Dioxide in the outdoor of Trowbridge Building from 31/8/92 to 7/9/92 (ppm)

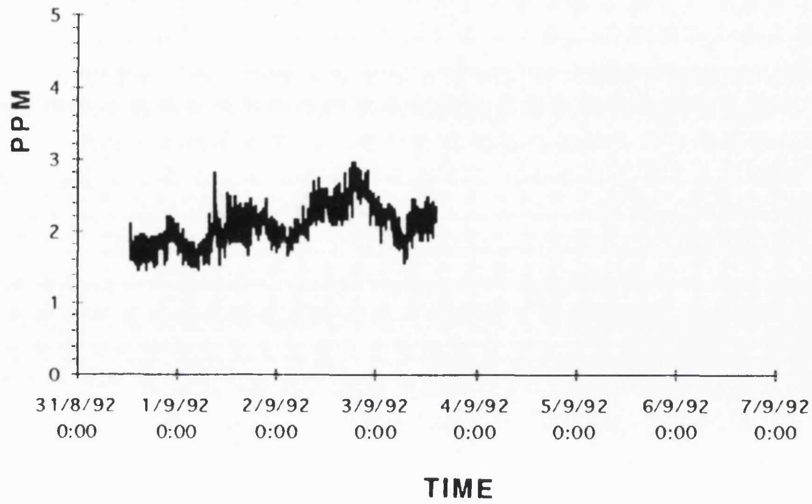


Fig 7.15
Profile of Carbon Monoxide in the outdoor of Trowbridge Building from 31/8/92 to 7/9/92 (ppm)

During working hours, the concentration of TVOC in the outdoor varied between 1.19 to 2.84 ppm. The average was 1.95 ppm and the standard deviation was 0.31 ppm. The concentration of carbon dioxide varied from 398 to 460 ppm. The average was 420 ppm and the standard deviation was 12 ppm. The concentration of carbon monoxide varied from 1.45 to 2.83 ppm. The average was 2.12 ppm and the standard deviation was 0.28 ppm. This analysis was based on 720 measurements.

During non-working hours of working days, the concentration of TVOC in the outdoor varied between 1.05 to 3.07 ppm. The average was 1.86 ppm and the standard deviation was 0.38 ppm. The concentration of carbon dioxide varied from 399 to 442 ppm. The average was 422 ppm and the standard deviation was 7 ppm. The concentration of carbon monoxide varied from 1.47 to 2.96 ppm. The average was 2.06 ppm and the standard deviation was 0.30 ppm. This analysis was based on 1,323 measurements.

7.6.2.4 Airborne Pollutants in the Indoor of the Test Building

During working hours, the concentration of TVOC in the indoor varied between 2.13 to 13.04 ppm. The average was 3.81 ppm and the standard deviation was 1.91 ppm. The concentration of carbon dioxide varied from 452 to 1,015 ppm. The average was 608 ppm and the standard deviation was 88 ppm. The concentration of carbon monoxide varied from 1.61 to 2.93 ppm. The average was 2.24 ppm and the standard deviation was 0.24 ppm. This analysis was based on 531 measurements: 458 measurements from the stationary long term monitoring at 2P2 and 73 measurements from the mobile monitoring.

During non-working hours of working days, the concentration of TVOC in the indoor varied between 2.11 to 15.05 ppm. The average was 6.12 ppm and the standard deviation was 3.10 ppm. The concentration of carbon dioxide varied from 417 to 995 ppm. The average was 475 ppm and the standard deviation was 58 ppm. The concentration of carbon monoxide varied from 1.72 to 2.82 ppm. The average was 2.31 ppm and the standard deviation was 0.19 ppm. This analysis was based on 817 measurements: 794 measurements from the stationary long term monitoring at 2P2 and 23 measurements from the mobile monitoring.

During non-working days, the concentration of TVOC in the indoor varied between 4.25 to 9.88 ppm. The average was 6.43 ppm and the standard deviation was 3.10 ppm. The concentration of carbon dioxide varied from 416 to 456 ppm. The average was 433 ppm and the standard deviation was 10 ppm. The concentration of carbon monoxide varied from 1.97 to 2.70 ppm. The average was 2.35 ppm and the standard deviation was 0.09 ppm. This analysis was based on 576 measurements from the stationary long term monitoring only. Mobile monitoring was not conducted during non working days.

In assessing particulates in the test building, only the measurements of the mobile monitoring were used. The stationary hourly monitoring at location 2P2 was not used since the workstation was not occupied. As stated earlier, the 2-minute average concentration of particulates in the indoor, except at print rooms MPR and CPR, varied between 0.00 to 0.05 milligram per cubic metre. The average was 0.3 milligram per cubic metre and the standard deviation was 0.01 milligram per cubic metre. This analysis was based on eighty-two measurements.

7.7 CONCLUSIONS

Mobility from one location to another monitoring location is a major problem in office environment. The monitoring area which may be accessible in one measurement may not be accessible in the next measurement. The power socket which is available during one measurement may not be accessible in the next measurement. The two factors not only delay the monitoring which shortened the monitoring time available for each monitoring location but also causethe sequential mobile monitoring to be out of step.

If only one gas monitor is available and mobile monitoring is necessary, the author suggests that the number of locations should be limited to about five after taking into account the time taken to move the gas monitor to the various locations. The reason is to have a longer monitoring time so that a sufficient data may be collected at each location.

However, in the author's opinion, stationary monitoring using several gas monitors is more suitable for application in an office in which the disturbance to office activities should be minimal. Once installed the gas monitors could be left unattended for a long time. Furthermore, the gas monitor is more suitable for stationary monitoring because it requires the use of mains and its battery power pack, if used, is quite heavy.

Chapter 8
DEVELOPMENT OF THE METHODOLOGY FOR ASSESSING AIRBORNE POLLUTANTS

8.1 SUMMARY

Mobile monitoring is not practical to study time, seasonal, and spatial variation of hazardous gases in office buildings. For these purposes, a multiplexer is required to be fitted to the gas monitor so that automatic stationary monitoring could be conducted sequentially.

8.2 INTRODUCTION

The objective of this chapter is to examine the development of methodology in the test buildings, including the pilot test building, with special reference to achieving reliability, validity, and practicality.

As stated in Chapter 1, this thesis attempts to develop a practical but valid, and reliable methodology in assessing indoor pollutants in office buildings. This thesis has two products. The main product, described in Chapter 2 through Chapter 9, is a practical, reliable and valid methodology for the SERC/LINK Project to implement. The other product, described in Chapters 7 and 9, is the valid, reliable and, practical data of indoor pollutants so that the SERC/LINK Project could relate them with the findings of other research teams for psycho social, thermal comfort, air distribution, and spatial analysis studies.

To put the discussion on the development of the methodology into a complete perspective, the discussion in Chapter 7 is repeated in this and the next chapter where necessary. In this discussion, the MECH Building, Trowbridge is known as Trowbridge Building, The Royal Insurance Building, Peterborough is known as Peterborough

Building, the Lakeside Municipal Building, Kendal is known as Kendal Building, and The Pearl Building, Cardiff is known as Cardiff Building.

This chapter is divided into three sections. The first section (8.3) is the methodology. It describes further improvement of the methodology in the next three buildings focusing on the monitoring approach, validity of monitoring area, and validity of monitoring location. The second section (8.4) describes the monitoring areas in the Peterborough, Kendal, and Cardiff Buildings, and the third section (8.5) discusses the recommended application of the result. This chapter ends with the conclusion.

8.3 METHODOLOGY

The discussion on methodology consists of three topics: monitoring approach, validity of monitoring areas, and validity of monitoring locations.

8.3.1 Monitoring Approach

Both mobile and stationary monitoring approaches were used in the monitoring of the gaseous pollutants in this thesis. Since a multiplexer was not yet available, the mobile monitoring became a major part of the monitoring at the Trowbridge and Peterborough Buildings. The multiplexer was available during the monitoring at the Kendal and Cardiff Buildings. Therefore, at these buildings only stationary monitoring was used.

At both the Trowbridge and Peterborough Buildings, manual mobile and automatic stationary monitorings were used. At the Trowbridge Building, the manual mobile monitoring was conducted at twenty-four monitoring locations in five working days excluding the outdoor. The stationary monitoring was conducted at the monitoring location 2P2.

In the Peterborough Building, the methodology was improved. To improve accuracy, the manual mobile monitoring in winter was conducted in this building for about one-half of an hour at each of the twelve monitoring locations excluding the outdoor. The number of days used in the monitoring was the same as that in the Trowbridge Building. That means more measurements per monitoring location was possible at the Peterborough Building than that at the Trowbridge Building. Besides the mobile monitoring, a long-term stationary monitoring was also conducted in one indoor location, L2Z32.

The methodology was further improved in the summer monitoring in the Peterborough Building. Firstly, the number of monitoring locations was reduced to seven and secondly, the monitoring period was reduced from five to one day. This was an attempt to minimise time variation of the concentration of gaseous pollutants, so that the concentration at the seven locations could be compared.

Two further improvements were made in the monitorings at Kendal and Cardiff Building. Firstly, the time variation was further reduced from one day to forty-eight minutes. In these buildings, the monitoring were stationary, long term, automatic, and sequential. The monitoring at a particular location was repeated approximately every forty-eight minutes. Secondly, more measurements were made compared to the previous buildings. Approximately ten measurements during working hours and twenty measurements during non- working hours were conducted daily at each of the monitoring locations in these two buildings.

8.3.2 Validity of Monitoring Areas

The validity of the monitoring areas was mainly resolved in the buildings subsequent to the Trowbridge Building. As stated in Chapter 7, at the time of the pilot test in the Trowbridge Building, the result of the questionnaire on symptoms of building sickness was not yet available. Consequently, the SERC/LINK Project was unable to determine the monitoring areas. However, some or all of the monitoring areas in the subsequent buildings were determined by the SERC/LINK Project prior to the monitorings based on the result of the questionnaire which was then available.

At the Peterborough Building, a total of thirteen areas was selected for indoor monitoring in winter and seven areas in summer. Monitoring areas L1Z21, L1Z31, L1Z32, L2Z11, L2Z21, L2Z22, L2Z31, and L3Z11 were determined by the SERC/LINK Project (See Figure 8.1). The other five monitoring areas, L1Z11, L1Z22, L2Z12, L2Z32, and L3Z11, were selected on site. The on site selection of mobile monitoring areas was based on two considerations. Firstly, to cover all occupied building zones. In Level 3, zone 3 was unoccupied most of the time and zone 2 was partially occupied. Therefore, the two zones were not selected. Secondly, the monitoring area selected should be far from full wall. In this case, full wall means a partition from floor to ceiling. Since this is an open plan office, the location near the full wall was not considered as representative of the monitoring locations.

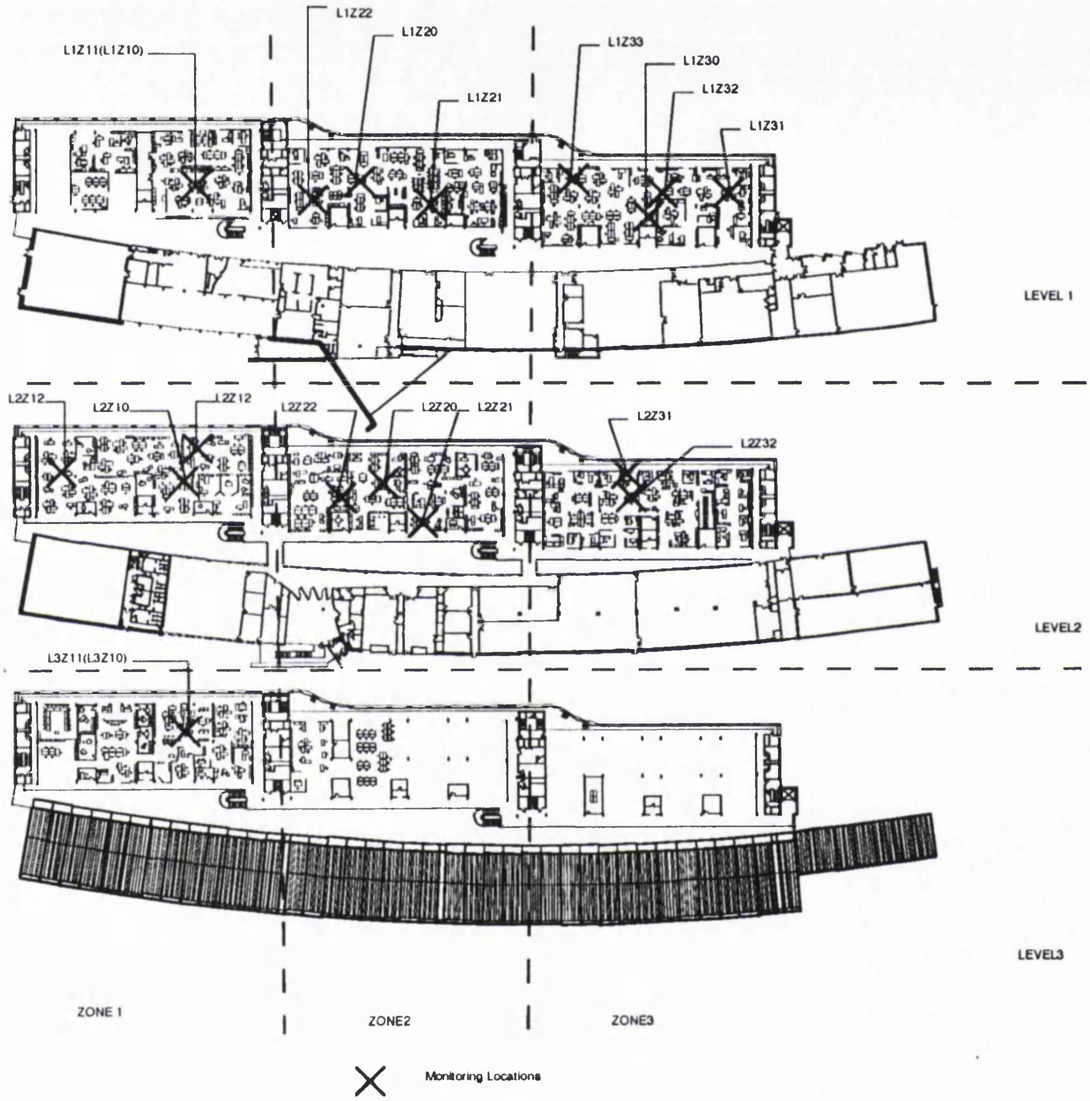


Figure 8.1
Monitoring Locations in Peterborough Building

The monitoring areas L1Z11 and L3Z11 were in healthy clusters. L1Z22, L1Z31, L1Z32, L2Z11, L2Z21, L2Z22, and L2Z31 were in unhealthy clusters and L1Z21, L1Z22, L1Z33, L2Z12, and L2Z32 were in mixed clusters.

The monitoring areas in summer in the Peterborough Building was reduced to seven locations. This was the number of monitoring locations that was considered to be manageable by manual mobile monitoring. The monitoring areas consisted of two areas in the healthy clusters, one area in the unhealthy clusters, and four areas in the mixed clusters. The monitoring locations in the healthy clusters were P11 and P31, the location in the unhealthy clusters was P13 and the locations in the mixed clusters were P21, P23, P12, and P22.

At the Kendal Building, all of the six areas selected for indoor monitoring were determined by the SERC/LINK Project. As discussed in Chapter 6, the other two monitoring areas determined by SERC/LINK Project, one area in each of the healthy and unhealthy clusters, were not selected due to instrument limitation. In this building, the monitoring areas LOC-1 and LOC-3 were in healthy clusters and areas LOC-2, LOC-4, LOC-5, and LOC-6 were in unhealthy clusters (See Figure 8.2).

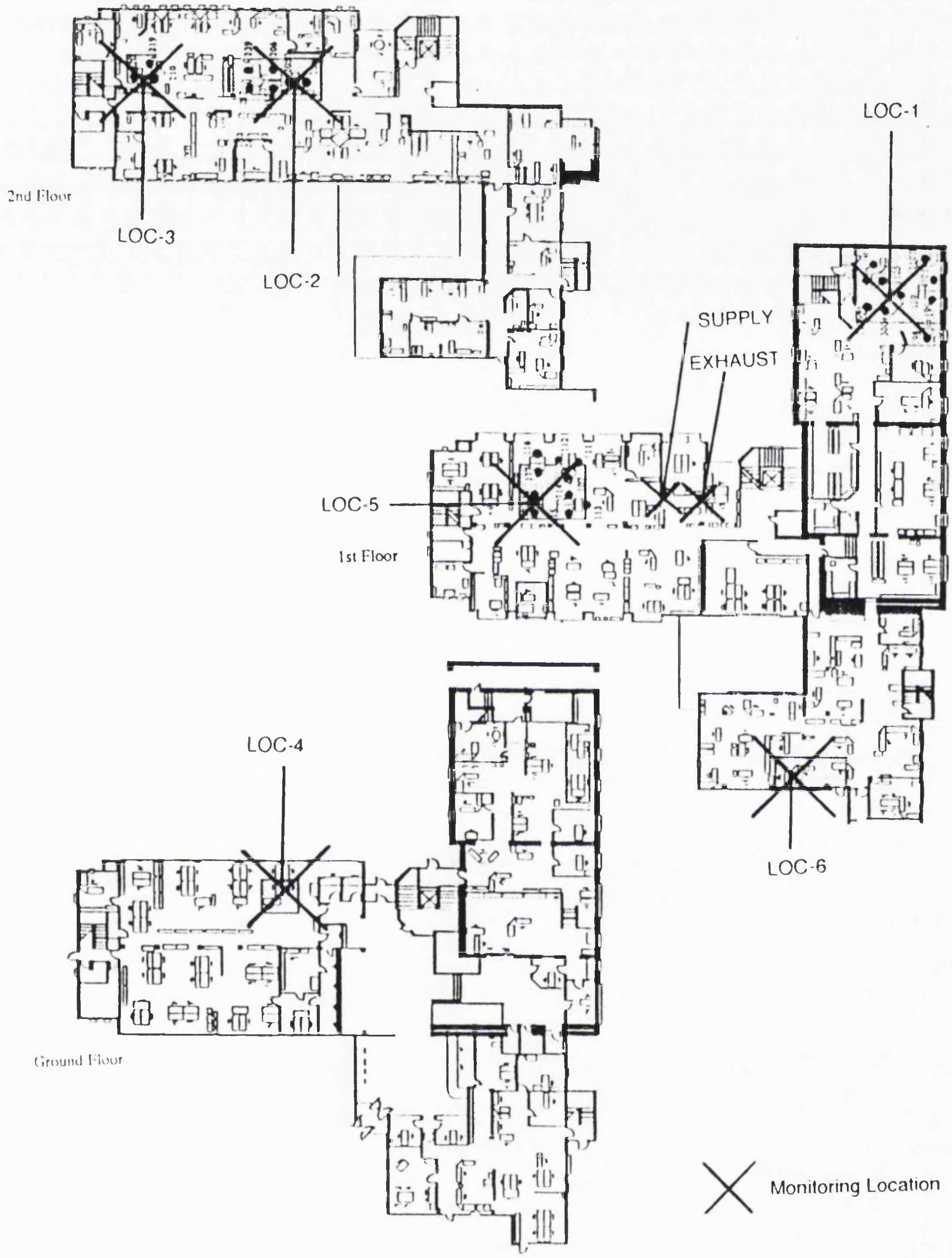


Figure 8.2
Monitoring Locations in Kendal Building

At the Cardiff Building, all of the monitoring floors and areas were determined by the SERC/LINK Project. The monitoring floors were Floor 8, 11, 16, and 22. The monitoring areas at each floor were known as LOC-1, LOC-2, LOC-3, LOC-4, and LOC-5. Areas LOC-2 and LOC-4 of Floor 8 (See Figure 8.3), LOC-1 and LOC-4 of Floor 11(See Figure 8.4), LOC-1 and LOC-5 of Floor 16 (See Figure 8.5), and LOC-1 and LOC-3 of Floor 22 (See Figure 8.6) were in healthy clusters. LOC-1 of Floor 8(See Figure 8.3), LOC-2 and LOC-5 of Floor 11 (See Figure 8.4), LOC-2 and LOC-5 of Floor 16 (See Figure 8.5), and LOC-5 of Floor 22 (See Figure 8.6) were in mixed cluster whereas LOC-3 and LOC-5 of Floor 8 (See Figure 8.3), LOC-3 of Floor 11 (See Figure 8.4), LOC-4 of Floor 16 (See Figure 8.5), and LOC-2 and LOC-4 of Floor 22 (See Figure 8.6) were in unhealthy clusters.

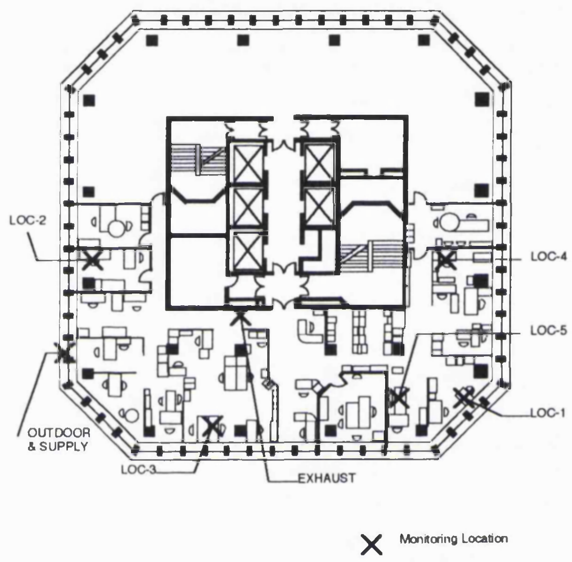


Figure 8.3
Monitoring Locations in Cardiff Building, Floor 8

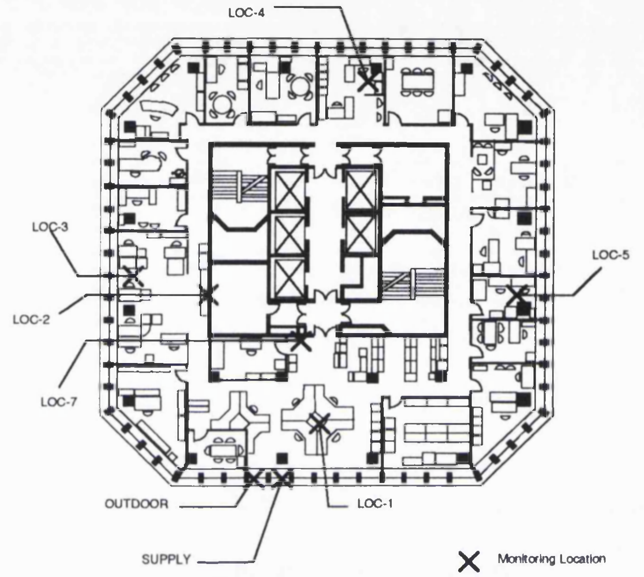


Figure 8.4
Monitoring Locations in Cardiff Building, Floor 11

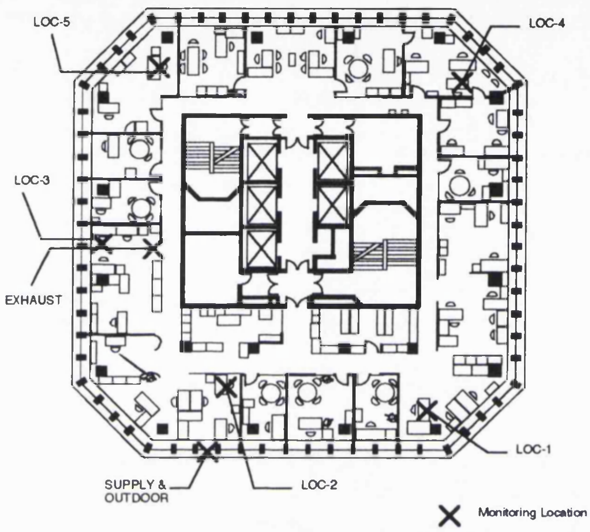


Figure 8.5
Monitoring Locations in Cardiff Building, Floor 16

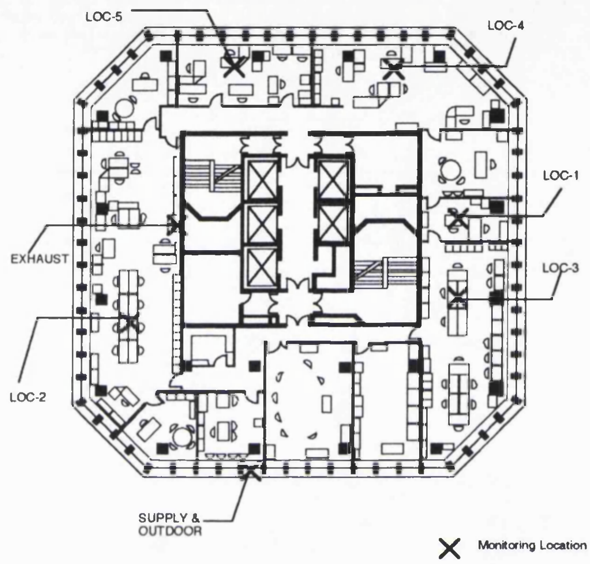


Figure 8.6
Monitoring Locations in Cardiff Building, Floor 22

8.3.3 Validity of Monitoring Location

As stated earlier, in the Peterborough Building, nine monitoring areas were determined by the SERC/LINK Project and five were selected on site. The exact monitoring locations within the monitoring areas were selected based on practicality: they should cause minimal interruption to the office activities. As for long term monitoring, if two monitoring areas were possible in the building, the monitoring would have been conducted each at a healthy and an unhealthy clusters. Since only one area was possible, L2Z31 in the unhealthy cluster was selected. However, this is an area used for clerical work where many cross- referencing and paperwork are expected. After considering the interruption it would have caused to the office activities in this location, the nearest practical location to it is L2Z32. This area is mainly used for computing work. Furthermore, it is more spacious than L2Z31; the four computers in this area are rarely used by more than two persons at any one time.

Fig. 8.2 shows the monitoring areas in the Kendal Building. In this building, the selection of monitoring locations which affects validity occurred at two stages. Firstly, during the selection of six out of the eight monitoring areas determined earlier by the SERC/LINK Project and secondly, during the selection of the exact monitoring location within the monitoring area. The selection is discussed in detail in Chapter 6.

Fig. 8.3, 8.4, 8.5 and 8.6 show the monitoring areas in the Cardiff Building. Fig. 8.3 shows the monitoring areas in Floor 8, Fig. 8.4 shows the monitoring areas in Floor 11, Fig. 8.5 shows the monitoring areas in Floor 16, and Fig. 8.6 shows the monitoring areas in Floor 22. As stated earlier, all of the monitoring areas were determined by the SERC/LINK Project. However, the selection of the exact monitoring location within the monitoring area was based on practicality.

8.4 MONITORING AREAS

This section describes the monitoring areas in Trowbridge, Peterborough, Kendal, and Cardiff Buildings.

8.4.1 Trowbridge Building

The monitorings in the Trowbridge Building were mainly mobile. However, both mobile and stationary monitorings were used in this building. They were conducted in summer 1992.

The mobile monitoring of gaseous pollutants and particulates were conducted in five working days from 8/7/1992 to 10/7/1992, on 13/7/1992, and on 14/7/1992. The five working days were considered as a single monitoring period during which the monitoring of gaseous pollutants were conducted during and after working hours but mainly during working hours after approximately 10:00 a.m. The monitoring of particulate pollutants was, however, conducted during working hours only.

In the mobile monitoring, a total of twenty-four indoor locations was monitored; ten of which were selected based on the recommendation of the maintenance engineer and Personnel Department that the areas were symptomatic. The monitoring locations were 0P1, 1P1, 1P3, 2P3, 2P4, 2P5, 2P6, 2P7, 3P1, and 3P2. Three other locations, 2P14, CPR, and MPR, were also selected because they were expected to be problem areas. Another eleven locations were selected as control areas, eight of which were in the second floor, to give enough sample for possible spatial studies. The other three control areas were 0P2, 1P1, and 3P3.

The mobile monitoring of the indoor gaseous pollutants were conducted at all of the twenty-four locations but, the monitoring of particulates were conducted at these twenty-two monitoring locations only: 0P1, 0P2, 1P1, 2P1, 2P2, 2P3, 2P4, 2P5, 2P6, 2P7, 2P8, 2P9, 2P10, 2P11, 2P12, 2P13, 2P14, 3P1, 3P2, 3P3, CPR, and MPR.

During the mobile monitoring, an attempt was made to measure sequentially the concentration of indoor pollutants at all locations. The intention was to compare the concentration of the indoor pollutants in the morning with that in the afternoon and study the daily variation of the concentrations. This attempt was abandoned for two reasons. Firstly, the monitoring at each location was longer then expected. Many unforeseen problems were discovered. For example, questions from the office workers had to be entertained or a free mains socket was not always available. The monitoring at all of the locations could not be covered within one-half of a day. Therefore, it was not possible to compare the concentration of the indoor pollutants in the morning with that in the afternoon. Consequently, it was also not possible to study the daily variation of the concentrations. Secondly, sequencing was not always possible. For example, monitoring could not be conducted when the monitoring area was used for discussion or the office worker was answering an important call and referring to several files. In this case, if the correct sequence was to be maintained, the monitoring in this area would have been delayed.

Stationary automatic monitoring of gaseous pollutants was also conducted in this building but at two locations only, one in the indoor at 2P2 and the other in the outdoor. At 2P2, the stationary automatic monitoring at 5-minutes interval time was conducted during working hours, non- working hours, and non working day from 6:00 a.m. on 22/7/1992 to 2:09 p.m. on 29/7/1992. In the outdoor, at the parapet wall opposite the main air intake, the monitoring at 2-minutes interval time was conducted during working hours, non-working hours, and non working day from 12:18 p.m. on 31/8/1992 to 2:00 p.m. on 3/9/1992.

Manual stationary monitoring of particulates at approximately one hour interval time was also conducted in the building but only at a location close to 2P2.

8.4.2 Peterborough Building

The monitorings in the Peterborough Building were mainly mobile although both mobile and stationary monitorings were used. The mobile monitoring of gaseous and particulate indoor pollutants were conducted both in winter 1992 and summer 1993.

The mobile monitoring in winter 1992 were conducted in five working days from 23/11/1992 to 27/11/1992. In this period, which was considered as a single period, a total of thirteen indoor locations was monitored for gaseous and particulate pollutants. Nine of the locations were monitored during working hours and three after working hours. Monitoring of the gaseous pollutants were conducted during and after working hours but, mainly during working hours after approximately 10:00 a.m. whereas monitoring of the particulate was conducted during working hours only.

For the monitoring of the gaseous pollutants during working hours, the gas monitor was placed for about one-half of an hour in the indoor at the nine monitoring locations, L1Z11, L1Z21, L1Z22, L1Z32, L1Z33, L2Z12, L2Z21, L2Z22, and L3Z11. The location code refers to level, zone, and area. For example, L1Z32 refers to level 1, zone 3 and area 1. After working hours, the monitor was left overnight in three indoor locations, namely L1Z31, L2Z11, L2Z31. These monitoring locations were not monitored during the mobile monitoring. However, at L1Z31 and L2Z31, the monitoring ended during working hours of the next day. At location L1Z31, the overnight monitoring was conducted from 5:41 p.m. on 23/11/1992 to 10:01 a.m. the next day. At location L2Z11, the overnight monitoring was conducted from 6:28 p.m. on 24/11/1992 to 8:56 a.m. the next day. At location L2Z31, the overnight monitoring was conducted from 6:04 p.m. on 25/11/1992 to 10:01 a.m. the next day.

During the winter mobile monitoring of gaseous pollutants, described above, an attempt was made to obtain a vertical profile of the gas concentrations at the air supply, working area and air return at the first few clusters. In the attempt, three separate Teflon tubes were used. One end of the first tube was located inside the air supply diffuser in the floor and one end of the second tube was located on a table top at the height of the face of a sitting person. Since the air in the monitored area returned at the ceiling, one end of the third tube was located at a height of about 15 cm from the ceiling. The other ends of the tubes were placed close to and sequentially inserted into the air inlet of the gas monitor.

This attempt was abandoned for two reasons. Firstly, the operation of the gas monitor is automatically stopped when its air line is blocked either internally or at the Teflon tubes. The blockage message, however, is not shown in the display screen of the gas monitor until the suction of next air sampling. Logically in this manual sampling, the sampling tube from the next location should have been connected before the beginning of suction. Therefore, when there is a blockage, the location where the blockage occurs is skipped. Secondly, even if the operation is free from air blockage, this manual sequencing is subject to human error.

As mentioned earlier in the discussion, the particulates were monitored in winter during working hours only. Approximately ten measurements of 2-minute average concentration of the particulate were made at L1Z11, L1Z21, L2Z22, L1Z31, L1Z32,

L1Z33, L2Z11, L2Z12, L2Z21, L2Z22, L2Z31, L2Z32, and L3Z11.

Other than the mobile monitoring of the airborne pollutants in the indoor, stationary monitoring of the pollutants was also conducted during winter 1992. However, it was conducted only at monitoring location L2Z32 during working hours, non- working hours, and non working day from 12:27 p.m. on 26/11/1992 to 4:14 p.m. on 4/12/1992.

In summer 1993, the monitoring of the pollutants in this building was conducted using a mobile monitoring approach. Unlike in winter 1992, the monitoring at this time of the year was conducted for only one day on 27/7/1993 and only one location was selected to represent a zone. For example, either L1Z11 or L1Z12 would represent the monitoring area at zone 1 of level 1. The other difference with the mobile monitoring in winter was that the monitoring was conducted during working hours only.

It should be noted that in between the winter 1992 and summer 1993 monitorings, the gas monitor was calibrated. The calibration was conducted at the Kendal Building on 31/3/1992. Therefore, the data should be corrected using the Equation 8 derived in Section 6.4.3.

8.4.3 Kendal Building

The monitorings of gaseous pollutants in the Kendal Building were stationary only. In this and subsequent buildings, a mechanical multiplexer was used. By means of the multiplexer, air at up to eight monitoring locations could be sampled automatically and sequentially. At each monitoring location, one end of a Teflon tube is hung at head height while the other end was connected to one of the eight inlets of the multiplexer. At a preset time intervals of 360 seconds (six minutes), the air from each of the eight locations was pumped by the multiplexer into the gas analyser in sequence. The time intervals include the time required to flush the whole length of the tubes. A sufficient flushing time should be set by selecting the running length of not less than the longest tube in the sampling system. In this building, the running length was set at 50 metres.

Some precautions were taken in running the monitoring lines. A thorough check was made to ensure the monitoring lines were free from kinking. As practical as possible, bending and constriction were minimised. Excessive bending, constriction, and a poor air quality in the tube may increase the resistance, and consequently increase the risk of the pump being stopped. If this occurs the monitoring will have to be repeated at the same location. Under these circumstances, the multiplexer was programmed to correct the monitoring sequence automatically.

The monitoring locations are shown in Fig P7.2. LOC-4 was on the ground floor, LOC-1, LOC-5 and LOC-6 were on the first floor, and LOC-2 and LOC-3 were on the second floor. The other two locations were the SUPPLY and EXHAUST on the ceiling, halfway between LOC-5 and the lift on the first floor. SUPPLY and EXHAUST refer to the air supply and air exhaust diffusers in the ceiling respectively. Due to the complexity involved in running the tube, the outdoor was not monitored.

Using a sampling duration of about one week (the actual data recorded was between three to eight days), the air in the eight monitoring locations was monitored for eight sampling weeks in winter beginning 16/3/1993 and one sampling week in summer beginning 15/7/1993. The sampling weeks in winter were KEN1, KEN2, KEN3, KEN4, KEN5, KEN6, KEN7 and KEN8, and the sampling week in summer was KSUM. The recording time during the sampling weeks were as the following:

1) data in the sampling week KEN1 was recorded from 11:41 a.m. on Tuesday 16/3/1993 to 8:26 a.m. on Friday 19/3/1993.
2) data in the week KEN2 was recorded from 11:21 a.m. on Friday 19/3/1993 to 11:52 a.m. on Thursday 25/3/1993.
3) data in the week KEN3 was recorded from 12:24 a.m. on Thursday 25/3/1993 to 1:08 p.m. on Friday 30/3/1993.
4) data in the week KEN4 was recorded from 2:00 p.m. on Thursday 1/4/1993 to 5:24 a.m. on Thursday 8/4/1993.
5) data in the week KEN5 was recorded from 12:19 p.m. on Thursday 8/4/1993 to 9:24 a.m. on Friday 16/4/1993.
6) data in the sampling week KEN6 was recorded from 10:09 a.m. on Friday 16/4/1993 to 8:51 a.m. on Friday 23/4/1993.
7) data in the week KEN7 was recorded from 9:35 a.m. on Friday 23/4/1993 to 11:34 a.m. on Friday 30/4/1993
8) data in the week KEN8 was recorded from 12:12 a.m. on Friday 30/4/1993 to

3:53 p.m. on Friday 7/4/1993.

9) data in the week KSUM was recorded from 8:15 a.m. on Thursday 15/7/1993 to 10:25 a.m. on Sunday 24/7/1993.

The data stored in the gas monitor was downloaded into a PC at the end of each sampling week. On 31/3/1993, between sampling weeks KEN3 and KEN4, the gas monitor was partially calibrated for the first time. However, all the data was corrected to the calibration setting made on 23/8/1993. In the calibration, the negative data was considered as zero.

8.4.4 Cardiff Building

The monitorings of gaseous pollutants in the Cardiff Building were stationary only. This is a high-storey building and is bigger than the previous buildings. It has several openable high windows on each floor. There were five monitoring locations on each floor. The other three monitoring locations were the air supply in the window ventilation unit, the return diffuser in the ceiling, and the outdoor air at one of the openable high windows.

The monitoring of the pollutants was conducted on floors 8, 11, 16, and 22. To minimise the seasonal effect when comparing the results of different floors, the monitoring began on floor 11, followed by floor 16, floor 22, and finally it ended on floor 8. The sampling duration was about one week (the actual data recorded was between 3 to 7 days). Floor 11 was monitored for four weeks beginning 3/8/1993. The gas monitor was calibrated on 23/8/1993 before the 2-week monitoring on floor 16 which began on 2/9/1993. Floor 22 was monitored for five weeks from 7/9/13 and floor 8 was monitored for two weeks from 21/9/13.

8.5 DISCUSSION OF THE USE TO WHICH THE RESULTS CAN BE PUT

As elaborated in Chapter 5, the monitoring of indoor pollutants is characteristic of the monitoring time and location. In other words, ideally the monitorings at two locations should not be compared for spatial variation unless they were conducted simultaneously. Similarly, the monitorings at two monitoring time should not be compared for time or seasonal variation unless they were conducted at the same location.

The four floors in the Cardiff Building may be considered as different buildings. Therefore, the monitorings at each of the four floors in this building and at the Kendal Building may be used to study time variation. In terms of monitoring time, the monitoring in the Cardiff Building was conducted at four separate periods. During each monitoring period, a different floor was monitored and the measurements were repeated at the same monitoring locations within the monitored floor. Similarly, in the Kendal Building, the measurements were repeated at the same monitoring locations. Therefore, the time variation study is valid in the Kendal Building and all four floors of the Cardiff Building.

The monitorings in these two buildings may also be used to study spatial variation: at different monitoring locations or between healthy and unhealthy clusters. Ideally, to study spatial variation the concentration of indoor pollutants at different locations should be measured simultaneously. In this case, sequential monitoring is the practical approximation of simultaneous monitoring. In both buildings the monitoring locations were sequentially monitored. There was a time delay of between six to forty-two minutes between the monitoring time at two monitoring locations. Consequently, there was an error in the comparison of the measurements at the two monitoring locations. This error may be estimated using the values suggested in Chapter 6.

The monitoring at all monitoring areas in the Kendal Building, and the monitoring areas L1Z11 and L3Z11 in the Peterborough Building may be used to study seasonal variation. In these areas the measurements in different seasons were repeated at the same monitoring locations. Therefore the seasonal variation study is valid.

The mobile monitoring of the indoor and outdoor and the stationary monitoring of indoor pollutants at the Trowbridge and Peterborough Buildings are quite limited in application. It should be noted that the monitoring at the Trowbridge and Peterborough Buildings were conducted during the early stage of development. Except at monitoring areas L1Z11 and L3Z11 in Peterborough Building, the monitorings in the Trowbridge and Peterborough Buildings should be analysed separately. As stated earlier, the monitoring areas L1Z11 and L3Z11 in the Peterborough Building may be used to study seasonal variation.

The monitorings in the Trowbridge and Peterborough Buildings were not valid to study spatial or time variation. However, the mobile monitorings of the indoor in the Trowbridge and Peterborough Buildings may give an approximate indication of the concentration of gaseous pollutants in the buildings as a whole. Therefore, the monitorings at Trowbridge and Peterborough Buildings may be used to study the relative concentration of indoor pollutants in the four buildings.

Three types of analysis may be conducted separately in the Trowbridge and Peterborough Buildings:

1. the analysis of the data taken during the mobile monitoring at different locations. In this case, the five- day monitoring period in winter in Peterborough Building should be considered as single monitoring period and the one-day period in summer should be considered as another single monitoring period. Similarly, the five-day monitoring period in the Trowbridge Building should be considered as a single monitoring period. The analysis of the data collected during these periods may give an indication the typical concentration of gaseous pollutants in the buildings;

2. the analysis of the data taken during the long-term stationary monitorings in the two buildings may provide an indication of the typical concentration of gaseous pollutants in the indoor during working hours, non-working hours of working day and non-working days;

3. the analysis of the data taken during the long-term stationary monitoring of the outdoor in Trowbridge Building may provide an indication of the typical concentration of gaseous pollutants in the outdoor during working hours, non-working hours of working day and non-working days.

The mobile monitoring in the Trowbridge and Peterborough Buildings were not valid for studying time and spatial variation because the measurements taken at different locations in the buildings were not conducted at the same time. The twenty-five monitoring locations at the Trowbridge Building were monitored at different times within five working days: on 8/7, 9/7, 10/7, 13/7, and 14/7/1992. The eleven monitoring locations at the Peterborough Building in winter 1992 were monitored at different times within five working days: on 23/11, 24/11, 25/11, 26/11, and 27/11/1992. The seven monitoring locations in this building in summer 1993 were monitored at different times of the day on 27/7/1993.

The mobile monitoring in the monitoring areas L1Z11 and L3Z11 of the Peterborough Building were been conducted both in summer and winter. In summer L1Z11 was known as PS11 and L3Z11 was known as PS31. Therefore, in these areas seasonal variation may be studied. In the other monitoring areas of the building, the study of seasonal variation is not valid. During summer , the number of monitoring locations were reduced from thirteen to seven which means that some of the monitoring locations selected in winter were not monitored in summer.

The problem of time variation is minimised by incorporating a multiplexer in the monitoring conducted in the Kendal and Cardiff Buildings. Therefore, the data collected in these buildings may be used to study time, seasonal, and spatial variation. In both buildings the measurements were repeated at the same monitoring locations. In the Kendal Building, the same monitoring locations were used for summer monitoring. Therefore, the time and seasonal variation studies are valid.

The four floors in the Cardiff Building may be considered as different buildings. In terms of monitoring time, the monitoring were conducted at four separate periods. During each period, a different set of eight monitoring locations were monitored.

8.6 CONCLUSION

Mobile monitoring, either sequential or non-sequential, is very limited in application since mobility from one location to another monitoring location is a major problem in office environment. If this monitoring approach is necessary, for example, only one gas monitor is available, only selected locations may be monitored. The selection which is normally decided in situ may be drastically different from that initially planned. The location selected earlier may not be selected in the next sequence. Due to this restriction, two limitations may occur:

1. The measures at selected locations, if different from those intended, may

not give a reliable average, maximum, minimum, and standard deviation of the measures to represent the condition found in the study building.

2. If the sequence is out of step, the measures could not be matched to compare the simultaneous condition at several location.s

The gas monitor used in this research is more suitable for stationary rather than mobile monitoring. Stationary monitoring using several gas monitors should be used in offices. Once the gas monitor is placed it can be left running unattended for a long time. Therefore, it does not interrupt the office activities except that it is noisy. The number of the gas monitors required is determined by the locations/ clusters to be monitored simultaneously. If only one gas monitor is available, an almost simultaneous monitoring may be conducted using a mechanical multiplexer. Aperfect simultaneous monitoring is not possible due to time delay in changing the connection of the gas monitor from one monitoring inlet to the next inlet.

Chapter 9
RESULTS AND THEIR ANALYSIS

9.1 SUMMARY

The average concentration of gaseous pollutants and respirable particulates in healthy areas were not different from those in unhealthy areas. Except those of TVOC, the concentration of gaseous pollutants in winter were also not significantly different from those in summer. In all of the monitorings, they were well below the relevant standards. However, the average concentration of TVOCsand carbon dioxide exceeded some suggested concentration limits for offices. During the monitorings, the errors during static calibration were relatively high such that not all of the monitored data could be used for those analysis.

9.2 INTRODUCTION

This chapter is divided into three major sections: results, analysis, and the limitation and problems of the original data. This chapter ends with the conclusion.

9.3 RESULTS

This section is divided into three parts according to buildings: 1) Peterborough Building, 2) Kendal Building, and 3) Cardiff Building.

9.3.1 Peterborough Building

The result of the monitoring in this building is divided into four parts: measurement during working hours in winter, overnight stationary monitoring, long term stationary monitoring, and measurement during working hours in summer.

9.3.1.1 Measurements During Working Hours in Winter

The results of measurements in winter are summarised in Tables 9.1, 9.2, 9.3, and 9.4. Table 9.1 shows the results of mobile monitoring of TVOC, Table 9.2 shows the results of carbon dioxide, and Table 9.3 shows the results of carbon monoxide. In these tables, MAX, AVG, MIN, STD and N, refer to the maximum, average, minimum, standard deviation, and the number of data respectively. The results are made more useful by calculating these parameters. The range of concentrations detected by the gas monitor during the monitoring varied from the minimum to the maximum. The possible range of concentration in the monitoring area may be estimated from the standard deviation and the average concentration. Table 9.4 shows the measurement of respirable particulates averaged over 2 minutes.

	MAX	AVG	MIN	STD	N
L1Z11	3.78	3.38	3.04	0.15	38
L1Z21	3.70	2.86	2.56	0.24	23
L1Z22	3.79	2.95	2.60	0.30	33
L1Z31	4.35	3.66	3.06	0.29	32
L1Z32	3.35	2.70	2.29	0.18	63
L1Z33	3.63	2.92	2.60	0.20	43
L2Z12	3.52	3.05	2.69	0.20	30
L2Z21	3.87	2.61	2.34	0.32	20
L2Z22	3.54	2.81	2.43	0.25	17
L2Z31	3.63	3.44	3.11	0.12	30
L2Z32	4.00	3.23	2.47	0.33	528
L3Z11	3.27	2.72	2.43	0.17	39
OUT	3.24	1.11	0.00	0.62	96

Table 9.1
Measures of TVOC in Peterborough Building in Winter (ppm)

	MAX	AVG	MIN	STD	N
L1Z11	723	653	601	33	38
L1Z21	622	601	587	8	23
L1Z22	735	617	571	40	33
L1Z31	516	483	453	20	31
L1Z32	686	593	559	22	62
L1Z33	700	673	654	11	42
L2Z12	711	670	644	17	30
L2Z21	677	616	590	22	20
L2Z22	692	638	611	25	17
L2Z31	487	446	426	18	30
L2Z32	760	573	466	32	528
L3Z11	791	657	604	40	39
OUT	522	449	423	17	94

Table 9.2
Measures of Carbon Dioxide in Peterborough Building in Winter (ppm)

	MAX	AVG	MIN	STD	N
L1Z11	2.16	1.97	1.77	0.10	37
L1Z21	2.38	2.21	1.94	0.13	23
L1Z22	2.16	1.97	1.64	0.11	33
L1Z31	2.56	2.24	2.02	0.17	31
L1Z32	2.18	1.82	1.61	0.12	62
L1Z33	2.22	1.87	1.65	0.16	42
L2Z12	2.07	1.85	1.71	0.10	29
L2Z21	1.89	1.71	1.49	0.12	20
L2Z22	2.37	2.12	1.83	0.14	17
L2Z31	2.41	2.08	1.95	0.10	30
L2Z32	2.32	1.91	1.51	0.19	527
L3Z11	1.92	1.77	1.52	0.10	39
OUT	2.55	1.64	1.16	0.26	92

Table 9.3
Measures of Carbon Monoxide in Peterborough Building in Winter (ppm)

LOCATION	MAX	AVG	MIN	STD	N
O2/1	0.03	0.03	0.03	0	2
O2/2	0.07	0.03	0	0.03	11
O3/1	0.07	0.05	0.04	0.01	10
O3/2	0.05	0.03	0.01	0.01	7
O4/1	0.05	0.04	0.03	0.01	10
O4/2	0.05	0.01	0	0.02	10
L1Z11	0.03	0.02	0.01	0.01	10
L1Z21	0.02	0.01	0.01	0.01	10
L1Z22	0.04	0.02	0.01	0.01	10
L1Z31	0.03	0.02	0.01	0.01	10
L1Z32	0.03	0.02	0.01	0.01	10
L1Z33	0.04	0.02	0.02	0.01	11
L2Z11	0.05	0.03	0.02	0.01	12
L2Z12	0.03	0.02	0.01	0.01	11
L2Z21	0.03	0.02	0.02	0	10
L2Z22	0.03	0.02	0.01	0.01	10
L2Z31/1	0.02	0.01	0.01	0.01	10
L2Z31/2	0.04	0.02	0.01	0.01	10
L3Z11	0.03	0.02	0.01	0.01	10

Table 9.4
Respirable Particulates Concentration in Peterborough Bldg (mg/m3)

9.3.1.2 `Overnight' (Short Term) Stationary Monitoring

The results of the overnight stationary monitoring in winter are summarised in Tables 9.5, 9.6, and 9.7. Table 9.5 shows the measures of TVOC, Table 9.6 shows the measures of carbon dioxide, and Table 9.7 shows the measures of carbon monoxide.

LOC	TIME	MAX	AVG	MIN	STD	N
L1Z31	NON	3.82	3.12	2.47	0.21	441
L1Z31	OFH	4.35	3.66	3.06	0.29	32
L2Z11	NON	4.33	3.63	2.97	0.19	427
L2Z31	NON	4.47	3.86	2.29	0.44	453
L2Z31	OFH	3.63	3.44	3.11	0.12	30

Table 9.5
Measures of TVOC During Overnight Monitoring in Peterborough Building (ppm)

LOC	TIME	MAX	AVG	MIN	STD	N
L1Z31	NON	598	459	414	43	441
L1Z31	OFH	516	483	453	20	31
L2Z11	NON	632	445	405	49	427
L2Z31	NON	688	455	414	46	453
L2Z31	OFH	487	446	426	18	30

Table 9.6
Measures of Carbon Dioxide During Overnight Monitoring in Peterborough Building (ppm)

LOC	TIME	MAX	AVG	MIN	STD	N
L1Z31	NON	2.50	1.99	1.62	0.14	441
L1Z31	OFH	2.56	2.24	2.02	0.17	31
L2Z11	NON	2.74	2.30	1.86	0.18	427
L2Z31	NON	2.85	2.28	1.61	0.22	453
L2Z31	OFH	2.41	2.08	1.95	0.10	30

Table 9.7
Measures of Carbon Monoxide During Overnight Monitoring in Peterborough Building (ppm)

9.3.1.3 Long Term Stationary Monitoring

The results of the long term stationary monitoring in location L2Z32 in winter are summarised in Tables 9.8, 9.9, and 9.10. Table 9.8 shows the measures of TVOC, Table 9.9 shows the measures of carbon dioxide, and Table 9.10 shows the measures of carbon monoxide.

TIME	MAX	AVG	MIN	STD	N
NON	4.31	3.28	2.46	0.29	960
OFH	4.00	3.23	2.47	0.33	528
WEND	3.95	3.48	2.99	0.19	576

Table 9.8
Measures of TVOC During Long Term Monitoring at L2Z32 in Peterborough Building (ppm)

TIME	MAX	AVG	MIN	STD	N
NON	2.32	1.79	1.38	0.15	960
OFH	2.32	1.90	1.51	0.19	527
WEND	2.42	1.84	1.49	0.20	576

Table 9.9
Measures of Carbon Dioxide During Long Term Monitoring at L2Z32 in Peterborough Building (ppm)

TIME	MAX	AVG	MIN	STD	N
NON	604	469	427	40	960
OFH	760	573	466	32	528
WEND	561	463	442	13	576

Table 9.10
Measures of Carbon Monoxide During Long Term Monitoring at L2Z32 in Peterborough Building (ppm)

9.3.1.4 Measurements During Working Hours in Summer

The results of the mobile monitoring in summer are summarised in Tables 9.11, 9.12, 9.13, and 9.14. Table 9.11 shows the measures of TVOC, Table 9.12 shows the measures of carbon dioxide, and Table 9.13 shows the measures of carbon monoxide. In these tables MAX, AVG, MIN, STD, and N refer to the maximum, average, minimum, standard deviation, and the number of data respectively. Table 9.14 shows the measures of respirable particulates.

	MAX	AVG	MIN	STD	N
L1Z10	0	0	0	0	19
L1Z20	0	0	0	0	19
L1Z30	0	0	0	0	19
L2Z10	0	0	0	0	21
L2Z20	0	0	0	0	24
L2Z30	0	0	0	0	20
L3Z10	0	0	0	0	20
OUT	0	0	0	0	12

Table 9.11
Measures of TVOC in Peterborough Building in Summer (ppm)

	MAX	AVG	MIN	STD	N
L1Z10	465	444	428	12	19
L1Z20	480	448	423	16	19
L1Z30	464	436	416	15	19
L2Z10	494	436	420	17	21
L2Z20	503	457	423	23	24
L2Z30	427	406	396	8	20
L3Z10	677	465	432	51	20
OUT	392	379	374	5	12

Table 9.12
Measures of Carbon Dioxide in Peterborough Building in Summer (ppm)

	MAX	AVG	MIN	STD	N
L1Z10	0.11	0.01	0.00	0.03	19
L1Z20	0.22	0.04	0.00	0.06	19
L1Z30	0.19	0.01	0.00	0.04	19
L2Z10	0.00	0.00	0.00	0.00	21
L2Z20	0.00	0.00	0.00	0.00	24
L2Z30	0.00	0.00	0.00	0.00	20
L3Z10	0.02	0.00	0.00	0.00	20
OUT	0.09	0.01	0.00	0.03	12

Table 9.13
Measures of Carbon Monoxide in Peterborough Building in Summer (ppm)

CLUSTER	MAX	AVG	MIN	STD	N
L1Z10	0.03	0.02	0.01	0.01	10
L1Z20	0.04	0.02	0.01	0.01	20
L1Z30	0.04	0.02	0.01	0.01	31
L2Z10	0.05	0.02	0.01	0.01	23
L2Z20	0.03	0.02	0.01	0.01	20
L2Z30	0.04	0.02	0.01	0.01	20
L3Z10	0.03	0.02	0.01	0.01	10

Table 9.14
Respirable Particulates Concentration in Peterborough Bldg in Summer (mg/m3)

9.3.2 Kendal Building

The results of the measurements in this buildings are divided into four parts: weekly summaries of gaseous pollutants, respirable particulates, summer summaries of gaseous pollutants, and winter summaries of gaseous pollutants.

9.3.2.1 Weekly Summaries of Gaseous Pollutants

The results of sequential monitoring of gaseous pollutants are summarised by week in Appendix IV - Tables A.1 through A.30, B.1 through B.30, C.1 through C.30, D.1 through D.24, E.1 through E.24, and F.1 through F.24 - and their corresponding figures in Appendix V.

In these tables, MAX, AVG, MIN, STD, and N also refer to the maximum, average, minimum, standard deviation, and the number of data respectively.

In these figures this convention is used in the vertical axis. The average concentration of the gases is represented by a thick continuous line (AVG). The range of average concentration is bounded by a pair of light continuous lines; the top is the maximum (MAX) and the bottom is the minimum (MIN). The standard deviation of variation about the average is bounded by a pair of dotted lines; the top is the upper boundary (UPB) and the bottom is the lower boundary (LOB). This standard deviation band shows the spread of the data. Since the standard deviationband indicates plus and minus, one standard error of the average, statistically 66.67% of the data, lies within the standard deviation band. The vertical axes display the concentration of the gases expressed in PPM. The scale of these axes is selected so that the figures of the same gas measures may be compared to each other. Therefore the resolution of the information displayed on these axes, namely the range, average and its error, is not optimised.

Figures A.1 through A.30, in Appendix V, which are based on Tables A.1 through A.30 respectively, show the concentration of the TVOC in the indoor of the Kendal Building at all monitoring locations, namely LOC-1, LOC-2, LOC-3, LOC-4, LOC-5, LOC-6, SUPPLY, and EXHAUST, during the standard monitoring weeks. SUPPLY and EXHAUST refer to the air supply and air exhaust diffusers in the ceiling near LOC-5 respectively.

The format of the Tables A.1 through A.30 in Appendix IV, thus the figures A.1 through A.30, in Appendix V, are as follows. The tables are assembled in groups of three. Therefore there are 10 groups altogether. Groups refer to a standard monitoring week of data collection beginning at midnight on a Sunday and ending at midnight on the following Sunday. Groups 1 through 10 refer to the standard monitoring weeks W-1, W-2, W-3, W-4, W-5, W-6, W-7, W-8, S- 1, and S-2:

i) W-1 refers to the standard monitoring week in winter from 15/3/1993 to 21/3/1993,

ii) W-2 refers to the standard monitoring week in winter from 22/3/1993 to 28/3/1993,

iii) W-3 refers to the standard monitoring week in winter from 29/3/1993 to 4/4/1993,

iv) W-4 refers to the standard monitoring week in winter from 5/4/1993 to 11/4/1993,

v) W-5 refers to the standard monitoring week in winter from 12/4/1993 to 18/4/1993,

vi) W-6 refers to the standard monitoring week in winter from 19/4/1993 to 25/4/1993,

vii) W-7 refers to the standard monitoring week in winter from 26/4/1993 to 2/5/1993,

viii) W-8 refers to the standard monitoring week in winter from 3/5/1993 to 9/5/1993,

ix) S-1 refers to the standard monitoring week in summer from 12/7/1993 to 18/7/1993, and

x) S-2 refers to the standard monitoring week in summer from 19/7/1993 to 25/7/1993.

For example, Tables and Figures A.10 through A.12 show the TVOC measured in the standard monitoring week in winter from 5/4/1993 to 11/4/1993.

Within each group of three, the tables and figures are also arranged consistently. In the arrangement, the first refer to the measurement during non working hours of working days. The second and third refer to working hours and non- working days respectively. As stated earlier, Tables and Figures A.10 through A.12 show the TVOC measured in winter week from 5/4/1993 to 11/4/1993. Therefore, Table and Figure A.11 show the TVOC measures taken during working hours. This measures exclude non-working days which are Saturday, Sunday and holidays. In this case, Good Friday was on 9/4/1993. Therefore, in arriving at the TVOC measures displayed in Table and Figure A.11, the data from 0.01 a.m. 9/4/1993 to 24.00 pm 11/4/1993 was excluded. Furthermore, in the remaining data, the measures outside working hours was excluded. Working hours refer to the time from 9.00 am to 5.00 pm during working days.

Tables and Figures B and C are arranged in a similar manner. Tables and Figures B show the measurements of carbon dioxide while Tables and Figures C show the measurement of carbon monoxide.

Figures D.1 through D.24, which are based on Tables D7.1 through D.24 respectively, show the concentration of the TVOC in the indoor of the Kendal Building at all monitoring weeks, namely W-1, W-2, W-3, W-4, W-5, W-6, W-7, W-8, S-1, and S-2.

The format of the Tables D.1 through D.24, thus the figures D.1 through D.24, are as follows: the vertical axes show the concentration of TVOC in ppm and the horizontal axes are labelled with the standard monitoring weeks W-1, W-2, W-3, W-4, W-5, W-6, W-7, W-8, S-1, and S-2.

The tables are assembled in groups of three. Therefore, there are 8 groups altogether. The groups refer to monitoring locations, namely LOC-1, LOC-2, LOC-3, LOC-4, LOC-5, LOC-6, SUPPLY, and EXHAUST. Within each group of three, the tables and figures are also arranged consistently as in the above tables and figures.

9.3.2.2 Respirable Particulates

The result of the measurement of respirable particulates in winter are summarised in Tables 9.15 through 9.22. Tables 9.15 through 9.18 summarise the concentration averaged over 2 minute. Tables 9.15, 9.16, and 9.17, show the measurements at 9.30 am, 12.30 pm, and 3.30 pm on 16, 17, and 18 March 1993. Table 9.18 shows the measurement at 9.30 am on 19 March 1993. Tables 9.19 through 9.22 summarise the concentration averaged over 5 minute. Tables 9.19, 9.20, and 9.21, show the measurements at 9.30 am, 12.30 pm, and 3.30 pm on 16, 17, and 18 March 1993. Table 9.22 shows the measurement at 9.30 am on 19 March 1993. No measurement was conducted in summer.

CLUSTER	9:30 am	12:30 pm	3:30 pm
LOC-1	0.01	0.03	0.02
LOC-2	0.02	0.02	0.03
LOC-3	0.02	0.02	0.02
LOC-4	0.02	0.04	0.03
LOC-5	0.02	0.03	0.03
LOC-6	0.03	0.04	0.03

Table 9.15
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (16/3/1993)(2-minutes duration)

CLUSTER	9:30 am	12:30 pm	3:30 pm
LOC-1	0.04	0.04	0.03
LOC-2	0.03	0.02	0.03
LOC-3	0.03	0.02	0.03
LOC-4	0.05	0.05	0.03
LOC-5	0.03	0.03	0.02
LOC-6	0.04	0.03	0.04
OUTDOOR	0.03	0.03	0.03

Table 9.16
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (17/3/1993)(2-minutes duration)

CLUSTER	9:30 am	12:30 pm	3:30 pm
LOC-1	0.03	0.03	0.04
LOC-2	0.02	0.02	0.02
LOC-3	0.02	0.02	0.03
LOC-4	0.05	0.04	0.03
LOC-5	0.02	0.01	0.03
LOC-6	0.02	0.03	0.03
OUTDOOR	0.02	0.04	0.03

Table 9.17
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (18/3/1993)(2-minutes duration)

CLUSTER	9:30 am
LOC-1	0.03
LOC-2	0.02
LOC-3	0.03
LOC-4	0.04
LOC-5	0.02
LOC-6	0.03
OUTDOOR	0.03

Table 9.18
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (19/3/1993)(2-minutes duration)

CLUSTER	9:30 am	12:30 pm	3:30 pm
LOC-1	0.02	0.02	0.02
LOC-2	0.01	0.02	0.02
LOC-3	0.02	0.01	0.02
LOC-4	0.02	0.03	0.03
LOC-5	0.02	0.02	0.02
LOC-6	0.03	0.03	0.02

Table 9.19
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (16/3/1993)(5 minutes duration)

CLUSTER	9:30 am	12:30 pm	3:30 pm
LOC-1	0.04	0.03	0.03
LOC-2	0.03	0.02	0.03
LOC-3	0.03	0.02	0.03
LOC-4	0.04	0.04	0.03
LOC-5	0.03	0.03	0.02
LOC-6	0.04	0.03	0.04
OUTDOOR	0.03	0.03	0.03

Table 9.20
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (17/3/1993)(5 minutes duration)

CLUSTER	9:30 am	12:30 pm	3:30 pm
LOC-1	0.03	0.02	0.03
LOC-2	0.02	0.02	0.02
LOC-3	0.02	0.02	0.02
LOC-4	0.04	0.03	0.04
LOC-5	0.02	0.02	0.02
LOC-6	0.02	0.03	0.02
OUTDOOR	0.02	0.04	0.03

Table 9.21
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (18/3/1993)(5 minutes duration)

CLUSTER	9:30 am
LOC-1	0.03
LOC-2	0.02
LOC-3	0.03
LOC-4	0.03
LOC-5	0.02
LOC-6	0.03
OUTDOOR	0.03

Table 9.22
Respirable Particulates Concentration in Kendal Bldg (mg/m3) (19/3/1993)(5 minutes duration)

9.3.2.3 Winter Summaries of Gaseous Pollutants

The results of the measurements in winter are summarised in Tables 9.15 through 9.25. Tables 9.15 through 9.18 show the measures of respirable particulates averaged over 2 minutes. Tables 9.19 through 9.22 show the measures of respirable particulates averaged over 5 minutes. Tables 9.23 through 9.25 show the sequential monitoring of gaseous pollutants in winter. Table 9.23 shows the monitoring of TVOC. Table 9.24 shows the monitoring of carbon dioxide. Table 9.25 shows the monitoring of carbon monoxide.

	MAX	AVG	MIN	STD	N
LOC-1	9.78	1.76	0.00	2.47	326
LOC-2	34.60	1.80	0.00	2.99	326
LOC-3	56.83	2.31	0.00	4.69	326
LOC-4	12.16	1.88	0.00	2.70	326
LOC-5	11.08	1.78	0.00	2.60	326
LOC-6	6.76	1.50	0.00	2.32	325
SUPPLY	26.99	1.45	0.00	2.78	321
EXHAUST	20.51	1.71	0.00	2.77	319
INDOOR	56.83	1.84	0.00	3.08	1955

Table 9.23
Measures of TVOC in Kendal Building During Working Hours in Winter (ppm)

	MAX	AVG	MIN	STD	N
LOC-1	1176	747	433	115	326
LOC-2	1109	708	429	117	326
LOC-3	1275	751	429	142	326
LOC-4	2125	951	433	273	326
LOC-5	1018	701	430	90	326
LOC-6	1453	898	431	148	325
SUPPLY	1057	595	429	121	321
EXHAUST	1186	703	429	94	319
INDOOR	2125	793	429	186	1955

Table 9.24
Measures of Carbon Dioxide in Kendal Building During Working Hours in Winter (ppm)

	MAX	AVG	MIN	STD	N
LOC-1	4.91	1.64	0.24	0.90	326
LOC-2	3.84	1.41	0.18	0.77	326
LOC-3	4.00	1.41	0.18	0.74	326
LOC-4	4.84	1.71	0.34	0.87	326
LOC-5	4.01	1.47	0.23	0.79	326
LOC-6	4.77	1.62	0.12	0.83	325
SUPPLY	4.83	1.41	0.15	0.79	321
EXHAUST	3.93	1.33	0.18	0.75	319
INDOOR	4.91	1.54	0.12	0.82	1955

Table 9.25
Measures of Carbon Monoxide in Kendal Building During Working Hours in Winter (ppm)

9.3.2.4 Summer Summaries of Gaseous Pollutants

Table 9.26 through 9.28 show the sequential monitoring of gaseous pollutants in summer. Table 9.26 shows the monitoring of TVOC, Table 9.27 shows the monitoring of carbon dioxide, and Table 9.28 shows the monitoring of carbon monoxide.

	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	60
LOC-2	0.00	0.00	0.00	0.00	60
LOC-3	0.00	0.00	0.00	0.00	60
LOC-4	0.00	0.00	0.00	0.00	60
LOC-5	0.00	0.00	0.00	0.00	60
LOC-6	0.00	0.00	0.00	0.00	60
SUPPLY	1.26	0.02	0.00	0.16	60
EXHAUST	8.29	0.20	0.00	1.16	60
INDOOR	0.00	0.00	0.00	0.00	360

Table 9.26
Measures of TVOC in Kendal Building During Working Hours in Summer (ppm)

	MAX	AVG	MIN	STD	N
LOC-1	912	775	630	62	60
LOC-2	723	621	527	40	60
LOC-3	911	792	588	73	60
LOC-4	651	543	490	25	60
LOC-5	733	649	561	39	60
LOC-6	779	651	544	57	60
SUPPLY	793	637	542	50	60
EXHAUST	915	674	510	88	60
INDOOR	912	672	490	101	360

Table 9.27
Measures of Carbon Dioxide in Kendal Building During Working Hours in Summer (ppm)

	MAX	AVG	MIN	STD	N
LOC-1	2.79	1.12	0.41	0.49	60
LOC-2	1.77	0.92	0.28	0.39	60
LOC-3	2.30	1.08	0.23	0.56	60
LOC-4	2.57	0.95	0.26	0.52	60
LOC-5	1.63	0.87	0.21	0.37	60
LOC-6	2.51	1.18	0.25	0.55	60
SUPPLY	1.72	0.87	0.27	0.37	60
EXHAUST	1.76	0.87	0.23	0.34	60
INDOOR	2.79	1.02	0.21	0.49	360

Table 9.28
Measures of Carbon Monoxide in Kendal Building During Working Hours in Summer (ppm)

9.3.3 Cardiff Building

The results of the measurements in this building are summarised in Tables 9.29 through 9.41.

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	20.03	0.31	0.00	2.16	88
LOC-2	6.74	0.22	0.00	0.86	86
LOC-3	5.09	0.10	0.00	0.58	87
LOC-4	32.47	0.60	0.00	3.81	87
LOC-5	19.37	0.39	0.00	2.32	87
SUPPLY	4.17	0.08	0.00	0.49	87
EXHAUST	2.25	0.12	0.00	0.44	87
OUTDOOR	0.00	0.00	0.00	0.00	86
INDOOR	32.47	0.32	0.00	2.26	435

Table 9.29
Measures of TVOC at Floor 8, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1111	719	573	93	88
LOC-2	1214	726	527	135	86
LOC-3	789	657	551	50	87
LOC-4	1108	745	604	98	87
LOC-5	916	675	518	76	87
SUPPLY	569	502	434	26	87
EXHAUST	926	711	573	66	87
OUTDOOR	543	468	439	22	86
INDOOR	1214	705	518	100	435

Table 9.30
Carbon Dioxide Measures at Floor 8, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.81	0.51	0.01	0.38	88
LOC-2	2.92	0.85	0.03	0.62	86
LOC-3	1.63	0.48	0.00	0.37	87
LOC-4	1.58	0.51	0.03	0.37	87
LOC-5	1.90	0.49	0.00	0.39	87
SUPPLY	2.10	0.41	0.00	0.35	87
EXHAUST	1.75	0.48	0.00	0.36	87
OUTDOOR	2.13	0.51	0.00	0.45	86
INDOOR	2.92	0.57	0.00	0.46	435

Table 9.31
Carbon Monoxide Measures at Floor 8, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	59.97	3.57	0.00	10.07	138
LOC-2	577.60	20.09	0.00	73.82	138
LOC-3	953.42	26.87	0.00	108.32	137
LOC-4	183.45	3.83	0.00	17.96	138
LOC-5	10.40	0.29	0.00	1.23	138
SUPPLY	0.00	0.00	0.00	0.00	137
EXHAUST	183.45	5.69	0.00	20.63	134
OUTDOOR	0.00	0.00	0.00	0.00	133
INDOOR	953.42	10.91	0.00	60.00	689

Table 9.32
Measures of TVOC at Floor 11, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	867	620	481	65	138
LOC-2	939	617	439	90	138
LOC-3	795	619	444	77	137
LOC-4	768	623	492	53	138
LOC-5	1203	623	459	99	138
SUPPLY	689	489	441	33	137
EXHAUST	752	608	507	47	134
OUTDOOR	491	447	418	14	133
INDOOR	1203	620	439	78	689

Table 9.33
Carbon Dioxide Measures at Floor 11, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.23	0.26	0.00	0.20	138
LOC-2	0.79	0.23	0.00	0.19	138
LOC-3	1.03	0.23	0.00	0.20	137
LOC-4	1.16	0.25	0.00	0.19	138
LOC-5	1.21	0.22	0.00	0.20	138
SUPPLY	0.70	0.21	0.00	0.16	137
EXHAUST	0.96	0.23	0.00	0.18	134
OUTDOOR	0.85	0.21	0.00	0.18	133
INDOOR	1.23	0.24	0.00	0.20	689

Table 9.34
Carbon Monoxide Measures at Floor 11, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	86
LOC-2	5.11	0.09	0.00	0.62	84
LOC-3	5.36	0.07	0.00	0.58	86
LOC-4	0.83	0.01	0.00	0.09	85
LOC-5	0.00	0.00	0.00	0.00	85
SUPPLY	0.00	0.00	0.00	0.00	85
EXHAUST	5.76	0.11	0.00	0.70	84
OUTDOOR	0.00	0.00	0.00	0.00	84
INDOOR	5.36	0.03	0.00	0.38	426

Table 9.35
Measures of TVOC at Floor 16, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	672	578	469	47	86
LOC-2	756	608	483	57	84
LOC-3	877	625	497	71	86
LOC-4	754	625	491	68	85
LOC-5	761	593	490	60	85
SUPPLY	518	470	430	19	85
EXHAUST	865	629	515	58	84
OUTDOOR	471	431	389	18	84
INDOOR	877	606	469	64	426

Table 9.36
Carbon Dioxide Measures at Floor 16, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.69	0.22	0.00	0.20	86
LOC-2	0.79	0.21	0.00	0.19	84
LOC-3	1.04	0.22	0.00	0.21	86
LOC-4	1.20	0.19	0.00	0.21	85
LOC-5	1.26	0.21	0.00	0.22	85
SUPPLY	0.67	0.18	0.00	0.18	85
EXHAUST	0.89	0.21	0.00	0.19	84
OUTDOOR	0.70	0.16	0.00	0.18	84
INDOOR	1.26	0.21	0.00	0.21	426

Table 9.37
Carbon Monoxide Measures at Floor 16, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	69
LOC-2	1.02	0.02	0.00	0.12	68
LOC-3	0.00	0.00	0.00	0.00	67
LOC-4	0.00	0.00	0.00	0.00	68
LOC-5	0.00	0.00	0.00	0.00	68
SUPPLY	0.00	0.00	0.00	0.00	68
EXHAUST	0.00	0.00	0.00	0.00	66
OUTDOOR	0.00	0.00	0.00	0.00	67
INDOOR	1.02	0.00	0.00	0.06	340

Table 9.38
Measures of TVOC at Floor 22, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	824	615	456	87	69
LOC-2	819	618	454	93	68
LOC-3	808	621	460	94	67
LOC-4	851	644	463	98	68
LOC-5	991	724	466	133	68
SUPPLY	618	502	459	38	68
EXHAUST	865	656	457	103	66
OUTDOOR	534	458	437	16	67
INDOOR	991	645	454	110	340

Table 9.39
Carbon Dioxide Measures at Floor 22, Cardiff Building During Working Hours (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.12	0.36	0.03	0.21	69
LOC-2	1.26	0.34	0.09	0.22	68
LOC-3	1.16	0.36	0.00	0.23	67
LOC-4	1.14	0.38	0.11	0.22	68
LOC-5	1.03	0.34	0.06	0.20	68
SUPPLY	1.15	0.30	0.01	0.21	68
EXHAUST	1.10	0.35	0.00	0.19	66
OUTDOOR	1.32	0.30	0.00	0.24	67
INDOOR	1.26	0.36	0.00	0.21	340

Table 9.40
Carbon Monoxide Measures at Floor 22, Cardiff Building During Working Hours (ppm)

FLOOR	CLUSTER	9:30 am	12:30 pm	3:30 pm
8	1	0.02	0.01	0.02
	2	0.03	0.02	0.02
	3	0.02	0.02	0.01
	4	0	0.02	0.01
	5	0.02	0.02	0.02
11	1	0.02	0.01	0.02
	2	0.02	0.02	0.01
	3	0.02	0.01	0.01
	4	0.03	0.01	0.01
	5	0.03	0.02	0.01
16	1	0.01	0.02	0.03
	2	0.05	0.02	0.02
	3	0.09	0.03	0.02
	4	0.02	0.02	0.01
	5	0.02	0.02	0.02
22	1	0.05	0.04	0.03
	2	0.03	0.03	0.03
	3	0.04	0.02	0.03
	4	0.03	0.02	0.01
	5	0.01	0.02	0.02

Table 9.41
Respirable Particulates concentration in Cardiff Building (mg/m3)

Tables 9.29 through 9.31 show the result of sequential monitoring of gaseous pollutants at Floor 8 during working hours. Table 9.29 shows the result of monitoring of TVOC, Table 9.30 shows the result of monitoring of carbon dioxide, and Table 9.31 shows the result of monitoring of carbon monoxide.

Tables 9.32 through 9.34 show the result of sequential monitoring of gaseous pollutants at Floor 11 during working hours. Table 9.32 shows the result of monitoring of TVOC, Table 9.33 shows the result of monitoring of carbon dioxide, and Table 9.34 shows the result of monitoring of carbon monoxide.

Tables 9.35 through 9.37 show the result of sequential monitoring of gaseous pollutants at Floor 16 during working hours. Table 9.35 shows the result of monitoring of TVOC, Table 9.36 shows the result of monitoring of carbon dioxide, and Table 9.37 shows the result of monitoring of carbon monoxide.

Tables 9.38 through 9.40 show the result of sequential monitoring of gaseous pollutants at Floor 22 during working hours. Table 9.38 shows the result of monitoring of TVOC, Table 9.39 shows the result of monitoring of carbon dioxide, and Table 9.40 shows the result of monitoring of carbon monoxide.

Table 9.41 shows the measures of respirable particulates averaged over 2 minutes in winter.

9.4 THE ANALYSIS

This discussion on the analysis is divided into four parts: 1)individual buildings, 2) all buildings during office hours, 3) seasonal effects on gaseous pollutants, and 4) the effect of gaseous pollutants on building sickness.

9.4.1 Individual Building

The discussion in this section is divided into six parts according to building. Each of the floors in Cardiff building is considered as a separate building because the monitoring in each of them was conducted at different times. Therefore, the six parts are: a) Peterborough Building, b) Kendal Building, c) Cardiff Floor 8, d) Cardiff Floor 11, e) Cardiff Floor 11, and f) Cardiff Floor 22

9.4.1.1 Peterborough Building

The discussion on the analysis of the measurements in this building is divided into four parts: measurements in winter, overnight stationary monitoring, long term stationary monitoring, and mobile monitoring in summer.

i) Measurements in Winter

The concentration of TVOC in the indoor in the mobile monitoring during working hours varied from 2.29 ppm to 4.35 ppm. (See Table 9.1). The average was from 2.61 ppm to 3.38 ppm. The concentration of TVOC in the outdoor varied from 0 ppm to 3.24 ppm with an average of 1.11 ppm.

The concentration of carbon dioxide in the indoor in the mobile monitoring during working hours varied from 426 ppm to 791 ppm. (See Table 9.2). The average was from 446 ppm to 673 ppm. The concentration of carbon dioxide in the outdoor varied from 423 ppm to 522 ppm with an average of 449 ppm.

The concentration of carbon monoxide in the indoor in the mobile monitoring during working hours varied from 1.49 ppm to 2.56 ppm. (See Table 9.3). The average was from 1.71 ppm to 2.24 ppm. The concentration of carbon monoxide in the outdoor varied from 1.16 ppm to 2.55 ppm with an average of 1.64 ppm.

During the mobile monitoring days, the concentration of particulates in the indoor averaged over 2 minutes varied from 0.01 to 0.05 milligram per cubic metre (See Table 9.31). The concentration of particulates in outdoor averaged over 2 minutes varied from 0 to 0.07 milligram per cubic metre.

ii) `Overnight' (Short Term) Stationary Monitoring

At the monitoring location L1Z31, the concentration of TVOC during working hours varied from 3.06 ppm to 4.35 ppm with an average of 3.66 ppm (See Table 9.5). During non-working hours it varied from 2.47 ppm to 3.82 ppm with an average of 3.12 ppm. The concentration of carbon dioxide during working hours varied from 453 ppm to 516 ppm with an average of 483 ppm (See Table 9.6). During non-working hours it varied from 414 ppm to 598 ppm with an average of 459 ppm. The concentration of carbon monoxide during working hours varied from 2.02 ppm to 2.56 ppm with an average of 2.24 ppm (See Table 9.7). During non-working hours it varied from 1.62 ppm to 2.50 ppm with an average of 1.99 ppm.

At the monitoring location L2Z31, the concentration of TVOC during working hours varied from 3.11 ppm to 3.63 ppm with an average of 3.44 ppm (See Table 9.5). During non-working hours it varied from 2.29 ppm to 4.47 ppm with an average of 3.86 ppm. The concentration of carbon dioxide during working hours varied from 426 ppm to 487 ppm with an average of 446 ppm (See Table 9.6). During non-working hours it varied from 414 ppm to 688 ppm with an average of 455 ppm. The concentration of carbon monoxide during working hours varied from 1.95 ppm to 2.41 ppm with an average of 2.08 ppm (See Table 9.7). During non-working hours it varied from 1.61 ppm to 2.85 ppm with an average of 2.28 ppm.

At the monitoring location L2Z11, the concentration of TVOC during non working hours varied from 2.97 ppm to 4.33 ppm with an average of 3.63 ppm (See Table 9.5). The concentration of carbon dioxide during that time varied from 405 ppm to 632 ppm with an average of 445 ppm (See Table 9.6). The concentration of carbon monoxide during non working hours varied from 1.86 ppm to 2.74 ppm with an average of 2.30 ppm (See Table 9.7).

iii) Long Term Stationary at L2Z32

The concentration of TVOC during working hours varied from 2.47 ppm to 4.00 ppm with an average of 3.23 ppm (See Table 9.8). During non-working hours it varied from 2.46 ppm to 4.31 ppm with an average of 3.28 ppm. During non-working days it varied from 2.99 ppm to 3.95 ppm with an average of 3.48 ppm.

The concentration of carbon dioxide during working hours varied from 466 ppm to 760 ppm with an average of 573 ppm (See Table 9.9). During non-working hours it varied from 427 ppm to 604 ppm with an average of 469 ppm. During non- working days it varied from 442 ppm to 561 ppm with an average of 463 ppm.

The concentration of carbon monoxide during working hours varied from 1.51 ppm to 2.32 ppm with an average of 1.90 ppm (See Table 9.10). During non-working hours it varied from 1.38 ppm to 2.32 ppm with an average of 1.79 ppm. During non-working days it varied from 1.49 ppm to 2.42 ppm with an average of 1.84 ppm.

iv) Mobile Monitoring in Summer

As can be seen from Table 9.11, the concentration of TVOC during working hours in summer were always below detection level. The concentration of carbon dioxide in the indoor during working hours varied from 396 ppm to 432 ppm (See Table 9.12). The average was from 406 ppm to 465 ppm. The concentration of carbon dioxide in the outdoor varied from 374 ppm to 392 ppm with an average of 379 ppm. The concentration of carbon monoxide in the building in the mobile monitoring during working hours varied from 0 ppm to 0.22 ppm (See Table 9.13). The average was from 0 ppm to 0.04 ppm. The concentration of carbon monoxide in the outdoor varied from 0 ppm to 0.09 ppm with an average of 1.64 ppm.

9.4.1.2 Kendal

The analysis of the measurements in this building is divided into four parts: i) general pattern of gaseous pollutants, ii) winter monitoring, iii) summer monitoring, and iv) respirable particulates.

i) General Pattern of Gaseous Pollutants

It may appear as if there is a correlation between TVOC and building sickness. However, statistical analysis shows this not to be the case (see section 9.4.4). A relatively high concentration of TVOC occurred mainly in LOC-3 which is in a healthy cluster. A relatively low concentration of TVOC occurred mainly in LOC-6 which is in an unhealthy cluster. This suggests a weak link between the concentration of TVOC and building sickness.

It may appear as if there is a correlation between carbon dioxide and building sickness. However, statistical analysis shows this not to be the case (see section 9.4.4). A relatively high concentration of carbon dioxide occurred mainly in LOC-4 and LOC-6 in winter and LOC-1 and LOC-3 in summer. In other locations, the concentrations were about average. LOC-4 and LOC-6 are in unhealthy clusters but LOC-1 and LOC-3 are in healthy clusters.

The weak link between carbon monoxide and building sickness may also be suggested. A relatively high concentration of carbon monoxide occurred in LOC-4, LOC-6, and LOC-1. LOC-6 is in an unhealthy cluster but LOC-1 is in a healthy cluster. A relatively low concentration of carbon monoxide occurred mostly in LOC-2 and LOC-3. LOC-2 is in an unhealthy cluster but LOC-3 is in a healthy cluster.

In subsequent paragraphs, some of the above inspections are elaborated. This paragraph describes TVOC. A relatively low concentration of TVOC occurred mainly in LOC-6. In this location, some of the office activities include production of drawings which involved the use of spray paints. In LOC- 6, the low concentration of TVOC occurred in W-3 and W-8. The low concentration also occurred in LOC-2 in W-1 and LOC-4 in W-8. A relatively high concentration of TVOC occurred mainly in LOC-3. In this location, most of the office activities involved paperwork. In LOC-3, the high concentrations occurred in W-2, W-4, W-6, and W-7. The high concentration also occurred in LOC-2 in W-4 and in LOC-4 in W-3.

This paragraph describes carbon monoxide. A relatively high concentration of carbon monoxide occurred in LOC-4, LOC-6, and LOC-1. As stated earlier, LOC-1 and LOC-6 are next to a busy road. This suggests that the higher concentration of carbon monoxide came from the traffic. In winter from W-1 to W-7, the low concentration occurred in LOC-4 which is on the ground floor close to a carpark. This suggests that the carbon monoxide came from the carpark. In other monitoring weeks, in summer and winter, except in W-1, W-2, and W-4, the low concentration occurred in LOC-6. In other monitoring weeks, in summer and winter, except in W-3, W-5, W-7, W-8, and S-1, the low concentration occurred in LOC-1. A relatively low concentration of carbon monoxide occurred mostly in LOC-2 and LOC-3. Sometimes, the low concentration also occurred in LOC-4, and LOC-5. LOC-4 is on the ground floor close to a carpark for the office workers. LOC-1 and LOC-6 are next to a busy road. LOC-5 is on the same wing as LOC-4 but on the first floor. LOC-2 and LOC-3 are on the same wing but on the second floor. Except for LOC-3, the other locations are in the unhealthy clusters. LOC-3 is in a healthy cluster. Except in W-4 and W-8, in winter, the low concentration occurred mostly in LOC-2 and LOC-3. At the end of winter monitoring weeks, week W-8, and in summer monitoring weeks the low concentration occurred in LOC-5. In summer, the low concentration also occurred in LOC-4.

Generally, a visual inspection of the tables in Appendix IV and figures in Appendix V suggests that the concentration of TVOC and carbon monoxide declined over time. In this case, time refers to the standard monitoring weeks from W-1 in winter to S-2 in summer. There is no consistent pattern for carbon dioxide. The detail of the inspection is described under its own heading: TVOC, carbon dioxide, and carbon monoxide.

TVOC

There was a consistent decline over time in the average concentration of TVOC in the monitoring clusters until the average concentration was below detection level. In this case, time refers to the monitoring weeks. The figures representing the data during non-working days show the fastest decline followed by working hours. The slowest decline was shown by the data during non-working hours of working day. During non-working days, at all monitoring clusters, the decline in the average TVOC reached the detection level at W-3. During working hours the average concentration of TVOC at LOC-1, LOC-2, and LOC-3 declined below detection level from monitoring week W-5 (See Figures D.2, D.5, and D.8). At LOC-4, LOC-5, and LOC-6 the average concentration of TVOC during working hours declined below detection level earlier from monitoring week W-4 (See Figures D.11, D.14, and D.17).

The decline over time in the average concentration of TVOC during non-working hours of working days was generally slower than those during working hours. In LOC-4 the decline in the average of TVOC reached the detection level at week S-1. In LOC-2 and LOC-3 the decline in the average TVOC reached the detection level at W-5. In LOC-1 and LOC-6 the decline in the average TVOC reached the detection level at W-3.

Carbon Dioxide

As can be seen from Figure E.20, in Appendix V, in the supply diffuser, the average concentration of carbon dioxide during working hours of most of the monitoring weeks was within a concentration band of between 500 ppm to 600 ppm. It rose above the band to 863 ppm at W-3 and then declined to 684 ppm at W-4 (See Table E.20, in Appendix IV). The concentration was within the band from W-4 to W-7. During S- 1 and S-2 the average concentration was above the band. The spread of the average concentration was wide during W-3, W- 4, and W-8. During W-1, W-2, and S-1 the spread was narrow.

Generally, the rise, during the first three weeks of the monitoring week, in the average concentration during working hours, at W-3, could be seen in the figures for all monitoring clusters. At LOC-1 the decline was gradual until about 700 ppm in W-7 and W-8. Then it rose to about 800 ppm in S-1 and S-2 (See Figure E.2 and Table E.2). At LOC-2 the decline was more abrupt. After W-5 the average concentration never exceeded 700 ppm (See Figure E.5 and Table E.5). At LOC-3 the decline was abrupt until W-5. Then it rose twice, first at W-6 and then after W-7. At LOC-4 the decline was abrupt until W-5. Then there was a further but slower decline until W-8. Another abrupt decline occurred during S- 1 and S-2. At LOC-5 the decline was gradual until W-7. Then it rose slightly in W-8 before dropping again in S-1 and S- 2. The pattern at LOC-6 was similar to that of LOC-4.

During non-working days, two wide spreads of the average concentration of carbon dioxide occurred at all monitoring clusters (See Figures E.3, E.6, E.9, E.12, E.15, and E.18). The one which occurred during the monitoring week W-7 was wider than that which occurred during W-2. As can be seen from Figure E.12, at LOC-4, besides the two, another one occurred during W-5.

During non-working hours of working day, a relatively wide spread of the average concentration of carbon dioxide occurred during the monitoring week W-3 (See Figures E.1, E.4, E.7, E.10, E.13, and E.16). As can be seen from Figure E.10, during W-3, the average concentration of carbon dioxide at LOC-4 had also risen.

Carbon Monoxide

An inspection of Figures F.2, F.5, F.8, F.11, F.14, and F.17 show that there was a consistent decline in the average concentration of carbon monoxide in all of the monitoring clusters during working hours from monitoring weeks W-1 to W-8, then a slight rise in monitoring week S-1 and then decline again in monitoring week S-2. A relatively wide spread of the average concentration of carbon monoxide was noticed somewhere between monitoring weeks W-3 and W-4 depending on the monitoring clusters.

The same pattern of rise and decline in the average concentration of carbon monoxide during office hours was also seen in the supply and return air diffusers in the ceiling (See Figures F.20 and F.23).

Although with a wider spread of the average, approximately a similar pattern of rise and decline to those during working hours may be seen in the average concentration of carbon monoxide during non-working hours of working day (See Figures F.1, F.4, F.7, F.10, F.13, and F.16).

In contrast, the pattern of concentration of carbon monoxide during the non-working days was different from those during working hours and non-working hours of working days. The average concentration of carbon monoxide during the first two monitoring weeks were higher by about 2 ppm than those during the next eight monitoring weeks (See Figures F.3, F.6, F.9, F.12, F.15, and F.18).

Generally, in the monitoring clusters, the spread of the average concentration of carbon monoxide was seen wider during non working hours of working day than on working hours and non working days (See Figures F.1 through F.18).

ii) Winter Monitoring

Winter monitoring refers to the monitoring in Kendal Building in monitoring weeks W-1 through W-8. A mobile monitoring for particulates was conducted in the monitoring week W-1.

The average concentration of TVOC in the indoor during working hours varied between 0 ppm to 56.83 ppm, with an average of 1.84 ppm and the standard deviation of the average of 3.08 ppm (See Table 9.23). The average concentration in the supply varied between 26.99 ppm to 4.17 ppm, with an average of 1.45 ppm and the standard deviation of the average of 2.78 ppm. The average concentration in the exhaust varied between 0 ppm to 20.51 ppm, with an average of 1.71 ppm and the standard deviation of the average of 2.77 ppm.

The average concentration of carbon dioxide in the indoor during working hours varied between 494 ppm to 2,125 ppm, with an average of 793 ppm and the standard deviation of the average of 186 ppm (See Table 9.24). The average concentration in the supply varied between 465 ppm to 1,057 ppm, with an average of 595 ppm and the standard deviation of the average of 121 ppm. The average concentration in the exhaust varied between 484 ppm to 1,186 ppm, with an average of 703 ppm and the standard deviation of the average of 94 ppm.

The average concentration of carbon monoxide in the indoor during working hours varied between 0.12 ppm to 4.91 ppm, with an average of 1.54 ppm and the standard deviation of the average of 0.82 ppm (See Table 9.25). The average concentration in the supply varied between 0.15 ppm to 4.83 ppm, with an average of 1.41 ppm and the standard deviation of the average of 0.79 ppm. The average concentration in the exhaust varied between 0.18 ppm to 3.93 ppm, with an average of 1.33 ppm and the standard deviation of the average of 0.75 ppm.

iii) Summer Monitoring

Summer monitoring refers to the monitoring in the Kendal Building in monitoring weeks S-1 and S-2. There was no mobile monitoring for particulates in summer.

The average concentration of TVOC in the indoor during working hours was consistently below detection level (See Table 9.26). The average concentration in the supply varied between 0 ppm to 1.26 ppm, with an average of 0.02 ppm and the standard deviation of the average of 0.16 ppm. The average concentration in the exhaust varied between 0 ppm to 8.29 ppm, with an average of 0.20 ppm and the standard deviation of the average of 1.16 ppm.

The average concentration of carbon dioxide in the indoor during working hours varied between 490 ppm to 912 ppm, with an average of 672 ppm and the standard deviation of the average of 88 ppm (See Table 9.17). The average concentration in the supply varied between 542 ppm to 793 ppm, with an average of 637 ppm and the standard deviation of the average of 50 ppm. The average concentration in the exhaust varied between 510 ppm to 915 ppm, with an average of 674 ppm and the standard deviation of the average of 88 ppm.

The average concentration of carbon monoxide in the indoor during working hours varied between 0.21 ppm to 2.79 ppm, with an average of 1.02 ppm and the standard deviation of the average of 0.49 ppm (See Table 9.28). The average concentration in the supply varied between 0.27 ppm to 1.72 ppm, with an average of 0.87 ppm and the standard deviation of the average of 0.37 ppm. The average concentration in the exhaust varied between 0.23 ppm to 1.76 ppm, with an average of 0.87 ppm and the standard deviation of the average of 0.34 ppm.

iv) Respirable Particulates

The concentration of respirable particulates averaged over 2 minutes in the indoor varied from 0.01 to 0.05 milligram per cubic metre (See Tables 9.15 through 9.18). The average over 5 minutes in the indoor varied from 0.01 to 0.04 milligram per cubic metre (See Tables 9.19 through 9.22). The average over 2 minutes in the outdoor varied from 0.02 to 0.04 milligram per cubic metre (See Tables 9.15 through 9.18). The average over 5 minutes in the outdoor also varied from 0.02 to 0.04 milligram per cubic metre (See Tables 9.19 through 9.22).

9.4.1.3 Cardiff Building Floor 8

The average concentration of TVOC in the indoor during working hours varied between 0 ppm to 32.47 ppm, with an average of 0.32 ppm and the standard deviation of the average of 2.26 ppm (See Table 9.29). The average concentration in the outdoor was always below detection level. The average concentration in the air supply varied between 0 ppm to 4.17 ppm, with an average of 0.08 ppm and the standard deviation of the average of 0.49 ppm. The average concentration in the air exhaust varied between 0 ppm to 2.25 ppm, with an average of 0.12 ppm and the standard deviation of the average of 0.44 ppm.

The average concentration of carbon dioxide in the indoor during working hours varied between 518 ppm to 1,214 ppm, with an average of 705 ppm and the standard deviation of the average of 100 ppm (See Table 9.30). The average concentration in the outdoor varied between 439 ppm to 543 ppm, with an average of 468 ppm and the standard deviation of the average of 22 ppm. The average concentration in the air supply varied between 434 ppm to 569 ppm, with an average of 502 ppm and the standard deviation of the average of 26 ppm. The average concentration in the air exhaust varied between 573 ppm to 926 ppm, with an average of 711 ppm and the standard deviation of the average of 66 ppm.

The average concentration of carbon monoxide in the indoor during working hours varied between 0 ppm to 2.92 ppm, with an average of 0.57 ppm and the standard deviation of the average of 0.46 ppm (See Table 9.31). The average concentration in the outdoor varied between 0 ppm to 2.13 ppm, with an average of 0.51 ppm and the standard deviation of the average of 0.45 ppm. The average concentration in the air supply varied between 0 ppm to 2.10 ppm, with an average of 0.41 ppm and the standard deviation of the average of 0.35 ppm. The average concentration in the air exhaust varied between 0 ppm to 1.75 ppm, with an average of 0.48 ppm and the standard deviation of the average of 0.36 ppm.

The concentration of particulates averaged over 2 minutes varied from 0 to 0.03 milligram per cubic metre (See Table 9.41). The measurement was conducted in the indoor only.

9.4.1.4 Cardiff Building Floor 11

The average concentration of TVOC in the indoor during working hours varied between 0 ppm to 953.42 ppm, with an average of 10.91 ppm and the standard deviation of the average of 60 ppm (See Table 9.32). The average concentration in the outdoor and air supply were always below detection level. The average concentration in the air exhaust varied between 0 ppm to 183.45 ppm, with an average of 5.69 ppm and the standard deviation of the average of 20.63 ppm.

The average concentration of carbon dioxide in the indoor during working hours varied between 439 ppm to 1,203 ppm, with an average of 620 ppm and the standard deviation of the average of 78 ppm (See Table 9.33). The average concentration in the outdoor varied between 418 ppm to 491 ppm, with an average of 447 ppm and the standard deviation of the average of 14 ppm. The average concentration in the air supply varied between 441 ppm to 689 ppm, with an average of 489 ppm and the standard deviation of the average of 33 ppm. The average concentration in the air exhaust varied between 507 ppm to 752 ppm, with an average of 608 ppm and the standard deviation of the average of 47 ppm.

The average concentration of carbon monoxide in the indoor during working hours varied between 0 ppm to 1.23 ppm, with an average of 0.24 ppm and the standard deviation of the average of 0.20 ppm (See Table 9.34). The average concentration in the outdoor varied between 0 ppm to 0.85 ppm, with an average of 0.21 ppm and the standard deviation of the average of 0.18 ppm. The average concentration in the air supply varied between 0 ppm to 0.70 ppm, with an average of 0.21 ppm and the standard deviation of the average of 0.16 ppm. The average concentration in the air exhaust varied between 0 ppm to 0.96 ppm, with an average of 0.23 ppm and the standard deviation of the average of 0.18 ppm.

The concentration of particulates averaged over 2 minutes varied from 0.01 to 0.03 milligram per cubic metre (See Table 9.41). The measurement was conducted in the indoor only.

9.4.1.5 Cardiff Building Floor 16

The average concentration of TVOC in the indoor during working hours varied between 0 ppm to 5.36 ppm, with an average of 0.03 ppm and the standard deviation of the average of 0.38 ppm (See Table 9.35). The average concentration in the outdoor and air supply were always below detection level. The average concentration in the air exhaust varied between 0 ppm to 5.76 ppm, with an average of 0.11 ppm and the standard deviation of the average of 0.70 ppm.

The average concentration of carbon dioxide in the indoor during working hours varied between 469 ppm to 877 ppm, with an average of 606 ppm and the standard deviation of the average of 64 ppm (See Table 9.36). The average concentration in the outdoor varied between 389 ppm to 471 ppm, with an average of 431 ppm and the standard deviation of the average of 18 ppm. The average concentration in the air supply varied between 430 ppm to 518 ppm, with an average of 470 ppm and the standard deviation of the average of 19 ppm. The average concentration in the air exhaust varied between 515 ppm to 865 ppm, with an average of 629 ppm and the standard deviation of the average of 58 ppm.

The average concentration of carbon monoxide in the indoor during working hours varied between 0 ppm to 1.26 ppm, with an average of 0.21 ppm and the standard deviation of the average of 0.21 ppm (See Table 9.37). The average concentration in the outdoor varied between 0 ppm to 0.70 ppm, with an average of 0.16 ppm and the standard deviation of the average of 0.18 ppm. The average concentration in the air supply varied between 0 ppm to 0.67 ppm, with an average of 0.18 ppm and the standard deviation of the average of 0.18 ppm. The average concentration in the air exhaust varied between 0 ppm to 0.89 ppm, with an average of 0.21 ppm and the standard deviation of the average of 0.19 ppm.

The concentration of particulates averaged over 2 minutes varied from 0.01 to 0.09 milligram per cubic metre (See Table 9.41). The measurement was conducted in the indoor only.

9.4.1.6 Cardiff Building Floor 22

The average concentration of TVOC in the indoor during working hours varied between 0 ppm to 1.02 ppm, with an average of 0 ppm and the standard deviation of the average of 0.06 ppm (See Table 9.38). The average concentration in the outdoor, air supply, and air exhaust were always below detection level.

The average concentration of carbon dioxide in the indoor during working hours varied between 454 ppm to 991 ppm, with an average of 645 ppm and the standard deviation of the average of 110 ppm (See Table 9.39). The average concentration in the outdoor varied between 437 ppm to 534 ppm, with an average of 458 ppm and the standard deviation of the average of 16 ppm. The average concentration in the air supply varied between 459 ppm to 618 ppm, with an average of 502 ppm and the standard deviation of the average of 38 ppm. The average concentration in the air exhaust varied between 457 ppm to 865 ppm, with an average of 656 ppm and the standard deviation of the average of 103 ppm.

The average concentration of carbon monoxide in the indoor during working hours varied between 0 ppm to 1.26 ppm, with an average of 0.36 ppm and the standard deviation of the average of 0.21 ppm (See Table 9.40). The average concentration in the outdoor varied between 0 ppm to 1.32 ppm, with an average of 0.30 ppm and the standard deviation of the average of 0.24 ppm. The average concentration in the air suppiy varied between 0.01 ppm to 1.15 ppm, with an average of 0.30 ppm and the standard deviation of the average of 0.21 ppm. The average concentration in the air exhaust varied between 0 ppm to 1.10 ppm, with an average of 0.35 ppm and the standard deviation of the average of 0.19 ppm.

The concentration of particulates averaged over 2 minutes varied from 0.01 to 0.05 milligram per cubic metre (See Table 9.41). The measurement was conducted in the indoor only.

9.4.2 All Four Buildings During Office Hours

The discussion in this section is divided into four parts: TVOC, carbon dioxide, carbon monoxide, and respirable particulates.

9.4.2.1 TVOC

Table 9.42 compares the measures of TVOC in all buildings during working hours. In this table, MAX, AVG, MIN, STD, and N refer to the maximum, average, minimum, standard deviation, and the number of data respectively. In the first column, KEN-SUM, KEN-WTR, PET-SUM, PET-WIN, F08, F11, F16, F22, and TROW refer to the monitorings in Kendal Building in summer, Kendal Building in winter, Peterborough Building in summer, Peterborough Building in winter, Cardiff Building Floor 8, Cardiff Building Floor 11, Cardiff Building Floor 16, Cardiff Building Floor 22, and Trowbridge Building, respectively.

	MAX	AVG	MIN	STD	N
KEN-SUM	0.00	0.00	0.00	0.00	360
KEN-WTR	56.83	1.84	0.00	3.08	1955
PET-SUM	0.00	0.00	0.00	0.00	142
PET-WIN	3.87	2.89	2.89	0.31	306
F08	32.47	0.32	0.00	2.26	435
F11	953.42	10.91	0.00	60.00	689
F16	5.36	0.03	0.00	0.38	426
F22	1.02	0.00	0.00	0.06	340
TROW	12.59	6.16	2.13	3.53	96

Table 9.42
TVOC in All Buildings During Working Hours (ppm)

Tables 9.43 through 9.46 show the result of t test of significance on the average concentration of TVOC in all buildings during working hours against the four suggested limits described in Chapter 3. There is no standard for TVOC. As described in Chapter 3, four limits of the concentrations were suggested by different sources: 0.45 ppm (0.3 milligram per cubic metre)(Seifert, 1990), 0.8 ppm (0.5 milligram per cubic metre)(Dingle and Murray, 1993), 1.5 ppm (1 milligram per cubic metre)(Tucker, 1998), and 7.6 ppm (5 milligram per cubic metre)(Molhave et al, 1986). The concentration in the bracket is the original value quoted. In this conversion, 1 milligram per cubic metre is assumed as equivalent to 1.52 ppm. The suggested limits for table 9.43, 9.44. 9.45, and 9.46 are 0.45 ppm, 0.8 ppm, 1.5 ppm, and 7.6 ppm, respectively.

	AVG	STD	N	ERR	D.F	t
KEN-SUM	0	0	360	0.72	359	inf
KEN-WTR	1.84	3.08	1955	0.76	1954	9.06
PET-SUM	0	0	142	0.50	141	inf
PET-WIN	2.89	0.31	306	0.29	305	121.38
F08	0.32	2.26	435	0.73	434	nr
F11	10.91	60	689	0.95	688	4.16
F16	0.03	0.38	426	0.72	425	nr
F22	0	0.06	340	0.72	339	nr
TROW	6.16	3.53	96	0.62	95	14.14

Table 9.43
Significance Test on The Conformity of the Average Concentration of TVOC to the First Suggested Limit (0.45 ppm).

	AVG	STD	N	ERR	D.F	t
KEN-SUM	0	0	360	0.72	359	inf
KEN-WTR	1.84	3.08	1955	0.76	1954	4.04
PET-SUM	0	0	142	0.50	141	inf
PET-WIN	2.89	0.31	306	0.29	305	101.63
F08	0.32	2.26	435	0.73	434	nr
F11	10.91	60	689	0.95	688	4.01
F16	0.03	0.38	426	0.72	425	2.68
F22	0	0.06	340	0.72	339	24.59
TROW	6.16	3.53	96	0.62	95	13.17

Table 9.44
Significance Test on The Conformity of the Average Concentration of TVOC to the Second Suggested Limit (0.8 ppm).

	AVG	STD	N	ERR	D.F	t
KEN-SUM	0	0	360	0.72	359	inf
KEN-WTR	1.84	3.08	1955	0.76	1954	nr
PET-SUM	0	0	142	0.50	141	inf
PET-WIN	2.89	0.31	306	0.29	305	62.13
F08	0.32	2.26	435	0.73	434	4.18
F11	10.91	60	689	0.95	688	3.70
F16	0.03	0.38	426	0.72	425	40.70
F22	0	0.06	340	0.72	339	239.71
TROW	6.16	3.53	96	0.62	95	11.22

Table 9.45
Significance Test on The Conformity of the Average Concentration of TVOC to the Third Suggested Limit (1.5 ppm).

	AVG	STD	N	ERR	D.F	t
KEN-SUM	0	0	360	0.72	359	inf
KEN-WTR	1.84	3.08	1955	0.76	1954	71.80
PET-SUM	0	0	142	0.50	141	inf
PET-WIN	2.89	0.31	306	0.29	305	249.47
F08	0.32	2.26	435	0.73	434	60.48
F11	10.91	60	689	0.95	688	1.03
F16	0.03	0.38	426	0.72	425	372.02
F22	0	0.06	340	0.72	339	2114.35
TROW	6.16	3.53	96	0.62	95	2.29

Table 9.46
Significance Test on The Conformity of the Average Concentration of TVOC to the Fourth Suggested Limit (7.6 ppm).

In these tables, AVG, STD, N, ERR, D.F., and t refer to the average, standard deviation, the number of data, monitoring error, degree of freedom, and t value respectively. In the first column, KEN-SUM, KEN-WTR, PET-SUM, PET-WIN, F08, F11, F16, F22, and TROW refer to monitorings in Kendal Building in summer, Kendal Building in winter, Peterborough Building in summer, Peterborough Building in winter, Cardiff Building Floor 8, Cardiff Building Floor 11, Cardiff Building Floor 16, Cardiff Building Floor 22, and Trowbridge Building, respectively.

In these tables, ERR was calculated as follows:

1) except for the monitorings TROW and PET-WIN, ERR were calculated using equation 9 in Chapter 6. In this case, monitorings error type a is equal to 0.0050, error type b is equal to 0.0160, and error c is equal to 0.5 (See Table 6.48 and Equation 9). In those monitorings, except in PET-SUM, error type d is equal to e

(i.e. 0.22) because a monitoring interval of 48 minutes was used. In PET-SUM, there is no type d error because a monitoring interval of 6 minutes was used.

2) For TROW and PET-WIN, ERR is equal to ten percent of the average concentration because the gas monitor was statically calibrated at that time (Bruer and Kjaer, 1992).

In these tables, column 7 shows the calculated t values, `inf' or `nr'. An `inf' mean the t values is infinity, thus the difference is significant. An `nr` means the t test is not relevant because the difference is smaller than ERR.

From these tables the following observations could be made:

1) The average concentration of TVOC in KEN-SUM was significantly lower than all of the four suggested limits.

2) The average concentration of TVOC in KEN-WIN was significantly higher than the first two suggested limits and lower than the fourth suggested limit. It is not significantly higher than the third suggested limit.

3) The average concentration of TVOC in PET-SUM was significantly lower than all of the four suggested limits.

4) The average concentration of TVOC in PET-WIN was significantly higher than the first three suggested limits and lower than the fourth suggested limit.

5) The average concentration of TVOC in F08 was significantly lower than the third and fourth suggested limits. It was not significantly lower than the first two suggested limits.

6) The average concentration of TVOC in F11 was significantly higher than all of the four suggested limits.

7) The average concentration of TVOC in F16 was significantly lower than the last three suggested limits. It was not significantly higher than the first suggested limit.

8) The average concentration of TVOC in F22 was significantly higher than the first three limits but lower than the fourth suggested limit.

9.4.2.2 Carbon Dioxide

Table 9.47 compares the measures of carbon dioxide in all buildings during working hours. The format of this table is the same as that in Table 9.42 described above.

	MAX	AVG	MIN	STD	N
KEN-SUM	912	672	490	101	360
KEN-WTR	2125	793	494	186	1955
PET-SUM	677	442	396	30	142
PET-WIN	791	635	635	41	304
F08	1214	705	518	100	435
F11	1203	620	439	78	689
F16	877	606	469	64	426
F22	991	645	454	110	340
TROW	1015	723	489	148	96

Tabie 9.47
Carbon Dioxide Measures in All Buildings During Working Hours (ppm)

Tables 9.48 and 9.49 show that the average concentration of carbon dioxide in all of the monitorings was significantly lower than the ASHRAE limit of 1,000 ppm and higher than Potters's suggested limit of 500 ppm. These were well below the limit set by the Health and Safety Executive which is 5,000 ppm (See Chapter 3).

	AVG	STD	N	ERR	D.F	t
KEN-SUM	672	101	360	11.86	359	59.39
KEN-WTR	793	186	1955	13.90	1954	45.90
PET-SUM	442	30	142	7.97	141	218.48
PET-WIN	635	41	304	63.50	303	128.22
F08	705	100	435	12.41	434	58.94
F11	620	78	689	10.98	688	124.18
F16	606	64	426	10.74	425	123.60
F22	645	110	340	11.40	339	57.60
TROW	723	148	96	72.30	95	13.55

Table 9.48
Significance Test on The Conformity of the Average Concentration of Carbon Dioxide to the ASHRAE Standard (1,000 ppm).

	AVG	STD	N	ERR	D.F	t
KEN-SUM	672	101	360	11.86	359	30.08
KEN-WTR	793	186	1955	13.90	1954	66.35
PET-SUM	442	30	142	7.97	141	19.87
PET-WIN	635	41	304	63.50	303	30.41
F08	705	100	435	12.41	434	40.17
F11	620	78	689	10.98	688	36.69
F16	606	64	426	10.74	425	30.72
F22	645	110	340	11.40	339	22.40
TROW	723	148	96	72.30	95	9.98

Table 9.49
Significance Test on The Conformity of the Average Concentration of Carbon Dioxide to the Potter's Suggested Concentration (500 ppm).

The format of these tables and the way ERR and t are calculated is the same as that of Table 9.43 described above. In these tables, monitoring error type a is equal to 0.0009, error type b is equal to 0.0160, and error c is equal to 0.5 (See Table 6.48 and Equation 9). In these monitorings, type d error is equal to zero.

9.4.2.3 Carbon Monoxide

Table 9.50 compares the measures of carbon monoxide in all buildings during working hours. Table 9.51 shows that the average concentration of carbon monoxide in all buildings was significantly lower than the World Health Organisation's Concentration of Concern of 4.4 ppm. Other standards are higher than this limit. The limit set by the Health and Safety Executive is 50 ppm and the limit set by the Canadian Guideline is 11 ppm. Therefore, the average concentrations were well below those limits.

	MAX	AVG	MIN	STD	N
KEN-SUM	2.79	1.02	0.21	0.49	360
KEN-WTR	4.91	1.54	0.12	0.82	1955
PET-SUM	0.22	0.01	0.00	0.03	142
PET-WIN	0.46	0.37	0.37	0.03	304
F08	2.92	0.57	0.00	0.46	435
F11	1.23	0.24	0.00	0.20	689
F16	1.26	0.21	0.00	0.21	426
F22	1.26	0.36	0.00	0.21	340
TROW	2.93	2.29	1.61	0.32	96

Table 9.50
Measures of Carbon Monoxide in All Buiidings During Working Hours (ppm)

	AVG	STD	N	ERR	D.F	t
KEN-SUM	1.02	0.49	360	0.57	359	108.91
KEN-WTR	1.54	0.82	1955	0.60	1954	121.77
PET-SUM	0.01	0.03	142	0.50	141	1544.89
PET-WIN	0.37	0.03	304	0.04	303	1093.21
F08	0.57	0.46	435	0.54	434	149.28
F11	0.24	0.2	689	0.52	688	478.27
F16	0.21	0.21	426	0.51	425	361.31
F22	0.36	0.21	340	0.52	425	308.74
TROW	2.29	0.32	96	0.23	425	57.59

Table 9.51
Significance Test on The Conformity of the Average Concentration of Carbon Monoxide to the World Health Organisation Concentration of Concern (4.4 ppm).

The format of Table 9.51 and the way ERR and t are calculated is the same as that of Table 9.43 described above. In these tables, monitorings error type a is equal to 0.05, error type b is equal to 0.0160, and error c is equal to 0.5 (See Table 6.48 and Equation 9). In these monitorings, type d error is equal to zero.

9.4.2.4 Respirable Particulates

Table 9.52 shows the concentration of respirable particulates averaged over 2 minutes in the four buildings varied from 0 to 0.09 milligram per cubic metre. The particulates were sampled during working hours. The concentrations encountered in the buildings were below the limit set by the Health and Safety Executive, the Japanese Standard, and the Canadian Guidelines (See Chapter 3). The Health and Safety Executive Standard is 10 milligram per cubic metre for total inhalable particulates and 5 milligram per cubic metre for respirable particulates. The gas monitor used in this research detected both types of particulates. The Japanese Standard for particulates is 0.15 milligram per cubic metre and the Canadian Guidelines is 0.10 milligram per cubic metre.

BUILDING	MAX	AVG	MIN	STD	N
TROW	0.05	0.03	0	0.01	82
PET	0.05	0.02	0.01	0.01	134
KEN	0.05	0.03	0.01	0.01	57
CARD-8	0.03	0.02	0	0.01	15
CARD-11	0.03	0.02	0.01	0.01	15
CARD-16	0.09	0.03	0.01	0.02	15

Table 9.52
Respirable Particulates Concentration in all Building (mg/m3)

9.4.3 Seasonal Effect on Gaseous Pollutants

As stated earlier, the seasonal effect on gaseous pollutants was examined in the Peterborough and Kendal Buildings. The following discussion is divided into two according to buildings.

9.4.3.1 Peterborough Building

Tables 9.53, 9.54, and 9.55 compare the gaseous pollutants in summer and winter in the Peterborough Building. In these tables, AVG, STD, N, ERR, DIFF, DF, and t refer to the average, standard deviation, the number of data, monitoring error, difference between summer and winter, and t value respectively. In summer, location L1Z11 was called L1Z10. The location L3Z11 was called L3Z10.

		AVG	STD	N	ERR	DIFF	DF	t
L1Z10	SUMMER	0.00	0.00	19	0.84	-3.38	55	107.45
L1Z11	WINTER	3.38	0.15	38				
L3Z10	SUMMER	0.00	0.00	20	0.77	-2.72	57	70.51
L3Z11	WINTER	2.72	0.17	39				

Table 9.53
Significance Test of Seasonal Effect on TVOC in Peterborough Building

		AVG	STD	N	ERR	DIFF	DF	t
L1Z10	SUMMER	444	12	19	73.30	-209.21	55	22.85
L1Z11	WINTER	653	33	38				
L3Z10	SUMMER	465	51	20	74.05	-192.01	57	9.05
L3Z11	WINTER	657	40	39				

Table 9.54
Significance Test of Seasonal Effect on Carbon Dioxide in Peterborough Building

		AVG	STD	N	ERR	DIFF	DF	t
L1Z10	SUMMER	0.01	0.03	19	0.54	-0.37	55	nr
L1Z11	WINTER	0.38	0.03	38				
L3Z10	SUMMER	0.00	0.00	20	0.54	-0.37	57	nr
L3Z11	WINTER	0.37	0.03	39				

Table 9.55
Significance Test of Seasonal Effect on Carbon Monoxide in Peterborough Building

Table 9.53 shows that the average concentration of TVOC in location L1Z11 and L3Z11 in winter were higher than those in summer. The differences are statistically significant. In this table, ERR in summer was calculated using equation 9. In this case, monitorings error type a is equal to 0.0050, error type b is equal to 0.0160, and error type c is equal to 0.5 (See Table 6.48 and Equation 9). There is no type d error because a monitoring interval of 6 minutes were used. ERR in winter is ten percent of the average concentration.

Table 9.54 shows that the average concentration of carbon dioxide in location L1Z11 and L3Z11 in winter were also higher than those in summer. The differences are statistically significant. As in Table 9.53, ERR in winter is ten percent of the average concentration and ERR in summer was calculated using equation 9. In this case, monitorings error type a is equal to 0.0009, error type b is equal to 0.0160, and error type c is equal to 0.5 (See Table 6.48 and Equation 9). There is no type d error because a monitoring interval of 6 minutes ~~were~~ was used.

Table 9.55 shows that the average concentration of carbon monoxide in location L1Z11 and L3Z11 in winter were also higher than those in summer. In the table, `nr' means the t test is not relevant because the errors are greater than the differences. As in Table 9.53, ERR in winter is ten percent of the average concentration and ERR in summer was calculated using equation 9. In this case, monitorings error type a is equal to 0.050, error type b is equal to 0.0160, and error type c is equal to 0.5 (See Table 6.48 and Equation 9). There is no type d error because a monitoring interval of 6 minutes ~~were~~ was used.

9.4.3.2 Kendal Building

Tables 9.56, 9.57, and 9.58 compare the gaseous pollutants in summer and winter in the Kendal Building. The format of these tables are the same as that of table 9.53. INDOOR is a collection of data taken from all monitoring clusters in the indoor, namely LOC-1, LOC-2, LOC-3, LOC-4, LOC-5, and LOC-6. In these tables, ERR was calculated using equation 9 in Chapter 6.

		AVG	STD	N	ERR	DIFF	DF	t
LOC-1	SUMMER	0.00	0.00	60	0.68	-1.76	384	7.89
LOC-1	WINTER	1.76	2.47	326				
LOC-2	SUMMER	0.00	0.00	60	0.68	-1.80	384	6.76
LOC-2	WINTER	1.80	2.99	326				
LOC-3	SUMMER	0.00	0.00	60	0.73	-2.31	384	6.07
LOC-3	WINTER	2.31	4.69	326				
LOC-4	SUMMER	0.00	0.00	60	0.69	-1.88	384	7.93
LOC-4	WINTER	1.88	2.70	326				
LOC-5	SUMMER	0.00	0.00	60	0.68	-1.78	384	7.64
LOC-5	WINTER	1.78	2.60	326				
LOC-6	SUMMER	0.00	0.00	60	0.65	-1.50	383	6.64
LOC-6	WINTER	1.50	2.32	325				
INDOOR	SUMMER	0.00	0.00	360	0.68	-1.84	2313	16.59
INDOOR	WINTER	1.84	3.08	1955				
SUPPLY	SUMMER	0.02	0.16	60	0.65	-1.43	379	5.02
SUPPLY	WINTER	1.45	2.78	321				
EXHAUST	SUMMER	0.20	1.16	60	0.68	-1.52	377	3.87
EXHAUST	WINTER	1.71	2.77	319				

Table 9.56
Significance Test of Seasonal Effect on TVOC in Kendai Building

		AVG	STD	N	ERR	DIFF	DF	t
LOC-1	SUMMER	775	62	60	88.33	27.78	384	nr
LOC-1	WINTER	747	115	326				
LOC-2	SUMMER	621	40	60	81.76	-86.45	384	0.56
LOC-2	WINTER	708	117	326				
LOC-3	SUMMER	792	73	60	89.03	40.95	384	nr
LOC-3	WINTER	751	142	326				
LOC-4	SUMMER	543	25	60	104.77	-408.18	384	19.64
LOC-4	WINTER	951	273	326				
LOC-5	SUMMER	649	39	60	81.61	-52.10	384	nr
LOC-5	WINTER	701	90	326				
LOC-6	SUMMER	651	57	60	101.31	-247.40	383	13.24
LOC-6	WINTER	898	148	325				
INDOOR	SUMMER	672	101	360	91.13	-120.85	2313	4.38
INDOOR	WINTER	793	186	1955				
SUPPLY	SUMMER	637	50	60	70.79	41.29	379	nr
SUPPLY	WINTER	595	121	321				
EXHAUST	SUMMER	674	88	60	82.20	-29.19	377	nr
EXHAUST	WINTER	703	94	319				

Table 9.57
Significance Test of Seasonal Effect on Carbon Dioxide in Kendal Building

		AVG	STD	N	ERR	DIFF	DF	t
LOC-1	SUMMER	1.12	0.49	60	0.74	-0.52	384	nr
LOC-1	WINTER	1.64	0.90	326				
LOC-2	SUMMER	0.92	0.39	60	0.70	-0.49	384	nr
LOC-2	WINTER	1.41	0.77	326				
LOC-3	SUMMER	1.08	0.56	60	0.71	-0.33	384	nr
LOC-3	WINTER	1.41	0.74	326				
LOC-4	SUMMER	0.95	0.52	60	0.73	-0.77	384	0.41
LOC-4	WINTER	1.71	0.87	326				
LOC-5	SUMMER	0.87	0.37	60	0.70	-0.60	384	nr
LOC-5	WINTER	1.47	0.79	326				
LOC-6	SUMMER	1.18	0.55	60	0.74	-0.44	383	nr
LOC-6	WINTER	1.62	0.83	325				
INDOOR	SUMMER	1.02	0.49	360	0.72	-0.52	2313	nr
INDOOR	WINTER	1.54	0.82	1955				
SUPPLY	SUMMER	0.87	0.37	60	0.70	-0.53	379	nr
SUPPLY	WINTER	1.41	0.79	321				
EXHAUST	SUMMER	0.87	0.34	60	0.69	-0.45	377	nr
EXHAUST	WINTER	1.33	0.75	319				

Table 9.58
Significance Test of Seasonal Effect on Carbon Monoxide in Kendal Building

Table 9.56 shows that the average concentration of TVOC in each of monitoring clusters in the indoor, INDOOR, SUPPLY, and EXHAUST in winter were higher than those in summer. The differences are statistically significant. In this table, ERR in winter is ten percent of the average and ERR in summer was calculated using equation 9. In this case, monitorings error type a is equal to 0.0050, error type b is equal to 0.0160, error type c is equal to 0.5, and error type d is equal to 0.22 (See Table 6.48 and Equation 9).

Table 9.57 shows that the average concentration of carbon dioxide in winter were higher than those in summer in INDOOR, EXHAUST, LOC-2, LOC-4, LOC-5, and LOC-6. In INDOOR, LOC-4, and LOC-6, the differences are statistically significant. In LOC-5, the monitoring error is greater than the difference. In LOC-2, the difference is not statistically significant. In SUPPLY, LOC-1, and LOC-3, the average concentration of carbon dioxide in winter were lower than those in summer, however, the differences are not statistically significant. As in Table 9.56, ERR in winter is ten percent of the average and ERR in summer was calculated using equation 9. In this case, monitorings error type a is equal to 0.0009, error type b is equal to 0.0160, error type c is equal to 0.5, and error type d is equal to zero (See Table 6.48 and Equation 9).

Table 9.58 shows that the average concentration of carbon monoxide in each of monitoring clusters in the indoor, INDOOR, SUPPLY, and EXHAUST in winter were higher than those in summer. However, except in LOC-4, the monitoring errors are greater than the differences. In LOC-4, the difference is not statistically significant. As in Table 9.56, ERR in winter is ten percent of the average and ERR in summer was calculated using equation 9. In this case, monitorings error type a is equal to 0.0500, error type b is equal to 0.0160, error type c is equal to 0.5, and error type d is equal to zero (See Table 6.48 and Equation 9).

9.4.4 Effect of Gaseous Pollutants on Building Sickness

For the purpose of this comparison, the measurements in the Trowbridge and Peterborough Buildings were not used because the difference in the concentration of the gaseous pollutants due to time variation may be significant. In these buildings, the time interval between the monitoring at two different locations was anything up to 5 working days. However, in the Kendal and Cardiff Buildings, the time variation had been minimised by using sequential monitoring. In these buildings, the time interval was between 6 to 48 minutes.

The following discussion is divided into two according to buildings:

9.4.4.1 Kendal Building

Unfortunately , there was insufficient time to carry out a thorough statistical analysis of the building sickness versus concentration of gaseous pollutants, however, Tables 9.59, 9.60, and 9.61 give a crude comparison. The format of these tables are the same as that of Table 9.53. HEAL is a collection of data taken from healthy monitoring clusters and UNH is a collection of data taken from unhealthy monitoring clusters (See Chapter 8).

		AVG	STD	N	ERR	DIFF	DF	t
KEN	HEAL	1.58	3.45	772	0.28	0.11	2313	nr
KEN	UNH	1.47	2.53	1543				

Table 9.59
Significance Test of The Effect of TVOC on Building Sickness Kendal Building

		AVG	STD	N	ERR	DIFF	DF	t
KEN	HEAL	759	124	723	26.1	-25	2264	nr
KEN	UNH	784	203	1543				

Table 9.60
Significance Test of The Effect of Carbon Dioxide on Building Sickness Kendal Building

		AVG	STD	N	ERR	DIFF	DF	t
KEN	HEAL	1.38	0.77	723	0.19	-0.1	2264	nr
KEN	UNH	1.46	0.8	1543				

Table 9.61
Significance Test of The Effect of Carbon Monoxide on Building Sickness Kendal Building

Table 9.59 shows that the average concentration of TVOC in unhealthy cluster was lower than that in the healthy clusters. However, the monitoring error is greater than the difference. Therefore, t test of significance is not relevant. In this table, ERR was calculated using equation 9 in Chapter 6 where monitorings error type a is equal to 0.0050, error type b is equal to 0.0160, error type c cancels out because the calibration was unchanged in between the monitoring of healthy and unhealthy clusters within the same sequence, and error type d is equal to 0.22 (See Table 6.48 and Equation 9).

Table 9.60 shows that the average concentration of carbon dioxide in unhealthy cluster was higher than that in the healthy clusters. However, the monitoring error is greater than the difference. Therefore, t test of significance is not relevant. In this table, ERR was also calculated using equation 9 in Chapter 6 where monitorings error type a is equal to 0.0009, error type b is equal to 0.0160, error type c cancels out because the calibration was unchanged in between the monitoring of healthy and unhealthy clusters within the same sequence, and error type d is equal to zero (See Table 6.48 and Equation 9).

Table 9.61 shows that the average concentration of carbon monoxide in unhealthy cluster was higher than that in the healthy clusters. However, the monitoring error is greater than the difference. Therefore, t test of significance is not relevant. In this table, ERR was calculated using equation 9 in Chapter 6 where monitorings error type a is equal to 0.0500, error type b is equal to 0.0160, error type c cancels out because the calibration was unchanged in between the monitoring of healthy and unhealthy clusters within the same sequence, and error type d is equal to zero (See Table 6.48 and Equation 9).

An inspection of Tables 9.15 through 9.22 show that the concentration of respirable particulates in healthy clusters were not significantly different from those in unhealthy clusters. As stated in Chapter 8, LOC-1 and LOC-3 were healthy clusters and LOC-2, LOC-4, LOC-5, and LOC-6 were unhealthy clusters. The concentration in healthy clusters varied from 0.01 to 0.04 milligram per cubic metre and that in unhealthy clusters varied from 0.01 to 0.05 milligram per cubic metre.

9.4.4.2 Cardiff Building

Tables 9.62, 9.63, and 9.64 compare the gaseous pollutants in healthy and unhealthy clusters in the Cardiff Building. The format of these tables are the same as that of Table 9.53. HEAL is a collection of data taken from healthy monitoring clusters and UNH is a collection of data taken from unhealthy monitoring clusters (See Chapter 8).

		AVG	STD	N	ERR	DIFF	DF	t
CAR-08	HEAL	0.41	2.77	173	0.23	0.16	345	nr
CAR-08	UNH	0.24	1.69	174				
CAR-11	HEAL	3.7	14.5	276	0.86	-23.17	411	2.4
CAR-11	UNH	26.9	108	137				
CAR-16	HEAL	0	0	171	0.22	-0.01	254	nr
CAR-16	UNH	0.01	0.09	85				
CAR-22	HEAL	0	0	136	0.22	-0.01	270	nr
CAR-22	UNH	0.01	0.09	136				

Table 9.62
Significance Test of The Effect of TVOC on Building Sickness Cardiff Building

		AVG	STD	N	ERR	DIFF	DF	t
CAR-08	HEAL	736	118	173	23.7	69.32	345	4.46
CAR-08	UNH	666	65	174				
CAR-11	HEAL	622	59	276	20.97	2.11	411	nr
CAR-11	UNH	619	77	137				
CAR-16	HEAL	585	54	171	20.45	-39.39	254	2.24
CAR-16	UNH	625	68	85				
CAR-22	HEAL	618	90	136	21.12	-13.33	270	nr
CAR-22	UNH	631	96	136				

Table 9.63
Significance Test of The Effect of Carbon Dioxide on Building Sickness Cardiff Building

		AVG	STD	N	ERR	DIFF	DF	t
CAR-08	HEAL	0.68	0.54	173	0.08	0.19	345	2.24
CAR-08	UNH	0.49	0.38	174				
CAR-11	HEAL	0.25	0.2	276	0.03	0.02	411	nr
CAR-11	UNH	0.23	0.2	137				
CAR-16	HEAL	0.22	0.21	171	0.03	0.03	254	nr
CAR-16	UNH	0.19	0.21	85				
CAR-22	HEAL	0.36	0.22	136	0.05	0	270	nr
CAR-22	UNH	0.36	0.22	136				

Table 9.64
Significance Test of The Effect of Carbon Monoxide on Building Sickness Cardiff Building

Table 9.62 shows that, except in Floor 8, the average concentration of TVOC in the unhealthy cluster in the upper floors were higher than that in the healthy clusters. However, except in Floor 11, the monitoring error is greater than the difference. Therefore, t test of significance is not relevant. In Floor 11, the difference of 23.17 ppm is greater than the error of 0.86 ppm. Since the t value is 2.40, in Floor 11, the average concentration of TVOC in the unhealthy clusters were significantly higher than those In the healthy clusters. In Floor 8, the average concentration of TVOC in the unhealthy clusters were lower than those in the healthy clusters. However, the monitoring error is greater than the difference.

In this table, ERR was calculated using equation 9 in Chapter 6. In this case, monitorings error type a is equal to 0.0050, error type b is equal to 0.0160, error type c cancels out because the calibration was unchanged in between the monitoring of healthy and unhealthy clusters within the same sequence, and error type d is equal to 0.22 (See Table 6.48 and Equation 9).

Table 9.63 shows that the average concentration of carbon dioxide in unhealthy cluster was sometimes higher and sometimes lower than those in the healthy clusters. In the upper floors, Floor 16 and 22, the average concentration in unhealthy clusters were higher than those in healthy clusters. In Floor 16, the difference is statistically significant. But in Floor 22, the monitoring error is greater than the difference. Therefore, in this case, t test of significance is not relevant. In the lower floors, Floor 8 and 11, the average concentration in unhealthy clusters were lower than those in healthy clusters. In Floor 8, the difference is statistically significant. But in Floor 11, the monitoring error is greater than the difference. Therefore, in this case, t test of significance is not relevant.

In this table, ERR was also calculated using equation 9 in Chapter 6. In this case, monitorings error type a is equal to 0.0009, error type b is equal to 0.0160, error type c cancels out because the calibration was unchanged in between the monitoring of healthy and unhealthy clusters within the same sequence, and error type d is equal to zero (See Table 6.48 and Equation 9).

Table 9.64 shows that the average concentration of carbon monoxide in the unhealthy cluster were equal to or lower than that in the healthy clusters. In all floors above Floor 8 the monitoring errors are greater than the differences. Therefore, in this case, t test of significance is not relevant. In the lowest floor, Floor 8, the average concentration in unhealthy clusters was lower than that in healthy clusters. In Floor 8, the difference is statistically significant.

In this table, ERR was also calculated using equation 9 in Chapter 6. In this case, monitorings error type a is equal to 0.0500, error type b is equal to 0.0160, error type c cancels out because the calibration was unchanged in between the monitoring of healthy and unhealthy clusters within the same sequence, and error type d is equal to zero (See Table 6.48 and Equation 9).

An inspection of Table 9.41 shows that the concentration of respirable particulates in healthy clusters were not significantly different from those in unhealthy clusters. As stated in Chapter 8, LOC-2 and LOC-4 in Floor 8, LOC-1 and LOC-4 in Floor 11, LOC-1 and LOC-5 in Floor 16, and LOC-1 and LOC-3 in Floor 22 were healthy clusters and LOC-3 and LOC-5 in Floor 8, LOC-3 in Floor 11, LOC-4 in Floor 16, and LOC-2 and LOC-4 in Floor 22 were unhealthy clusters. The concentration in healthy clusters varied from 0 to 0.05 milligram per cubic metre and that in unhealthy clusters varied from 0.01 to 0.03 milligram per cubic metre.

9.5 THE LIMITATION AND PROBLEMS OF THE ORIGINAL DATA

This section describes the limitation of the original data stored in the gas monitor and the data processing procedure which was aimed at overcoming the problems associated with the data limitation so that reliability, validity, and practicality could be achieved.

9.5.1 The Problems

The original data recorded by the gas monitor had four problems which affected reliability, validity, and practicality. The first problem was due to the limitation of monitoring scheduling. This had caused the original data to be inconvenient for direct application. The other problems were due to equipment limitations. The second problem had caused the data to be inconvenient and invalid for direct use in any spreadsheet/statistical software. The third problem had caused the data to become unreliable: it may or may not be valid. The fourth problem had caused the data to be inconvenient.

The first problem, the original data was not collected within a standard monitoring week. A profile of indoor pollutants in a standard monitoring week was more convenient to interpret. A standard monitoring week means a seven day week beginning at midnight on a Sunday and ending at midnight on the following Sunday. The original data, however, was collected at anytime of the week at the time most convenient for the researcher to come and was permitted to work in the building. For example, data KEN2 was collected from 11:21 a.m. Friday 19/3/1993 to 11:52 a.m. Thursday 25/3/1993. Therefore this original data should be split into two standard monitoring weeks.

The second problem, due to the equipment limitation, the original data was not recorded in the standard data format. A standard data format means that the data is timed, dated and recorded continuously and consistently in columns or lines so that the data is suitable for any statistical/spreadsheet software. The calculation of simple statistics, such as average and maximum, requires that the data of each of the gases be located consistently in a particular column. The column should not contain other data or non-data text. Non-data text are the front portion, standard header and error messages. The front portion and the standard header, will be described in the next paragraph. The sorting of the data into those during working hours, non-working hours of working day, and non-working days requires that the data be dated.

The format of the original data is described here. The original data was recorded automatically by the gas monitor in a report format. Basically, the data consists of the front portion and the data pages. The front portion is the record of the system setting, including the sampling interval and the sampling tube length, start and stop time, air pressure, and normalisation temperature. After the front portion, the data pages are presented in several pages. Each of the pages begins with a standard header which is, the title of the data measured. The data containing the data number, the monitoring time of the day, and the concentration of the monitored gases and water vapour is presented after the standard header. System messages, if any, are written on the data pages. An air blockage or a restart are the examples of the system messages. System messages are written across the page in the columns allocated for the data. However the data did not contain the date of monitoring.

The third problem, again due to equipment limitation, was that some of the data was incompletely recorded. An incompletely recorded data may or may not be an error. This will be elaborated when discussing data processing procedure. The incomplete data was almost always found at the end of the data. For example 2.53 E+00 may be recorded as 2, 2., 2.53, 2.53 E, 2.53 E+ or 2.53 E+0. A thorough inspection and editing was therefore necessary before the original data could be converted into data format.

The fourth problem was that the SERC/LINK Project used Macintosh system for its data processing. The software to download the data in the memory of gas monitor was written for IBM PC. Therefore the data had to be converted from one system to the other.

9.5.2 Data Processing Procedure

The data processing procedure consisted of six steps. The first step had overcome the data problem of the data not presented in a suitable format. The second step had overcome the problem of the data being incompletely recorded and was IBM PC formatted. The fourth step had overcome the data problem of the original data not collected within a standard monitoring week. The other steps were aimed at separating the data into the appropriate channel and monitoring periods. The separation had two objectives. The first objective, to compare the data at different monitoring locations. The second objective, to compare the data during working hours with those during non-working days and non-working hours of working day.

In the first step, the original data was thoroughly inspected and edited to remove headers, error message and system warning, and to correct incomplete data. In the above example, the incomplete data 2.53 and 2.53 E+0 are acceptable. The other four versions, 2, 2., and 2.53 E+ should be replaced with blanks.

In the second step, the edited data was dated, calibrated and converted into a data format suitable for spreadsheet application in Macintosh. The conversion was not direct. The data, which was in binary form, was first read by Macintosh's EXCEL 4.0. However the EXCEL 4.0 treated the whole data line as a single data and placed them in a single column. To split the data into separate columns for date, time, and the measures of each gas, the EXCEL 4.0 data was imported into STATVIEW 4.0. But this file exchange required that the EXCEL 4.0 data be converted into its text format before the import. After the import into STATVIEW 4.0, the STATVIEW 4.0 data was imported back to EXCEL 4.0. Again this file exchange required that the STATVIEW 4.0 data be converted into its text format. All of the subsequent data processing would be using this final form of EXCEL 4.0 data. The reason was that the transfer of figures between the word processing software and the spreadsheet was easier than that between word processing software and the statistical software. During the data import some errors always occurred and was thoroughly inspected and corrected.

In the third step, the data file was split into individual channels. Each channel represents a particular monitoring location or cluster.

In the fourth step, the individual data file was split and recombined into its appropriate standard monitoring week. As stated earlier, a standard monitoring week means a seven day week beginning at midnight on a Sunday and ending at midnight on the following Sunday.

In the fifth step, the data which was grouped by the standard monitoring week was split into sub-groups which were working hours, non-working hours of working day, and non-working day. The sub-grouping was based on the date, the day of the week, and the time of the day.

In the sixth step, using the appropriate sub-grouped data, the maximum, minimum, average, standard deviation, and number of data during working hours, non-working hours of working day and non-working day were calculated.

9.6 CONCLUSION

The concentration of TVOCs in winter was higher than that in summer. The difference was statistically significant. This suggests that the monitoring should be conducted at least twice: once each in summer and winter.

The weak link between the concentration of gaseous pollutants and building sickness suggests two possibilities:

1. The criteria for determining healthy and unhealthy areas are not sufficently precise. In this case, the SERC/LINK refers areas/clusters with a PSI score of 3.3 and above as unhealthy and below 2.6 as healthy. To investigate the link further the concentration of gaseous pollutants should be compared directly with the PSI scores.
2. The gas monitor and particulate monitor are not precise. As stated previously, the gas monitor does not measures all of the TVOCs relevant to health nor does it

measure the concentrations of the individual TVOCs and express them in terms of their relative contribution to the intensity of building sickness. The particulate monitor is not able to relate the size of particulates with the amount: larger particulates will be of smaller amount than smaller particulates although they both weigh the same. The particulates monitor is also not able to identify the nature of the particulates, for example whether they are pollen or man-made mineral fibre.

Summer monitorings in Peterborough and Kendal Building show that the TVOC measures were zero in all locations. This is very surprising finding, the cause is unknown. Malfunctioning of the gas monitor is not suspected as other measures before and after the monitorings were normal.

In the author's opinion the indoor TVOCs measures were very low but not zero. Take LOC-5 at Kendal Building as an example. Although the TVOCs measures at the monitoring inlet of this particular location were zero, the measures at the monitoring inlets at EXHAUST and SUPPLY were not. The fresh air is supplied to the indoor through supply diffusers, one of which is SUPPLY. The used air is removed from the indoor through exhaust diffusers, one of which is EXHAUST. The TVOC measures at EXHAUST varied from zero to 8.29 ppm and the TVOC measures at SUPPLY varied from zero to 1.26 ppm. LOC-5, EXHAUST, and SUPPLY were located on the north wing of the First Floor but, the EXHAUST and SUPPLY were more than five metres away from LOC-5. Since the three locations were monitored sequentially, this suggests that during the monitoring the TVOCs were actually generated somewhere on the same floor but not at LOC-5. The generated TVOCs were picked up by the ventilation system as evidenced from the measures at EXHAUST and SUPPLY.

The reason for this phenomenon could be due to the influence on the behaviour of office workers of the previous monitoring in winter in both the Kendal and Peterborough Buildings. The office workers in summer were more aware of the monitoring and conscientously avoid conducting activities that could generate TVOCs in the monitored location.

9.7 REFERENCES

1. Bruer and Kjaer. (1992). Personal communication with Dr Tim Hoban, an application chemist at Bruer and Kjaer, London, on 1 Apr. 1992.

2. Dingle, P. and Murray, F. (1993). `Control and Regulation of Indoor Air: An Australian Perspective', Indoor Environment, 1993, Vol. 2, pp217-220.

3. Molhave, L. et al (1986). `Human Reactions to Low Concentrations of Volatile Organic Compounds'. Environ. Int. 12:167-175. in Godish, T. (1989). Indoor Air Pollution Control, Michigan: Lewis Publishers, Inc.

4. Potter, I. N. (1988). The Sick Building Syndrome. BSRIA Technical Note 4/88. Berkshire: The Building Services Research and Information Association

5. Seifert, B. (1990). `Regulating indoor Air'. Proceedings of Fifth International Conference on Indoor Air Quality and Climate. Vol. 5, pp35-49. Toronto, Canada in Grot, R. A. et al. `Indoor air quality evaluation of a new office building'. ASHRAE Journal, Sept. 1991, pp16-25

6. Tucker, G. (1998). `Factors influencing indoor air pollutants originating from surface materials. In pre-prints of `Healthy Buildings 88' Conference. Stockholm, Sweden: Swedish Council for Building Research. Grot, R.A. et al. `Indoor air quality evaluation of a new office building'. ASHRAE Journal, Sept. 1991, pp16-25

Chapter 10
CONCLUSION

10.1 INTRODUCTION

The objective of this thesis was to recommend the most practical but valid and reliable methodology of monitoring pollutants in the assessment of health hazards in building within the constraint of problem-solving research. The author believes this thesis has accomplished this objective.

The accomplishment of this objective may be assessed with the following two criteria:

a) within the constraint of problem-solving research, was it possible to develop a valid and reliable methodology ?

Yes it was. Within the permissible time scale and budget of the SERC/LINK Project, and the allowable intervention time in the study offices, the author believes a practical, valid, and reliable methodology was developed. In this thesis, all of the controversies and uncertainties concerning the methodology, as stated in Section 1.4.1, were reasonably addressed. Where possible the uncertainties were expressed in terms of error band so that the result of the monitoring could be presented with confidence.

The author believes the validity and reliability of the methodology were externally validated during the monitoring of four study buildings. The analysis of the data taken in the four study buildings conducted by the author (See Section 9.6) suggests that indoor pollutants alone do not cause building sickness. This finding is in strong agreement with an independent finding of the SERC/LINK Project. Within the context of multi disciplinary investigations of building sickness, indoor pollutants do not seems to play a major role (SERC/LINK, 1994).

b) Did the methodology assist the problem-solving research ?

Yes it did. By using this methodology, the contribution of indoor pollutants to building sickness can be reliably assessed. This allows the multi disciplinary SERC/LINK Project to have a greater confidence in its results by discounting one group of factors (SERC/LINK, 1994).

The rest of this chapter consists of two sections. The first section, Section 10.2, focuses on the summary of the recommended methodology. The Second section, Section 10.3, recommends the improvement to minimise the error band.

10.2 SUMMARY OF THE RECOMMENDED METHODOLOGY

The development of the methodology involved the identification of the most relevant indoor pollutants, the selection of the most suitable instrumentation to conduct the monitoring, the quality control of the monitoring instruments, and the selection of the method of monitoring.

The most relevant indoor pollutants to health hazards in office buildings are respirable particulates, VOCs, carbon dioxide and carbon monoxide. It is unlikely that any of the individual VOCs causes building sickness symptoms. Therefore, the net concentration of the VOCs, which is known as TVOC, is more relevant to the assessment of health hazards in office building than the concentration of individual VOC. The major problem in measuring the TVOCs is in finding a suitable representative VOC.

The existence of the above indoor pollutants should be monitored in symptomatic areas: the part of the buildings where the office workers complained of symptoms. Building sickness is more suitable to describe symptoms associated with unhealthy buildings. The extent of building sickness may be measured by distributing symptoms questionnaire to the office workers and the result expressed in the indices of PSI, BSS or Factor Score.

The above pollutants can be monitored using particulate and gas monitors. The recommended instrument for monitoring particulates is a piezobalance particulate monitor. In principle, light scattering is better than piezobalance because it can monitor particulate continuously. However in this particular research, both of the piezobalance and light scattering techniques require frequent cleaning and therefore unsuitable for continuous monitoring. Consequently, manual sampling was used. For manual sampling, the use of a particulate monitor using piezobalance technique is sufficient.

The quality control of the particulate monitor are calibration and regular cleaning of the quartz crystal. The particulate monitor was calibrated at the factory when it was delivered. The cleanliness of the crystal is indicated by the natural frequency of the crystal. For example, during the monitoring, the natural frequency of the particulate monitor used in this research should not exceed 1,000 Hertz beyond the base frequency of 1,430 Hertz.

The recommended instrument for monitoring TVOC, carbon dioxide, and carbon monoxide is an infra-red spectroscopy gas monitor. The use of the gas monitor for monitoring carbon dioxide and carbon monoxide is valid. The optical filter UA 0984 is specific to and carbon dioxide and was therefore calibrated with that gas. The optical filter UA 0983 is specific to carbon monoxide and was therefore calibrated with that gas.

However, the use of the gas monitor for monitoring TVOC is controversial for two reasons. Firstly, the optical filter UA 0987 does not measure all of the VOCs relevant to the symptoms of building sickness. Secondly, the optical filter is calibrated with methane. Methane is selected because it is common in the market and relatively cheap, however, it is not the VOC contributing to the symptoms of building sickness.

This thesis argues, in terms of validity, the gas monitor is as good as the more established gas chromatography technique. Although flame ionisation detection, the detection technique commonly used for gas chromatography, detects all of the VOCs relevant to health hazard, it is uncertain whether or not the current detected from each of them reflects their relative health hazards.

In terms of specificity, the gas monitor is inferior to the gas-chromatography technique but based on the latest knowledge, specificity is not important. In this research, the total concentration of VOCs is more important than the concentration of the individual VOC. Furthermore, the more important consideration in this research is continuous monitoring.

Gas chromatography requires laboratory analysis which makes continuous monitoring impossible. The validity of the indoor pollutants in gas chromatography is subjected to a high probability of human and technical errors involved from collecting the sample in the office to the analysis in the laboratory.

The quality control of the gas monitor is calibration. The gas monitor was not calibrated when it was delivered. The BOC pure nitrogen of grade N5.5 was used in the zero-calibration of all of the optical filters. The optical filter UA 0987 was span calibrated with methane of a concentration of 100 ppm in pure nitrogen. The optical filter UA 0983 with carbon dioxide of a concentration of 540 ppm in pure nitrogen. The optical filter UA 0984 was calibrated with carbon monoxide of a concentration of 10 ppm in pure nitrogen. The calibration was conducted both on site and in the laboratory.

The use of on site calibration as part of quality control against the possibility of off calibration due to the transportation of gas to the site is neither necessary nor practical. The possibility of off calibration may be traced by keeping a control chart. The control chart records the reading of standard gases measured during the monitoring at different sites. On site calibration is not practical since it requires a big space and takes quite a long time.

Both of the particulate monitor and the gas monitor were used to monitor the pollutants at the selected monitoring location at specific monitoring time. The monitoring location and time for the monitoring should be valid for the purpose of health hazard assessment in office buildings. The valid monitoring locations should be representative of the locations identified in the monitoring locations model. Besides the symptomatic area, these locations also include the control areas. The valid monitoring times should be representative of the times identified in the monitoring time model described in Chapter 5. Besides working hours, these times include the control times. Representative time and location may be achieved through random selection. The selected locations can be monitored using either a stationary monitoring approach or sequential mobile monitoring approach unless a multiplexer is fitted to the gas monitor. Using the multiplexer a sequential stationary approach can be used.

In this thesis, the author recommended a sequential stationary monitoring at eight locations, rather than sequential mobile monitoring. Theoretically, more monitoring locations can be selected if the gas monitor is moved sequentially to the monitoring locations. This mobile monitoring approach is however not practical for two reasons. Firstly, the gas monitor is not quite convenient for mobile monitoring in the offices because it requires the use of mains. In offices, a free power socket is not always available and if a battery power pack is used, it is quite heavy. Secondly, the office activities may interrupt the monitoring sequence.

The reliability and validity of the monitoring of indoor pollutants are subjected to significant uncertainties. Through tests and analysis, some of the errors in the concentrations due to those uncertainties were estimated in Chapter 6. In its true sense, the application of the estimation derived in the analysis in other monitorings is invalid because the monitoring used in the analysis and the other monitorings belong to different monitoring populations in terms of time and location. However, the estimated error may be used in a pessimistic way. If the difference in concentrations between two locations or times is not greater than the estimated error, the difference should be considered insignificant. These errors should be considered in interpreting the result of the monitoring as illustrated in Chapter 9.

In the methodology developed in this thesis, the error band is limited by the selection of the standard gases used in dynamic calibration. In this case, the error band for TVOC is plus or minus 2.1 percent of the measured concentration. The zero point error is 0.5 ppm. The error band for carbon dioxide is plus or minus 1.69 percent of the measured concentration. The zero point error is also 0.5 ppm. The error band for carbon monoxide is plus or minus 6.6 percent of the measured concentration. The zero point error is also 0.5 ppm. This error band can be minimised by using standard gases of better quality.

10.3 FUTURE IMPROVEMENT

While developing the proposed methodology, this thesis has raised five interesting problem-solving research issues which should be undertaken to further Improve the proposed methodology:

First, the reliability test on detection of gas monitor may be conducted again for different purposes such as to determine the required warm up time of the gas monitor and to estimate the instrument error after the warm up time. This test is important since the operation of the gas monitor at warm up time improves the instrument reliability. Furthermore, the instrument error estimated in the proposed research would be a better estimation than that proposed in this thesis. Since the reliability test in this research had observed an instability in the microphone signal at 3 hours and 7 minutes after the gas monitor was switched on, the proposed test should be conducted for at least 6 hours from the time the gas monitor is switched on during which time, all of the displayed microphone signals should be recorded.

Second, the reliability analysis to estimate the error in the concentration of gaseous pollutants due to monitoring time interval may be extended to as many buildings as possible. With a large number of data, a better estimation of the error may be proposed. However, as previously noted, in its true sense, this estimation is not valid. It should be seen as an error band within which any two concentrations should not be considered as significantly different from each other.

Third, the calibration error of the optical filters UA 0987 and UA 0984 should be minimised by using better quality standard gases which may have to be prepared by special request of the researcher. The reliability analysis, done in this thesis, to estimate the error in the concentration of TVOC and carbon monoxide due to monitoring time interval showed that the error of detection due to calibration was quite high. For the average concentration of TVOC, the error due to calibration was 0.5 ppm but the error due to monitoring time interval was only 0.42 ppm. For carbon monoxide, it was also 0.5 ppm, but the error due to monitoring time interval was only 0.07 ppm.

Fourth, the calibration error of the optical filters UA 0987 and UA 0984 should be minimised by analysing the contents of the standard gases. In this case, the same gases as used in this thesis, may be used. However, the standard gases for the calibration of the same monitoring project should be bought in a sufficient number of gas tanks. Arrangement should be made in advance so that all of the gas tanks are prepared from the same manufacturing batch. Then a sample of the standard gases should be sent to a chemistry laboratory for accurate analysis.

Fifth, the monitoring by gas monitor should be compared with that of gas-chromatography technique. This is to enable the monitoring results using the gas monitor to be compared with those conducted by most of the previous researchers. For this purpose, a gas sampler should be placed near the inlet tube of the gas monitor for a suitable monitoring period during the monitoring of TVOC. The exact time during which the gas sampler is placed should be recorded. Previous researchers used monitoring periods of between twenty-five minutes to twenty working hours (Goyer, 1990; Skov, 1990; Norback, 1990; Wolkoff, 1988). The gas sampler should then be sent to a chemistry laboratory for analysis. It should be noted however that the gas sampler is meant for integrative monitoring whereas the gas monitor is meant for real time monitoring. Therefore, only the comparison of the average concentration of the VOCs is possible.

Fifth, calibration curves are required to relate the concentrations of the TVOC as measured by the gas monitor, using methane as the standard, with those measured by flame ionisation detection using methane, toluene, and pentane. Past researchers used methane, toluene, or pentane as the standard gases and the detection technique for those gases were flame ionisation detection. The calibration curves are required in comparing the monitoring result using gas monitors with reference to methane with those using gas chromatography with reference to methane, toluene, and pentane.

This thesis is a small contribution to the development of the methodology of monitoring indoor pollutants in the office. The methodology developed here is reliable, valid, and practical for the monitoring of indoor pollutants at the various building sample selected by the SERC/LINK Project on Healthy Office. The author believes that should the above suggested researches be carried out to improve the methodology proposed by this thesis it will be more reliable, practical, and valid to assess the contribution of indoor pollutants to building sickness.

10.4 REFERENCE

SERC/LINK (1994). Personal communication with Nigel Vaughan, Project Manager, SERC/LINK Project on Healthy Office Buildings, Cardiff, 18 October 1994.

APPENDIX

APPENDIX I

Kjaergaard et al's List of VOCs

1. n-hexane
2. n-nonane
3. n-decane
4. n-undecane
5. 1-octene
6. 1-decene
7. cyclohexane
8. 3-xylene
9. ethylbenzene
10. 1,2,4-trimethylbenzene
11. n-propyl-benzene
12. alpha-pinene
13. n-pentanal
14. n-hexanal
15. iso-propanol
16. n-butanol
17. 2-butanone
18. 3-methyl-3-butanone
19. 4-methyl-2-pentanone
20. n-butylacetate
21. ethoxyethyl-acetate
22. 1,2-dichlor-ethane

APPENDIX II

Shah and Singh's List of VOCs

1. cumene
2. formaldehyde
3. carbon tetrachloride
4. acetone
5. chloroform
6. benzene
7. trichloroethane
8. methyl ethylketon
9. trichloroethene
10. 1,1,2,2-tetrachloroethane
11. A-pinene
12. dimethylbenzene
13. trimethylbenzene (identification number 20)
14. ethylbenzene
15. ethenylbenzene
16. benzaldehyde
17. dimethylbenzene
18. 1,4-dichlorobenzene
19. trimethylbenzene (identification number 14)
20. toluene
21. cyclohexane
22. octane
23. 2-butoxyethanol
24. nonane
25. 1,4-(dioxane)
26. decane
27. tetrachloroethene
28. decamethylcyclopentasil-oxane
29. 1,3-dichlorobenzene

30. tridecane
31. tetradecane
32. pentadecane
33. undecane
34. trichlorobenzene
35. dichlorobenzene

APPENDIX III

Dawidowicz's List of VOCs

1. n-hexane
2. n-heptane
3. n-octane
4. n-nonane
5. n-decane
6. n-undecane
7. n-dodecane
8. n-tridecane
9. n-tetradecane
10. 2-methylpentane
11. 2-methylhexane
12. 3-methylheptane
13. cyclohexane
14. methylcyclopentane
15. 1-octene
16. 1-decene
17. trichlorofluoromethane
18. dibromochloromethane
19. 1,2-dichloroethane
20. dichloromethane
21. trichloromethane
22. tetrachloromethane
23. 1,1,1-trichloroethane
24. trichloroethene
25. 1,1,2-trichloroethane
26. tetrachloroethene
27. chlorobenzene
28. 1,4-dichlorobenzene
29. methanol

30. ethanol
31. 2-propanol
32. 2-methyl-1-propanol
33. 1-butanol
34. 1-pentanol
35. 2-ethyl-cyclobutanol
36. formaldehyde
37. acetaldehyde
38. butanal
39. pentanal
40. hexanal
41. benzaldehyde
42. nonanal
43. 2-propanone
44. 2-butanone
45. 3-methyl-2-butanone
46. 3-heptanone
47. ethylacetate
48. n-butylacetate
49. 2-ethoxy-ethanolacetate
50. benzene
51. toluene
52. ethylbenzene
53. 1,3-dimethylbenzene
54. 1,4-dimethylbenzene
55. 1,2-dimethylbenzene
56. n-propylbenzene
57. 1,3,5-trimethylbenzene
58. 1,2,4-trimethylbenzene
59. C3-alkylbenzene
60. 1-methylethenylbenzene
61. 1-ethenyl-3-ethylbenzene
62. 1-ethenyl-4-ethylbenzene
63. naphtalene
64. biphenyl

65. alpha-pinene
66. beta-pinene
67. (delta three)-carene
68. limonene

APPENDIX IV

Tables of Measures at Kendal Buildings

CONTENTS

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	7.97	5.96	4.39	0.85	35
LOC-2	6.03	5.08	3.87	0.65	34
LOC-3	6.88	5.52	4.07	0.65	34
LOC-4	6.95	6.07	4.59	0.69	34
LOC-5	11.08	6.02	3.41	1.43	34
LOC-6	6.76	5.73	4.00	0.80	34
SUPPLY	12.97	4.66	2.38	1.61	33
EXHAUST	7.86	5.62	3.82	1.10	33

Table A.1
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	4.84	3.28	2.29	0.63	60
LOC-2	4.39	3.09	2.51	0.50	60
LOC-3	5.01	3.33	2.51	0.60	60
LOC-4	7.17	3.35	2.49	0.98	60
LOC-5	4.96	3.09	2.46	0.59	60
LOC-6	4.31	3.14	2.39	0.49	60
SUPPLY	4.24	2.79	2.21	0.50	60
EXHAUST	5.18	2.88	2.26	0.50	60

Table A.2
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	12.85	3.86	1.98	2.01	101
LOC-2	15.18	3.68	1.87	2.00	100
LOC-3	52.24	4.83	2.11	5.80	99
LOC-4	11.78	3.78	2.15	1.84	100
LOC-5	13.61	3.49	1.83	1.92	100
LOC-6	13.48	3.76	1.98	1.84	99
SUPPLY	21.47	3.32	1.85	2.80	100
EXHAUST	16.49	3.16	1.80	1.98	101

Table A.3
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	8.83	4.65	3.69	0.86	49
LOC-2	9.54	4.61	2.95	1.24	50
LOC-3	35.74	6.60	3.19	5.58	49
LOC-4	6.20	4.85	3.74	0.47	50
LOC-5	7.90	4.92	3.41	0.88	50
LOC-6	5.49	4.27	3.28	0.51	50
SUPPLY	4.50	3.40	2.85	0.39	48
EXHAUST	5.74	4.35	3.15	0.66	48

Table A.4
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	5.86	3.28	2.23	1.08	60
LOC-2	6.02	3.50	2.69	0.87	60
LOC-3	6.15	3.58	2.68	0.93	60
LOC-4	8.71	4.27	3.03	1.54	60
LOC-5	6.07	3.18	2.27	0.99	60
LOC-6	4.50	3.39	2.60	0.55	60
SUPPLY	5.96	3.56	2.85	0.81	60
EXHAUST	5.52	3.09	2.38	0.77	60

Table A.5
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	7.03	2.51	0.00	1.46	60
LOC-2	7.21	2.09	0.00	1.89	60
LOC-3	17.94	2.42	0.00	2.77	60
LOC-4	19.17	4.09	0.00	4.16	60
LOC-5	5.18	1.68	0.00	1.76	60
LOC-6	6.00	1.93	0.00	1.89	60
SUPPLY	6.87	2.43	0.00	2.04	60
EXHAUST	6.24	1.77	0.00	1.83	60

Table A.6
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	5.73	3.23	0.00	1.74	29
LOC-2	10.43	3.71	0.00	2.64	29
LOC-3	11.56	3.83	0.00	2.80	29
LOC-4	12.16	5.23	0.32	3.05	29
LOC-5	9.41	3.09	0.00	2.83	29
LOC-6	6.32	2.70	0.00	2.65	29
SUPPLY	8.03	3.31	0.00	2.57	29
EXHAUST	7.10	2.96	0.00	2.55	29

Table A.7
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.62	0.01	0.00	0.08	60
LOC-2	0.00	0.00	0.00	0.00	60
LOC-3	0.00	0.00	0.00	0.00	60
LOC-4	3.90	0.26	0.00	0.68	60
LOC-5	0.00	0.00	0.00	0.00	60
LOC-6	0.00	0.00	0.00	0.00	60
SUPPLY	0.00	0.00	0.00	0.00	60
EXHAUST	0.00	0.00	0.00	0.00	60

Table A.8
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	5.96	0.15	0.00	0.72	76
LOC-2	15.88	0.51	0.00	2.30	76
LOC-3	42.42	1.65	0.00	6.87	76
LOC-4	20.41	2.12	0.00	4.33	76
LOC-5	2.99	0.04	0.00	0.35	75
LOC-6	0.00	0.00	0.00	0.00	75
SUPPLY	1.77	0.11	0.00	0.36	75
EXHAUST	8.35	0.16	0.00	1.05	76

Table A.9
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	9.78	0.80	0.00	1.91	36
LOC-2	34.60	1.49	0.00	5.77	36
LOC-3	56.83	2.19	0.00	9.48	36
LOC-4	2.75	0.28	0.00	0.59	36
LOC-5	6.53	0.55	0.00	1.46	36
LOC-6	0.42	0.01	0.00	0.07	36
SUPPLY	26.99	0.82	0.00	4.51	36
EXHAUST	5.07	0.15	0.00	0.86	35

Table A.10
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.38	0.00	0.00	0.04	90
LOC-2	0.54	0.02	0.00	0.09	90
LOC-3	0.63	0.02	0.00	0.10	90
LOC-4	4.66	0.40	0.00	1.09	90
LOC-5	0.31	0.01	0.00	0.04	90
LOC-6	0.00	0.00	0.00	0.00	91
SUPPLY	0.84	0.02	0.00	0.11	90
EXHAUST	0.10	0.00	0.00	0.01	90

Table A.11
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	7.12	0.30	0.00	1.10	80
LOC-2	14.03	0.58	0.00	2.33	80
LOC-3	14.44	0.88	0.00	2.98	80
LOC-4	31.11	1.99	0.00	4.68	79
LOC-5	19.69	0.34	0.00	2.33	79
LOC-6	0.88	0.02	0.00	0.11	80
SUPPLY	24.42	1.22	0.00	3.54	81
EXHAUST	13.21	0.53	0.00	2.26	81

Table A.12
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.32	0.08	0.00	0.52	40
LOC-2	4.19	0.11	0.00	0.66	40
LOC-3	3.56	0.19	0.00	0.74	40
LOC-4	0.82	0.02	0.00	0.13	40
LOC-5	6.79	0.38	0.00	1.38	39
LOC-6	1.49	0.04	0.00	0.24	38
SUPPLY	0.00	0.00	0.00	0.00	38
EXHAUST	13.21	0.88	0.00	2.82	71

Table A.13
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	90
LOC-2	0.00	0.00	0.00	0.00	90
LOC-3	0.00	0.00	0.00	0.00	90
LOC-4	1.06	0.03	0.00	0.15	90
LOC-5	0.00	0.00	0.00	0.00	90
LOC-6	0.00	0.00	0.00	0.00	90
SUPPLY	0.00	0.00	0.00	0.00	90
EXHAUST	0.00	0.00	0.00	0.00	90

Table A.14
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	100
LOC-2	3.27	0.03	0.00	0.33	99
LOC-3	11.05	0.35	0.00	1.68	99
LOC-4	33.68	2.75	0.00	5.74	101
LOC-5	0.00	0.00	0.00	0.00	101
LOC-6	0.00	0.00	0.00	0.00	100
SUPPLY	3.38	0.06	0.00	0.41	100
EXHAUST	0.55	0.01	0.00	0.05	100

Table A.15
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	50
LOC-2	0.00	0.00	0.00	0.00	50
LOC-3	4.01	0.14	0.00	0.71	50
LOC-4	0.00	0.00	0.00	0.00	49
LOC-5	0.00	0.00	0.00	0.00	49
LOC-6	0.00	0.00	0.00	0.00	49
SUPPLY	0.00	0.00	0.00	0.00	49
EXHAUST	0.00	0.00	0.00	0.00	49

Table A.16
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.91	0.11	0.00	0.38	60
LOC-2	0.00	0.00	0.00	0.00	60
LOC-3	0.00	0.00	0.00	0.00	60
LOC-4	5.22	0.50	0.00	1.06	60
LOC-5	0.00	0.00	0.00	0.00	60
LOC-6	0.00	0.00	0.00	0.00	60
SUPPLY	0.35	0.01	0.00	0.05	60
EXHAUST	0.00	0.00	0.00	0.00	60

Table A.17
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	99
LOC-2	2.43	0.02	0.00	0.24	101
LOC-3	3.04	0.07	0.00	0.41	101
LOC-4	16.81	1.92	0.00	4.01	101
LOC-5	0.00	0.00	0.00	0.00	100
LOC-6	0.00	0.00	0.00	0.00	100
SUPPLY	1.07	0.01	0.00	0.11	100
EXHAUST	0.00	0.00	0.00	0.00	99

Table A.18
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.47	0.03	0.00	0.21	49
LOC-2	2.44	0.08	0.00	0.42	49
LOC-3	8.41	0.49	0.00	1.67	49
LOC-4	0.00	0.00	0.00	0.00	49
LOC-5	0.00	0.00	0.00	0.00	50
LOC-6	0.00	0.00	0.00	0.00	50
SUPPLY	0.00	0.00	0.00	0.00	49
EXHAUST	0.00	0.00	0.00	0.00	49

Table A.19
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	60
LOC-2	0.00	0.00	0.00	0.00	60
LOC-3	0.00	0.00	0.00	0.00	60
LOC-4	2.67	0.16	0.00	0.54	60
LOC-5	0.00	0.00	0.00	0.00	60
LOC-6	0.00	0.00	0.00	0.00	60
SUPPLY	0.00	0.00	0.00	0.00	60
EXHAUST	0.00	0.00	0.00	0.00	60

Table A.20
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	72
LOC-2	6.32	0.13	0.00	0.78	72
LOC-3	14.13	0.39	0.00	1.81	71
LOC-4	19.17	2.02	0.00	4.58	71
LOC-5	2.53	0.04	0.00	0.30	71
LOC-6	0.00	0.00	0.00	0.00	71
SUPPLY	19.69	0.33	0.00	2.37	71
EXHAUST	0.00	0.00	0.00	0.00	72

Table A.21
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	9.11	0.24	0.00	1.48	38
LOC-2	7.08	0.36	0.00	1.28	38
LOC-3	5.89	0.30	0.00	1.06	39
LOC-4	0.00	0.00	0.00	0.00	39
LOC-5	5.41	0.16	0.00	0.87	39
LOC-6	0.00	0.00	0.00	0.00	39
SUPPLY	23.29	0.60	0.00	3.73	39
EXHAUST	20.51	1.10	0.00	4.26	38

Table A.22
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	29
LOC-2	0.00	0.00	0.00	0.00	30
LOC-3	0.00	0.00	0.00	0.00	30
LOC-4	0.00	0.00	0.00	0.00	30
LOC-5	0.00	0.00	0.00	0.00	30
LOC-6	0.00	0.00	0.00	0.00	30
SUPPLY	0.00	0.00	0.00	0.00	30
EXHAUST	0.00	0.00	0.00	0.00	30

Table A.23
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	24.83	4.98	0.00	8.64	25
LOC-2	5.05	0.20	0.00	1.01	25
LOC-3	0.00	0.00	0.00	0.00	25
LOC-4	12.59	0.73	0.00	2.65	25
LOC-5	9.87	0.61	0.00	2.11	25
LOC-6	0.00	0.00	0.00	0.00	25
SUPPLY	13.62	0.79	0.00	2.92	24
EXHAUST	5.83	0.37	0.00	1.26	24

Table A.24
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	10
LOC-2	0.00	0.00	0.00	0.00	10
LOC-3	0.00	0.00	0.00	0.00	10
LOC-4	0.00	0.00	0.00	0.00	10
LOC-5	0.00	0.00	0.00	0.00	10
LOC-6	0.00	0.00	0.00	0.00	10
SUPPLY	0.00	0.00	0.00	0.00	10
EXHAUST	3.55	0.35	0.00	1.12	10

Table A.25
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	8.45	0.52	0.00	1.68	60
LOC-2	0.00	0.00	0.00	0.00	60
LOC-3	0.00	0.00	0.00	0.00	60
LOC-4	0.00	0.00	0.00	0.00	60
LOC-5	0.00	0.00	0.00	0.00	60
LOC-6	0.00	0.00	0.00	0.00	60
SUPPLY	0.00	0.00	0.00	0.00	61
EXHAUST	0.00	0.00	0.00	0.00	60

Table A.26
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	69.07	2.52	0.00	8.02	100
LOC-2	22.26	0.60	0.00	2.65	100
LOC-3	10.26	0.22	0.00	1.22	100
LOC-4	4.65	0.16	0.00	0.69	100
LOC-5	26.68	0.65	0.00	3.22	100
LOC-6	15.26	0.15	0.00	1.53	100
SUPPLY	13.41	0.35	0.00	1.60	100
EXHAUST	11.97	0.44	0.00	1.74	100

Table A.27
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	50
LOC-2	0.00	0.00	0.00	0.00	50
LOC-3	0.00	0.00	0.00	0.00	50
LOC-4	0.00	0.00	0.00	0.00	50
LOC-5	0.00	0.00	0.00	0.00	50
LOC-6	0.00	0.00	0.00	0.00	50
SUPPLY	1.26	0.03	0.00	0.18	50
EXHAUST	11.97	0.58	0.00	2.01	90

Table A.28
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	0.00	0.00	0.00	0.00	13
LOC-2	0.00	0.00	0.00	0.00	13
LOC-3	0.00	0.00	0.00	0.00	13
LOC-4	0.00	0.00	0.00	0.00	13
LOC-5	0.00	0.00	0.00	0.00	13
LOC-6	0.00	0.00	0.00	0.00	13
SUPPLY	0.00	0.00	0.00	0.00	13
EXHAUST	0.00	0.00	0.00	0.00	13

Table A.29
Table of TVOC Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	11.11	4.67	3.01	1.28	68
LOC-2	8.77	4.47	2.99	1.08	68
LOC-3	8.92	4.94	3.25	1.20	68
LOC-4	14.14	5.25	3.28	2.14	68
LOC-5	6.86	4.21	2.89	0.85	68
LOC-6	7.33	4.57	3.06	0.94	68
SUPPLY	5.41	3.74	2.63	0.63	69
EXHAUST	5.96	3.84	2.76	0.65	68

Table A.30
Table of TVOC Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	868	474	439	70	68
LOC-2	660	467	437	50	68
LOC-3	848	477	437	74	68
LOC-4	746	477	435	79	68
LOC-5	623	458	436	39	68
LOC-6	752	484	439	73	68
SUPPLY	520	452	437	17	69
EXHAUST	526	451	437	18	68

Table B.1
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	980	739	573	112	35
LOC-2	744	663	578	41	34
LOC-3	815	686	593	62	34
LOC-4	1000	871	707	76	34
LOC-5	794	720	602	48	34
LOC-6	1007	842	701	80	34
SUPPLY	596	544	507	22	33
EXHAUST	781	680	526	65	33

Table B.2
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	465	443	434	7	60
LOC-2	461	440	428	7	60
LOC-3	459	438	426	7	60
LOC-4	460	436	426	7	60
LOC-5	464	439	428	7	60
LOC-6	460	442	430	7	60
SUPPLY	465	441	428	7	60
EXHAUST	469	440	429	7	60

Table B.3
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	767	478	435	54	101
LOC-2	651	473	430	40	100
LOC-3	832	484	433	68	99
LOC-4	825	484	429	75	100
LOC-5	767	469	434	44	100
LOC-6	803	493	436	70	99
SUPPLY	551	464	434	21	100
EXHAUST	577	465	434	27	101

Table B.4
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	888	692	558	73	49
LOC-2	733	653	555	40	50
LOC-3	888	695	565	73	49
LOC-4	909	799	640	50	50
LOC-5	798	699	606	49	50
LOC-6	1191	818	660	97	50
SUPPLY	598	554	513	23	48
EXHAUST	785	682	599	42	48

Table B.5
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	511	460	441	21	60
LOC-2	508	451	432	22	60
LOC-3	508	451	430	22	60
LOC-4	567	452	404	43	60
LOC-5	510	452	437	21	60
LOC-6	514	458	438	21	60
SUPPLY	514	456	438	21	60
EXHAUST	513	453	436	22	60

Table B.6
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1394	497	438	149	60
LOC-2	930	507	435	121	60
LOC-3	962	511	432	128	60
LOC-4	1739	629	404	291	60
LOC-5	826	482	432	83	60
LOC-6	1166	575	437	175	60
SUPPLY	1067	511	433	126	60
EXHAUST	746	476	433	72	60

Table B.7
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1045	886	727	85	29
LOC-2	1109	954	760	100	29
LOC-3	1245	973	647	195	29
LOC-4	2125	1649	1097	224	29
LOC-5	998	835	664	88	29
LOC-6	1364	1136	931	137	29
SUPPLY	998	863	554	87	29
EXHAUST	998	839	625	92	29

Table B.8
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	460	431	417	10	60
LOC-2	453	426	413	11	60
LOC-3	450	425	411	10	60
LOC-4	491	399	380	21	60
LOC-5	486	433	412	19	60
LOC-6	511	437	422	18	60
SUPPLY	456	430	415	10	60
EXHAUST	485	434	413	17	60

Table B.9
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	861	474	414	94	76
LOC-2	865	481	407	101	76
LOC-3	1028	489	409	121	76
LOC-4	1176	537	378	178	76
LOC-5	810	464	402	79	75
LOC-6	1107	543	412	153	75
SUPPLY	740	476	406	76	75
EXHAUST	818	461	410	74	76

Table B.10
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1176	829	619	138	36
LOC-2	1097	811	646	145	36
LOC-3	1275	870	638	161	36
LOC-4	1680	1117	753	305	36
LOC-5	1018	782	643	94	36
LOC-6	1314	1051	797	133	36
SUPPLY	1057	684	507	168	36
EXHAUST	1008	742	484	128	35

Table B.11
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	442	431	420	4	90
LOC-2	441	423	414	6	90
LOC-3	439	422	415	5	90
LOC-4	438	400	377	16	90
LOC-5	465	426	411	8	90
LOC-6	479	433	419	10	91
SUPPLY	443	428	407	8	90
EXHAUST	442	427	412	5	90

Table B.12
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	825	467	425	79	80
LOC-2	763	472	419	79	80
LOC-3	917	478	416	99	80
LOC-4	1077	499	377	144	79
LOC-5	752	458	416	57	79
LOC-6	953	530	427	129	80
SUPPLY	697	474	421	65	81
EXHAUST	666	455	420	46	81

Table B.13
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	976	736	609	87	40
LOC-2	770	681	578	48	40
LOC-3	868	696	555	68	40
LOC-4	987	872	756	59	40
LOC-5	925	685	555	61	39
LOC-6	1087	866	703	78	38
SUPPLY	673	557	513	35	38
EXHAUST	1186	596	422	147	71

Table B.14
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	443	429	419	6	90
LOC-2	438	420	405	8	90
LOC-3	438	418	399	8	90
LOC-4	506	396	365	24	90
LOC-5	438	419	407	8	90
LOC-6	468	430	415	9	90
SUPPLY	439	425	406	8	90
EXHAUST	444	421	407	8	90

Table B.15
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	964	457	410	84	100
LOC-2	721	450	407	67	99
LOC-3	789	461	403	91	99
LOC-4	976	476	365	128	101
LOC-5	644	439	407	51	101
LOC-6	1107	513	415	143	100
SUPPLY	760	455	407	70	100
EXHAUST	758	439	407	49	100

Table B.16
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1038	764	590	102	50
LOC-2	795	683	583	47	50
LOC-3	1186	757	595	110	50
LOC-4	1008	870	710	70	49
LOC-5	773	664	560	49	49
LOC-6	1067	896	632	86	49
SUPPLY	787	540	489	41	49
EXHAUST	825	677	549	54	49

Table B.17
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	477	433	414	14	60
LOC-2	472	426	409	13	60
LOC-3	461	422	405	12	60
LOC-4	441	390	354	23	60
LOC-5	472	425	409	14	60
LOC-6	468	435	415	13	60
SUPPLY	471	428	396	15	60
EXHAUST	474	426	406	14	60

Table B.18
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	775	475	423	79	99
LOC-2	710	460	416	56	101
LOC-3	897	468	413	76	101
LOC-4	1038	556	365	167	101
LOC-5	663	453	418	51	100
LOC-6	920	509	418	111	100
SUPPLY	679	460	405	52	100
EXHAUST	612	444	417	37	99

Table B.19
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	860	695	571	63	49
LOC-2	754	640	548	53	49
LOC-3	888	679	528	97	49
LOC-4	998	862	665	76	49
LOC-5	750	619	541	52	50
LOC-6	1453	849	645	117	50
SUPPLY	626	538	465	30	49
EXHAUST	802	654	532	61	49

Table B.20
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	555	447	415	38	60
LOC-2	545	437	408	37	60
LOC-3	541	435	406	36	60
LOC-4	500	418	386	37	60
LOC-5	553	436	407	39	60
LOC-6	544	443	418	37	60
SUPPLY	543	441	408	35	60
EXHAUST	550	438	405	38	60

Table B.21
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	555	447	415	38	60
LOC-2	545	437	408	37	60
LOC-3	541	435	406	36	60
LOC-4	500	418	386	37	60
LOC-5	553	436	407	39	60
LOC-6	544	443	418	37	60
SUPPLY	543	441	408	35	60
EXHAUST	550	438	405	38	60

Table B.22
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	948	699	494	124	38
LOC-2	896	681	538	91	38
LOC-3	983	744	531	104	39
LOC-4	998	837	513	123	39
LOC-5	922	683	518	93	39
LOC-6	1077	828	545	143	39
SUPPLY	926	589	476	103	39
EXHAUST	956	697	551	97	38

Table B.23
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	507	460	433	25	29
LOC-2	502	453	421	26	30
LOC-3	495	451	425	25	30
LOC-4	509	440	404	25	30
LOC-5	504	457	426	27	30
LOC-6	495	455	429	24	30
SUPPLY	501	454	429	25	30
EXHAUST	509	456	423	29	30

Table B.24
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	837	518	403	109	25
LOC-2	544	427	396	36	25
LOC-3	809	516	447	88	25
LOC-4	553	451	419	37	25
LOC-5	486	425	392	24	25
LOC-6	602	439	406	45	25
SUPPLY	565	442	405	42	24
EXHAUST	625	450	407	57	24

Table B.25
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	912	804	630	92	10
LOC-2	682	630	549	42	10
LOC-3	911	818	639	78	10
LOC-4	581	552	515	21	10
LOC-5	726	637	566	45	10
LOC-6	721	631	544	49	10
SUPPLY	650	613	558	34	10
EXHAUST	774	667	580	60	10

Table B.26
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	461	386	347	25	60
LOC-2	457	398	379	22	60
LOC-3	448	414	396	16	60
LOC-4	443	404	378	16	60
LOC-5	459	400	378	22	60
LOC-6	460	413	389	20	60
SUPPLY	456	401	379	20	61
EXHAUST	445	398	377	19	60

Table B.27
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	718	480	344	103	100
LOC-2	633	425	384	54	100
LOC-3	797	482	392	94	100
LOC-4	609	437	375	49	100
LOC-5	575	421	383	39	100
LOC-6	618	432	392	53	100
SUPPLY	633	438	382	61	100
EXHAUST	668	448	379	79	100

Table B.28
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	879	769	677	53	50
LOC-2	723	619	527	40	50
LOC-3	910	787	588	71	50
LOC-4	651	541	490	26	50
LOC-5	733	652	561	38	50
LOC-6	779	655	544	58	50
SUPPLY	793	641	542	51	50
EXHAUST	915	594	398	128	90

Table B.29
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	441	393	368	23	13
LOC-2	396	390	382	4	13
LOC-3	432	409	393	12	13
LOC-4	407	395	382	6	13
LOC-5	395	391	383	3	13
LOC-6	403	398	392	4	13
SUPPLY	394	391	383	3	13
EXHAUST	390	386	381	3	13

Table B.30
Table of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	5.84	2.37	1.29	1.01	68
LOC-2	4.07	2.05	1.17	0.72	68
LOC-3	4.25	2.12	1.30	0.73	68
LOC-4	4.79	2.15	1.09	0.81	68
LOC-5	4.20	1.95	1.20	0.61	68
LOC-6	4.50	2.18	1.31	0.75	68
SUPPLY	3.82	1.99	1.15	0.59	69
EXHAUST	3.98	1.92	1.01	0.56	68

Table C.1
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	4.10	2.95	2.08	0.49	35
LOC-2	2.96	2.39	1.79	0.29	34
LOC-3	2.99	2.39	1.94	0.30	34
LOC-4	3.33	2.74	2.20	0.30	34
LOC-5	3.19	2.52	1.96	0.35	34
LOC-6	3.33	2.58	2.05	0.33	34
SUPPLY	3.16	2.33	1.86	0.35	33
EXHAUST	3.59	2.44	1.91	0.41	33

Table C.2
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.62	1.98	1.24	0.60	60
LOC-2	3.13	1.84	1.24	0.48	60
LOC-3	3.06	1.84	1.22	0.50	60
LOC-4	3.83	1.93	1.22	0.66	60
LOC-5	2.93	1.78	1.27	0.43	60
LOC-6	3.41	1.92	1.15	0.56	60
SUPPLY	3.78	1.86	1.22	0.55	60
EXHAUST	3.30	1.76	1.20	0.45	60

Table C.3
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	5.97	2.03	0.99	1.06	101
LOC-2	4.67	1.82	1.01	0.79	100
LOC-3	4.71	1.91	1.02	0.83	99
LOC-4	4.82	1.90	1.05	0.87	100
LOC-5	4.91	1.76	0.94	0.78	100
LOC-6	4.67	1.97	1.03	0.84	99
SUPPLY	3.97	1.72	0.96	0.65	100
EXHAUST	3.89	1.66	0.87	0.61	101

Table C.4
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.23	2.55	1.83	0.36	49
LOC-2	2.93	2.19	1.40	0.34	50
LOC-3	2.90	2.20	1.67	0.29	49
LOC-4	3.45	2.49	1.71	0.36	50
LOC-5	3.54	2.30	1.57	0.37	50
LOC-6	3.73	2.40	1.79	0.41	50
SUPPLY	3.95	2.10	1.36	0.46	48
EXHAUST	2.80	2.09	1.59	0.30	48

Table C.5
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.62	1.86	1.15	0.64	60
LOC-2	3.27	1.84	1.10	0.56	60
LOC-3	3.27	1.87	1.22	0.57	60
LOC-4	4.40	2.12	1.35	0.83	60
LOC-5	3.15	1.74	1.11	0.52	60
LOC-6	3.52	2.12	1.33	0.58	60
SUPPLY	3.57	1.95	1.35	0.59	60
EXHAUST	3.17	1.71	1.15	0.48	60

Table C.6
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.95	1.48	0.00	0.90	60
LOC-2	4.37	1.46	0.02	0.90	60
LOC-3	4.18	1.51	0.04	0.91	60
LOC-4	4.50	1.83	0.23	1.03	60
LOC-5	3.31	1.25	0.00	0.75	60
LOC-6	4.51	1.83	0.09	0.99	60
SUPPLY	4.98	1.70	0.01	1.00	60
EXHAUST	3.89	1.27	0.12	0.76	60

Table C.7
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.63	1.98	1.29	0.50	29
LOC-2	3.84	2.04	1.31	0.55	29
LOC-3	4.00	2.05	1.49	0.53	29
LOC-4	4.84	2.87	1.98	0.57	29
LOC-5	4.01	1.98	1.17	0.69	29
LOC-6	4.77	2.44	0.87	0.80	29
SUPPLY	4.83	2.36	1.58	0.64	29
EXHAUST	3.93	1.85	0.95	0.71	29

Table C.8
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.26	0.54	0.04	0.28	60
LOC-2	1.09	0.49	0.00	0.24	60
LOC-3	1.08	0.53	0.10	0.24	60
LOC-4	1.92	0.69	0.16	0.45	60
LOC-5	0.98	0.39	0.00	0.25	60
LOC-6	1.72	0.93	0.25	0.38	60
SUPPLY	1.70	0.72	0.13	0.41	60
EXHAUST	0.92	0.41	0.00	0.23	60

Table C.9
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Days Taken In Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	4.21	0.90	0.00	0.97	76
LOC-2	3.16	0.80	0.00	0.78	76
LOC-3	3.20	0.82	0.00	0.82	76
LOC-4	3.51	1.07	0.03	0.85	76
LOC-5	2.47	0.59	0.00	0.61	75
LOC-6	3.14	1.15	0.00	0.86	75
SUPPLY	4.76	1.12	0.00	1.13	75
EXHAUST	2.86	0.64	0.00	0.62	76

Table C.10
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Hours of Working Days Taken In Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	4.91	1.80	0.66	0.84	36
LOC-2	3.63	1.37	0.71	0.64	36
LOC-3	3.43	1.33	0.65	0.65	36
LOC-4	3.69	1.84	0.98	0.63	36
LOC-5	3.81	1.41	0.66	0.62	36
LOC-6	3.44	1.66	0.85	0.64	36
SUPPLY	2.85	1.46	0.43	0.52	36
EXHAUST	2.90	1.13	0.59	0.48	35

Table C.11
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Working Hours Taken In Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.67	0.57	0.00	0.63	90
LOC-2	2.64	0.58	0.00	0.63	90
LOC-3	2.55	0.62	0.00	0.64	90
LOC-4	4.09	0.90	0.12	1.06	90
LOC-5	2.52	0.47	0.00	0.52	90
LOC-6	2.59	0.75	0.04	0.63	91
SUPPLY	2.93	0.73	0.11	0.77	90
EXHAUST	2.95	0.48	0.00	0.56	90

Table C.12
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Days Taken In Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	3.92	0.78	0.00	0.87	80
LOC-2	3.66	0.82	0.00	0.79	80
LOC-3	3.38	0.82	0.00	0.81	80
LOC-4	3.19	0.95	0.05	0.76	79
LOC-5	2.83	0.52	0.00	0.54	79
LOC-6	4.23	1.25	0.10	1.05	80
SUPPLY	4.16	1.10	0.00	1.08	81
EXHAUST	3.35	0.58	0.00	0.60	81

Table C.13
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken In Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.84	1.26	0.63	0.59	40
LOC-2	2.39	1.04	0.37	0.46	40
LOC-3	2.62	1.06	0.52	0.45	40
LOC-4	3.04	1.32	0.65	0.51	40
LOC-5	3.18	1.12	0.39	0.52	39
LOC-6	2.41	1.32	0.72	0.47	38
SUPPLY	2.22	1.07	0.37	0.54	38
EXHAUST	3.35	0.97	0.27	0.53	71

Table C.14
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Working Hours Taken In Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.35	0.74	0.00	0.65	90
LOC-2	1.65	0.54	0.00	0.41	90
LOC-3	1.68	0.53	0.00	0.42	90
LOC-4	2.50	0.67	0.00	0.58	90
LOC-5	1.28	0.37	0.00	0.33	90
LOC-6	1.81	0.78	0.00	0.47	90
SUPPLY	2.76	0.83	0.02	0.64	90
EXHAUST	1.56	0.42	0.00	0.35	90

Table C.15
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Days Taken In Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	5.64	0.83	0.00	1.04	100
LOC-2	3.46	0.72	0.00	0.75	99
LOC-3	4.34	0.76	0.00	0.81	99
LOC-4	3.21	0.92	0.00	0.75	101
LOC-5	2.52	0.52	0.00	0.59	101
LOC-6	3.59	1.12	0.00	0.90	100
SUPPLY	5.71	1.02	0.00	1.10	100
EXHAUST	2.94	0.54	0.00	0.62	100

Table C.16
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Hours of Working Days Taken In Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.59	1.36	0.60	0.38	50
LOC-2	1.81	1.14	0.74	0.30	50
LOC-3	1.93	1.14	0.63	0.29	50
LOC-4	2.13	1.42	0.96	0.30	49
LOC-5	2.14	1.22	0.71	0.34	49
LOC-6	2.27	1.36	0.73	0.37	49
SUPPLY	2.00	1.17	0.66	0.33	49
EXHAUST	1.80	1.05	0.52	0.31	49

Table C.17
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	4.33	0.89	0.00	1.09	60
LOC-2	2.60	0.75	0.05	0.72	60
LOC-3	2.54	0.78	0.05	0.75	60
LOC-4	3.83	1.21	0.01	1.08	60
LOC-5	2.57	0.55	0.00	0.59	60
LOC-6	2.15	0.89	0.01	0.65	60
SUPPLY	3.26	1.04	0.02	0.94	60
EXHAUST	2.08	0.59	0.00	0.59	60

Table C.18
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.36	0.41	0.00	0.34	99
LOC-2	1.38	0.42	0.00	0.36	101
LOC-3	1.36	0.46	0.00	0.34	101
LOC-4	1.79	0.69	0.00	0.43	101
LOC-5	1.25	0.36	0.00	0.30	100
LOC-6	2.42	0.61	0.00	0.59	100
SUPPLY	1.66	0.55	0.00	0.45	100
EXHAUST	1.15	0.33	0.00	0.28	99

Table C.19
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.95	0.68	0.24	0.39	49
LOC-2	1.45	0.54	0.18	0.28	49
LOC-3	1.61	0.62	0.18	0.30	49
LOC-4	1.62	0.72	0.34	0.26	49
LOC-5	1.72	0.66	0.23	0.39	50
LOC-6	3.39	0.74	0.12	0.52	50
SUPPLY	1.50	0.51	0.15	0.28	49
EXHAUST	1.60	0.58	0.18	0.33	49

Table C.20
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.68	0.62	0.00	0.41	60
LOC-2	1.55	0.56	0.00	0.36	60
LOC-3	1.56	0.59	0.11	0.37	60
LOC-4	2.94	0.89	0.15	0.72	60
LOC-5	1.63	0.48	0.00	0.44	60
LOC-6	1.21	0.54	0.13	0.25	60
SUPPLY	1.63	0.83	0.08	0.40	60
EXHAUST	1.21	0.41	0.00	0.31	60

Table C.21
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Days Taken In Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.68	0.49	0.00	0.49	72
LOC-2	2.34	0.51	0.00	0.46	72
LOC-3	2.28	0.56	0.05	0.45	71
LOC-4	2.37	0.78	0.07	0.55	71
LOC-5	1.72	0.37	0.00	0.35	71
LOC-6	2.15	0.71	0.09	0.49	71
SUPPLY	2.46	0.74	0.06	0.56	71
EXHAUST	2.02	0.38	0.00	0.34	72

Table C.22
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Hours of Working Days Taken In Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.43	0.88	0.41	0.34	38
LOC-2	2.56	0.90	0.31	0.59	38
LOC-3	2.03	0.82	0.36	0.40	39
LOC-4	1.35	0.87	0.40	0.26	39
LOC-5	1.51	0.83	0.39	0.33	39
LOC-6	1.62	0.90	0.39	0.35	39
SUPPLY	1.80	0.79	0.25	0.40	39
EXHAUST	2.28	0.89	0.33	0.53	38

Table C.23
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Working Hours Taken In Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.03	0.56	0.03	0.29	29
LOC-2	0.89	0.40	0.04	0.20	30
LOC-3	0.94	0.43	0.09	0.20	30
LOC-4	0.88	0.45	0.14	0.20	30
LOC-5	0.52	0.28	0.07	0.11	30
LOC-6	1.00	0.44	0.13	0.20	30
SUPPLY	1.23	0.58	0.10	0.36	30
EXHAUST	0.71	0.31	0.00	0.17	30

Table C.24
Table of Carbon Monoxide Measures In Several Locations at Kendal Building During Non-Working Days Taken In Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.57	1.51	0.59	0.59	25
LOC-2	1.52	0.44	0.00	0.44	25
LOC-3	2.85	1.55	0.42	0.77	25
LOC-4	2.53	1.08	0.13	0.76	25
LOC-5	1.52	0.43	0.00	0.37	25
LOC-6	3.30	0.83	0.00	0.89	25
SUPPLY	2.02	0.69	0.00	0.59	24
EXHAUST	2.14	0.78	0.01	0.61	24

Table C.25
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.19	1.50	0.79	0.53	10
LOC-2	1.77	1.25	0.82	0.35	10
LOC-3	2.25	1.60	0.94	0.46	10
LOC-4	2.57	1.53	0.62	0.68	10
LOC-5	1.63	1.23	0.74	0.33	10
LOC-6	2.51	1.68	0.93	0.55	10
SUPPLY	1.72	1.22	0.80	0.28	10
EXHAUST	1.70	1.15	0.60	0.36	10

Table C.26
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.91	0.70	0.00	0.58	60
LOC-2	1.03	0.24	0.00	0.29	60
LOC-3	1.39	0.72	0.00	0.35	60
LOC-4	1.65	0.67	0.00	0.46	60
LOC-5	1.09	0.25	0.00	0.24	60
LOC-6	1.76	0.56	0.00	0.56	60
SUPPLY	1.12	0.37	0.00	0.33	61
EXHAUST	1.10	0.40	0.00	0.33	60

Table C.27
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.85	0.80	0.00	0.64	100
LOC-2	2.05	0.30	0.00	0.42	100
LOC-3	3.85	1.02	0.00	0.88	100
LOC-4	3.05	0.74	0.00	0.75	100
LOC-5	2.36	0.31	0.00	0.42	100
LOC-6	3.06	0.58	0.00	0.67	100
SUPPLY	2.33	0.49	0.00	0.54	100
EXHAUST	2.44	0.56	0.00	0.59	100

Table C.28
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	2.79	1.04	0.41	0.44	50
LOC-2	1.71	0.86	0.28	0.36	50
LOC-3	2.30	0.97	0.23	0.52	50
LOC-4	1.79	0.83	0.26	0.40	50
LOC-5	1.50	0.79	0.21	0.33	50
LOC-6	2.07	1.08	0.25	0.49	50
SUPPLY	1.70	0.80	0.27	0.35	50
EXHAUST	2.44	0.96	0.23	0.44	90

Table C.29
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

LOCATION	MAX	AVG	MIN	STD	N
LOC-1	1.27	0.52	0.03	0.35	13
LOC-2	0.60	0.11	0.00	0.17	13
LOC-3	1.51	0.61	0.22	0.39	13
LOC-4	0.90	0.32	0.07	0.30	13
LOC-5	0.52	0.15	0.00	0.18	13
LOC-6	0.76	0.28	0.00	0.28	13
SUPPLY	0.51	0.18	0.00	0.20	13
EXHAUST	0.75	0.21	0.02	0.23	13

Table C.30
Table of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

WEEK	MAX	AVG	MIN	STD	N
w1	11.11	4.67	3.01	1.28	68
w2	12.85	3.86	1.98	2.01	101
w3	7.03	2.51	0.00	1.46	60
w4	5.96	0.15	0.00	0.72	76
w5	7.12	0.30	0.00	1.10	80
w6	0.00	0.00	0.00	0.00	100
w7	0.00	0.00	0.00	0.00	99
w8	0.00	0.00	0.00	0.00	72
s1	24.83	4.98	0.00	8.64	25
s2	69.07	2.52	0.00	8.02	100

Table D.1
Table of TVOC Measures in Location LOC-1 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	7.97	5.96	4.39	0.85	35
w2	8.83	4.65	3.69	0.86	49
w3	5.73	3.23	0.00	1.74	29
w4	9.78	0.80	0.00	1.91	36
w5	3.32	0.08	0.00	0.52	40
w6	0.00	0.00	0.00	0.00	50
w7	1.47	0.03	0.00	0.21	49
w8	9.11	0.24	0.00	1.48	38
s1	0.00	0.00	0.00	0.00	10
s2	0.00	0.00	0.00	0.00	50

Table D.2
Table of TVOC Measures in Location LOC-1 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	4.84	3.28	2.29	0.63	60
w2	5.86	3.28	2.23	1.08	60
w3	0.62	0.01	0.00	0.08	60
w4	0.38	0.00	0.00	0.04	90
w5	0.00	0.00	0.00	0.00	90
w6	1.91	0.11	0.00	0.38	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	29
s1	8.45	0.52	0.00	1.68	60
s2	0.00	0.00	0.00	0.00	13

Table D.3
Table of TVOC Measures in Location LOC-1 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	8.77	4.47	2.99	1.08	68
w2	15.18	3.68	1.87	2.00	100
w3	7.21	2.09	0.00	1.89	60
w4	15.88	0.51	0.00	2.30	76
w5	14.03	0.58	0.00	2.33	80
w6	3.27	0.03	0.00	0.33	99
w7	2.43	0.02	0.00	0.24	101
w8	6.32	0.13	0.00	0.78	72
s1	5.05	0.20	0.00	1.01	25
s2	22.26	0.60	0.00	2.65	100

Table D.4
Table of TVOC Measures in Location LOC-2 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	6.03	5.08	3.87	0.65	34
w2	9.54	4.61	2.95	1.24	50
w3	10.43	3.71	0.00	2.64	29
w4	34.60	1.49	0.00	5.77	36
w5	4.19	0.11	0.00	0.66	40
w6	0.00	0.00	0.00	0.00	50
w7	2.44	0.08	0.00	0.42	49
w8	7.08	0.36	0.00	1.28	38
s1	0.00	0.00	0.00	0.00	10
s2	0.00	0.00	0.00	0.00	50

Table D.5
Table of TVOC Measures In Location LOC-2 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	4.39	3.09	2.51	0.50	60
w2	6.02	3.50	2.69	0.87	60
w3	0.00	0.00	0.00	0.00	60
w4	0.54	0.02	0.00	0.09	90
w5	0.00	0.00	0.00	0.00	90
w6	0.00	0.00	0.00	0.00	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	60
s2	0.00	0.00	0.00	0.00	13

Table D.6
Table of TVOC Measures In Location LOC-2 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	8.92	4.94	3.25	1.20	68
w2	52.24	4.83	2.11	5.80	99
w3	17.94	2.42	0.00	2.77	60
w4	42.42	1.65	0.00	6.87	76
w5	14.44	0.88	0.00	2.98	80
w6	11.05	0.35	0.00	1.68	99
w7	3.04	0.07	0.00	0.41	101
w8	14.13	0.39	0.00	1.81	71
s1	0.00	0.00	0.00	0.00	25
s2	10.26	0.22	0.00	1.22	100

Table D.7
Table of TVOC Measures In Location LOC-3 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	6.88	5.52	4.07	0.65	34
w2	35.74	6.60	3.19	5.56	49
w3	11.56	3.83	0.00	2.80	29
w4	56.83	2.19	0.00	9.48	36
w5	3.56	0.19	0.00	0.74	40
w6	4.01	0.14	0.00	0.71	50
w7	8.41	0.49	0.00	1.67	49
w8	5.89	0.30	0.00	1.06	39
s1	0.00	0.00	0.00	0.00	10
s2	0.00	0.00	0.00	0.00	50

Table D.8
Table of TVOC Measures in Location LOC-3 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	5.01	3.33	2.51	0.60	60
w2	6.15	3.58	2.68	0.93	60
w3	0.00	0.00	0.00	0.00	60
w4	0.63	0.02	0.00	0.10	90
w5	0.00	0.00	0.00	0.00	90
w6	0.00	0.00	0.00	0.00	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	60
s2	0.00	0.00	0.00	0.00	13

Table D.9
Table of TVOC Measures in Location LOC-3 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	14.14	5.25	3.28	2.14	68
w2	11.78	3.78	2.15	1.84	100
w3	19.17	4.09	0.00	4.16	60
w4	20.41	2.12	0.00	4.33	76
w5	31.11	1.99	0.00	4.68	79
w6	33.68	2.75	0.00	5.74	101
w7	16.81	1.92	0.00	4.01	101
w8	19.17	2.02	0.00	4.58	71
s1	12.59	0.73	0.00	2.65	25
s2	4.65	0.16	0.00	0.69	100

Table D.10
Table of TVOC Measures in Location LOC-4 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	6.95	6.07	4.59	0.69	34
w2	6.20	4.85	3.74	0.47	50
w3	12.16	5.23	0.32	3.05	29
w4	2.75	0.28	0.00	0.59	36
w5	0.82	0.02	0.00	0.13	40
w6	0.00	0.00	0.00	0.00	49
w7	0.00	0.00	0.00	0.00	49
w8	0.00	0.00	0.00	0.00	39
s1	0.00	0.00	0.00	0.00	10
s2	0.00	0.00	0.00	0.00	50

Table D.11
Table of TVOC Measures in Location LOC-4 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	7.17	3.35	2.49	0.98	60
w2	8.71	4.27	3.03	1.54	60
w3	3.90	0.26	0.00	0.68	60
w4	4.66	0.40	0.00	1.09	90
w5	1.06	0.03	0.00	0.15	90
w6	5.22	0.50	0.00	1.08	60
w7	2.67	0.16	0.00	0.54	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	60
s2	0.00	0.00	0.00	0.00	13

Table D.12
Table of TVOC Measures in Location LOC-4 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	6.86	4.21	2.89	0.85	68
w2	13.61	3.49	1.83	1.92	100
w3	5.18	1.68	0.00	1.76	60
w4	2.99	0.04	0.00	0.35	75
w5	19.69	0.34	0.00	2.33	79
w6	0.00	0.00	0.00	0.00	101
w7	0.00	0.00	0.00	0.00	100
w8	2.53	0.04	0.00	0.30	71
s1	9.87	0.61	0.00	2.11	25
s2	26.68	0.65	0.00	3.22	100

Table D.13
Table of TVOC Measures In Location LOC-5 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	11.08	6.02	3.41	1.43	34
w2	7.90	4.92	3.41	0.88	50
w3	9.41	3.09	0.00	2.83	29
w4	6.53	0.55	0.00	1.46	36
w5	6.79	0.38	0.00	1.38	39
w6	0.00	0.00	0.00	0.00	49
w7	0.00	0.00	0.00	0.00	50
w8	5.41	0.16	0.00	0.87	39
s1	0.00	0.00	0.00	0.00	10
s2	0.00	0.00	0.00	0.00	50

Table D.14
Table of TVOC Measures In Location LOC-5 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	4.96	3.09	2.46	0.59	60
w2	6.07	3.18	2.27	0.99	60
w3	0.00	0.00	0.00	0.00	60
w4	0.31	0.01	0.00	0.04	90
w5	0.00	0.00	0.00	0.00	90
w6	0.00	0.00	0.00	0.00	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	60
s2	0.00	0.00	0.00	0.00	13

Table D.15
Table of TVOC Measures in Location LOC-5 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	7.33	4.57	3.06	0.94	68
w2	13.48	3.76	1.98	1.84	99
w3	6.00	1.93	0.00	1.89	60
w4	0.00	0.00	0.00	0.00	75
w5	0.88	0.02	0.00	0.11	80
w6	0.00	0.00	0.00	0.00	100
w7	0.00	0.00	0.00	0.00	100
w8	0.00	0.00	0.00	0.00	71
s1	0.00	0.00	0.00	0.00	25
s2	15.26	0.15	0.00	1.53	100

Table D.16
Table of TVOC Measures In Location LOC-6 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	6.76	5.73	4.00	0.80	34
w2	5.49	4.27	3.28	0.51	50
w3	6.32	2.70	0.00	2.65	29
w4	0.42	0.01	0.00	0.07	36
w5	1.49	0.04	0.00	0.24	38
w6	0.00	0.00	0.00	0.00	49
w7	0.00	0.00	0.00	0.00	50
w8	0.00	0.00	0.00	0.00	39
s1	0.00	0.00	0.00	0.00	10
s2	0.00	0.00	0.00	0.00	50

Table D.17
Table of TVOC Measures In Location LOC-6 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	4.31	3.14	2.39	0.49	60
w2	4.50	3.39	2.60	0.55	60
w3	0.00	0.00	0.00	0.00	60
w4	0.00	0.00	0.00	0.00	91
w5	0.00	0.00	0.00	0.00	90
w6	0.00	0.00	0.00	0.00	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	60
s2	0.00	0.00	0.00	0.00	13

Table D.18
Table of TVOC Measures In Location LOC-6 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	5.41	3.74	2.63	0.63	69
w2	21.47	3.32	1.85	2.80	100
w3	6.87	2.43	0.00	2.04	60
w4	1.77	0.11	0.00	0.36	75
w5	24.42	1.22	0.00	3.54	81
w6	3.38	0.06	0.00	0.41	100
w7	1.07	0.01	0.00	0.11	100
w8	19.69	0.33	0.00	2.37	71
s1	13.62	0.79	0.00	2.92	24
s2	13.41	0.35	0.00	1.60	100

Table D.19
Table of TVOC Measures In Location LOC-7 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	12.97	4.66	2.38	1.61	33
w2	4.50	3.40	2.85	0.39	48
w3	8.03	3.31	0.00	2.57	29
w4	26.99	0.82	0.00	4.51	36
w5	0.00	0.00	0.00	0.00	38
w6	0.00	0.00	0.00	0.00	49
w7	0.00	0.00	0.00	0.00	49
w8	23.29	0.60	0.00	3.73	39
s1	0.00	0.00	0.00	0.00	10
s2	1.26	0.03	0.00	0.18	50

Table D.20
Table of TVOC Measures in Location LOC-7 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	4.24	2.79	2.21	0.50	60
w2	5.96	3.56	2.85	0.81	60
w3	0.00	0.00	0.00	0.00	60
w4	0.84	0.02	0.00	0.11	90
w5	0.00	0.00	0.00	0.00	90
w6	0.35	0.01	0.00	0.05	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	61
s2	0.00	0.00	0.00	0.00	13

Table D.21
Table of TVOC Measures in Location LOC-7 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	5.96	3.84	2.76	0.65	68
w2	16.49	3.16	1.80	1.98	101
w3	6.24	1.77	0.00	1.83	60
w4	8.35	0.16	0.00	1.05	76
w5	13.21	0.53	0.00	2.26	81
w6	0.55	0.01	0.00	0.05	100
w7	0.00	0.00	0.00	0.00	99
w8	0.00	0.00	0.00	0.00	72
s1	5.83	0.37	0.00	1.26	24
s2	11.97	0.44	0.00	1.74	100

Table D.22
Table of TVOC Measures in Location LOC-8 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	7.86	5.62	3.82	1.10	33
w2	5.74	4.35	3.15	0.66	48
w3	7.10	2.96	0.00	2.55	29
w4	5.07	0.15	0.00	0.86	35
w5	13.21	0.88	0.00	2.82	71
w6	0.00	0.00	0.00	0.00	49
w7	0.00	0.00	0.00	0.00	49
w8	20.51	1.10	0.00	4.26	38
s1	3.55	0.35	0.00	1.12	10
s2	11.97	0.58	0.00	2.01	90

Table D.23
Table of TVOC Measures in Location LOC-8 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	5.18	2.88	2.26	0.50	60
w2	5.52	3.09	2.38	0.77	60
w3	0.00	0.00	0.00	0.00	60
w4	0.10	0.00	0.00	0.01	90
w5	0.00	0.00	0.00	0.00	90
w6	0.00	0.00	0.00	0.00	60
w7	0.00	0.00	0.00	0.00	60
w8	0.00	0.00	0.00	0.00	30
s1	0.00	0.00	0.00	0.00	60
s2	0.00	0.00	0.00	0.00	13

Table D.24
Table of TVOC Measures in Location LOC-8 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	868	474	439	70	68
w2	767	478	435	54	101
w3	1394	497	438	149	60
w4	861	474	414	94	76
w5	825	467	425	79	80
w6	964	457	410	84	100
w7	775	475	423	79	99
w8	669	479	432	51	72
s1	837	518	403	109	25
s2	718	480	344	103	100

Table E.1
Table of Carbon Dioxide Measures in Location LOC-1 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	980	739	573	112	35
w2	888	692	558	73	49
w3	1045	886	727	85	29
w4	1176	829	619	138	36
w5	976	736	609	87	40
w6	1038	764	590	102	50
w7	860	695	571	63	49
w8	948	699	494	124	38
s1	912	804	630	92	10
s2	879	769	677	53	50

Table E.2
Table of Carbon Dioxide Measures in Location LOC-1 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	465	443	434	7	60
w2	511	460	441	21	60
w3	460	431	417	10	60
w4	442	431	420	4	90
w5	443	429	419	6	90
w6	477	433	414	14	60
w7	555	447	415	38	60
w8	507	460	433	25	29
s1	461	386	347	25	60
s2	441	393	368	23	13

Table E.3
Table of Carbon Dioxide Measures in Location LOC-1 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	660	467	437	50	68
w2	651	473	430	40	100
w3	930	507	435	121	60
w4	865	481	407	101	76
w5	763	472	419	79	80
w6	721	450	407	67	99
w7	710	460	416	56	101
w8	718	484	428	62	72
s1	544	427	396	36	25
s2	633	425	384	54	100

Table E.4
Table of Carbon Dioxide Measures in Location LOC-2 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	744	663	578	41	34
w2	733	653	555	40	50
w3	1109	954	760	100	29
w4	1097	811	646	145	36
w5	770	681	578	48	40
w6	795	683	583	47	50
w7	754	640	548	53	49
w8	896	681	538	91	38
s1	682	630	549	42	10
s2	723	619	527	40	50

Table E.5
Table of Carbon Dioxide Measures In Location LOC-2 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	461	440	428	7	60
w2	508	451	432	22	60
w3	453	426	413	11	60
w4	441	423	414	6	90
w5	438	420	405	8	90
w6	472	426	409	13	60
w7	545	437	408	37	60
w8	502	453	421	26	30
s1	457	398	379	22	60
s2	396	390	382	4	13

Table E.6
Table of Carbon Dioxide Measures In Location LOC-2 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	848	477	437	74	68
w2	832	484	433	68	99
w3	962	511	432	128	60
w4	1028	489	409	121	76
w5	917	478	416	99	80
w6	789	461	403	91	99
w7	897	468	413	76	101
w8	720	483	422	61	71
s1	809	516	447	88	25
s2	797	482	392	94	100

Table E.7
Table of Carbon Dioxide Measures In Location LOC-3 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	815	686	593	62	34
w2	888	695	565	73	49
w3	1245	973	647	195	29
w4	1275	870	638	161	36
w5	868	696	555	68	40
w6	1186	757	595	110	50
w7	888	679	528	97	49
w8	983	744	531	104	39
s1	911	818	639	78	10
s2	910	787	588	71	50

Table E.8
Table of Carbon Dioxide Measures In Location LOC-3 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	459	438	426	7	60
w2	508	451	430	22	60
w3	450	425	411	10	60
w4	439	422	415	5	90
w5	438	418	399	8	90
w6	461	422	405	12	60
w7	541	435	406	36	60
w8	495	451	425	25	30
s1	448	414	396	16	60
s2	432	409	393	12	13

Table E.9
Table of Carbon Dioxide Measures in Location LOC-3 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	746	477	435	79	68
w2	825	484	429	75	100
w3	1739	629	404	291	60
w4	1176	537	378	178	76
w5	1077	499	377	144	79
w6	976	476	365	128	101
w7	1038	556	365	167	101
w8	862	516	407	106	71
s1	553	451	419	37	25
s2	609	437	375	49	100

Table E.10
Table of Carbon Dioxide Measures in Location LOC-4 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	1000	871	707	76	34
w2	909	799	640	50	50
w3	2125	1649	1097	224	29
w4	1680	1117	753	305	36
w5	987	872	756	59	40
w6	1008	870	710	70	49
w7	998	862	665	76	49
w8	998	837	513	123	39
s1	581	552	515	21	10
s2	651	541	490	26	50

Table E.11
Table of Carbon Dioxide Measures in Location LOC-4 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	460	436	426	7	60
w2	567	452	404	43	60
w3	491	399	380	21	60
w4	438	400	377	16	90
w5	506	396	365	24	90
w6	441	390	354	23	60
w7	500	418	386	37	60
w8	509	440	404	25	30
s1	443	404	378	16	60
s2	407	395	382	6	13

Table E.12
Table of Carbon Dioxide Measures in Location LOC-4 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	623	458	436	39	68
w2	767	469	434	44	100
w3	826	482	432	83	60
w4	810	464	402	79	75
w5	752	458	416	57	79
w6	644	439	407	51	101
w7	663	453	418	51	100
w8	661	473	426	46	71
s1	486	425	392	24	25
s2	575	421	383	39	100

Table E.13
Table of Carbon Dioxide Measures in Location LOC-5 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	794	720	602	48	34
w2	798	699	606	49	50
w3	998	835	664	88	29
w4	1018	782	643	94	36
w5	925	685	555	61	39
w6	773	664	560	49	49
w7	750	619	541	52	50
w8	922	683	518	93	39
s1	726	637	566	45	10
s2	733	652	561	38	50

Table E.14
Table of Carbon Dioxide Measures in Location LOC-5 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	464	439	428	7	60
w2	510	452	437	21	60
w3	486	433	412	19	60
w4	465	426	411	8	90
w5	438	419	407	8	90
w6	472	425	409	14	60
w7	553	436	407	39	60
w8	504	457	426	27	30
s1	459	400	378	22	60
s2	395	391	383	3	13

Table E.15
Table of Carbon Dioxide Measures in Location LOC-5 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	752	484	439	73	68
w2	803	493	436	70	99
w3	1166	575	437	175	60
w4	1107	543	412	153	75
w5	953	530	427	129	80
w6	1107	513	415	143	100
w7	920	509	418	111	100
w8	985	531	441	109	71
s1	602	439	406	45	25
s2	618	432	392	53	100

Table E.16
Table of Carbon Dioxide Measures in Location LOC-6 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	1007	842	701	80	34
w2	1191	818	660	97	50
w3	1364	1136	931	137	29
w4	1314	1051	797	133	36
w5	1087	866	703	78	38
w6	1067	896	632	86	49
w7	1453	849	645	117	50
w8	1077	828	545	143	39
s1	721	631	544	49	10
s2	779	655	544	58	50

Table E.17
Table of Carbon Dioxide Measures in Location LOC-6 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	460	442	430	7	60
w2	514	458	438	21	60
w3	511	437	422	18	60
w4	479	433	419	10	91
w5	468	430	415	9	90
w6	468	435	415	13	60
w7	544	443	418	37	60
w8	495	455	429	24	30
s1	460	413	389	20	60
s2	403	398	392	4	13

Table E.18
Table of Carbon Dioxide Measures in Location LOC-6 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	520	452	437	17	69
w2	551	464	434	21	100
w3	1067	511	433	126	60
w4	740	476	406	76	75
w5	697	474	421	65	81
w6	760	455	407	70	100
w7	679	460	405	52	100
w8	693	485	423	47	71
s1	565	442	405	42	24
s2	633	438	382	61	100

Table E.19
Table of Carbon Dioxide Measures in Location LOC-7 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	596	544	507	22	33
w2	598	554	513	23	48
w3	998	863	554	87	29
w4	1057	684	507	168	36
w5	673	557	513	35	38
w6	787	540	489	41	49
w7	626	538	465	30	49
w8	926	589	476	103	39
s1	650	613	558	34	10
s2	793	641	542	51	50

Table E.20
Table of Carbon Dioxide Measures in Location LOC-7 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	465	441	428	7	60
w2	514	456	438	21	60
w3	456	430	415	10	60
w4	443	428	407	8	90
w5	439	425	406	8	90
w6	471	428	396	15	60
w7	543	441	408	35	60
w8	501	454	429	25	30
s1	456	401	379	20	61
s2	394	391	383	3	13

Table E.21
Table of Carbon Dioxide Measures In Location LOC-7 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks In Summer

WEEK	MAX	AVG	MIN	STD	N
w1	526	451	437	18	68
w2	577	465	434	27	101
w3	746	476	433	72	60
w4	818	461	410	74	76
w5	666	455	420	46	81
w6	758	439	407	49	100
w7	612	444	417	37	99
w8	665	473	421	47	72
s1	625	450	407	57	24
s2	668	448	379	79	100

Table E.22
Table of Carbon Dioxide Measures in Location LOC-8 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	781	680	526	65	33
w2	785	682	599	42	48
w3	998	839	625	92	29
w4	1008	742	484	128	35
w5	1186	596	422	147	71
w6	825	677	549	54	49
w7	802	654	532	61	49
w8	956	697	551	97	38
s1	774	667	580	60	10
s2	915	594	398	128	90

Table E.23
Table of Carbon Dioxide Measures in Location LOC-8 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks in Summer

WEEK	MAX	AVG	MIN	STD	N
w1	469	440	429	7	60
w2	513	453	436	22	60
w3	485	434	413	17	60
w4	442	427	412	5	90
w5	444	421	407	8	90
w6	474	426	406	14	60
w7	550	438	405	38	60
w8	509	456	423	29	30
s1	445	398	377	19	60
s2	390	386	381	3	13

Table E.24.
Table of Carbon Dioxide Measures in Location LOC-8 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	5.84	2.37	1.29	1.01	68
w2	5.97	2.03	0.99	1.06	101
w3	3.95	1.48	0.00	0.90	60
w4	4.21	0.90	0.00	0.97	76
w5	3.92	0.78	0.00	0.87	80
w6	5.64	0.83	0.00	1.04	100
w7	1.36	0.41	0.00	0.34	99
w8	2.68	0.49	0.00	0.49	72
s1	2.57	1.51	0.59	0.59	25
s2	2.85	0.80	0.00	0.64	100

Table F.1
Table of Carbon Monoxide Measures in Location LOC-1 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	4.10	2.95	2.08	0.49	35
w2	3.23	2.55	1.83	0.36	49
w3	3.63	1.98	1.29	0.50	29
w4	4.91	1.80	0.66	0.84	36
w5	2.84	1.26	0.63	0.59	40
w6	2.59	1.36	0.60	0.38	50
w7	1.95	0.68	0.24	0.39	49
w8	1.43	0.88	0.41	0.34	38
s1	2.19	1.50	0.79	0.53	10
s2	2.79	1.04	0.41	0.44	50

Table F.2
Table of Carbon Monoxide Measures in Location LOC-1 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.62	1.98	1.24	0.60	60
w2	3.62	1.86	1.15	0.64	60
w3	1.26	0.54	0.04	0.28	60
w4	2.67	0.57	0.00	0.63	90
w5	2.35	0.74	0.00	0.65	90
w6	4.33	0.89	0.00	1.09	60
w7	1.68	0.62	0.00	0.41	60
w8	1.03	0.56	0.03	0.29	29
s1	1.91	0.70	0.00	0.58	60
s2	1.27	0.52	0.03	0.35	13

Table F.3
Table of Carbon Monoxide Measures in Location LOC-1 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	4.07	2.05	1.17	0.72	68
w2	4.67	1.82	1.01	0.79	100
w3	4.37	1.48	0.02	0.90	60
w4	3.16	0.80	0.00	0.78	76
w5	3.66	0.82	0.00	0.79	80
w6	3.46	0.72	0.00	0.75	99
w7	1.38	0.42	0.00	0.36	101
w8	2.34	0.51	0.00	0.46	72
s1	1.52	0.44	0.00	0.44	25
s2	2.05	0.30	0.00	0.42	100

Table F.4
Table of Carbon Monoxide Measures in Location LOC-2 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	2.96	2.39	1.79	0.29	34
w2	2.93	2.19	1.40	0.34	50
w3	3.84	2.04	1.31	0.55	29
w4	3.63	1.37	0.71	0.64	36
w5	2.39	1.04	0.37	0.46	40
w6	1.81	1.14	0.74	0.30	50
w7	1.45	0.54	0.18	0.28	49
w8	2.56	0.90	0.31	0.59	38
s1	1.77	1.25	0.82	0.35	10
s2	1.71	0.86	0.28	0.36	50

Table F.5
Table of Carbon Monoxide Measures in Location LOC-2 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.13	1.84	1.24	0.48	60
w2	3.27	1.84	1.10	0.56	60
w3	1.09	0.49	0.00	0.24	60
w4	2.64	0.58	0.00	0.63	90
w5	1.65	0.54	0.00	0.41	90
w6	2.60	0.75	0.05	0.72	60
w7	1.55	0.56	0.00	0.36	60
w8	0.89	0.40	0.04	0.20	30
s1	1.03	0.24	0.00	0.29	60
s2	0.60	0.11	0.00	0.17	13

Table F.6
Table of Carbon Monoxide Measures in Location LOC-2 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	4.25	2.12	1.30	0.73	68
w2	4.71	1.91	1.02	0.83	99
w3	4.18	1.51	0.04	0.91	60
w4	3.20	0.82	0.00	0.82	76
w5	3.38	0.82	0.00	0.81	80
w6	4.34	0.76	0.00	0.81	99
w7	1.36	0.46	0.00	0.34	101
w8	2.28	0.56	0.05	0.45	71
s1	2.85	1.55	0.42	0.77	25
s2	3.85	1.02	0.00	0.88	100

Table F.7
Table of Carbon Monoxide Measures in Location LOC-3 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	2.99	2.39	1.94	0.30	34
w2	2.90	2.20	1.67	0.29	49
w3	4.00	2.05	1.49	0.53	29
w4	3.43	1.33	0.65	0.65	36
w5	2.62	1.06	0.52	0.45	40
w6	1.93	1.14	0.63	0.29	50
w7	1.61	0.62	0.18	0.30	49
w8	2.03	0.82	0.36	0.40	39
s1	2.25	1.60	0.94	0.46	10
s2	2.30	0.97	0.23	0.52	50

Table F.8
Table of Carbon Monoxide Measures in Location LOC-3 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.06	1.84	1.22	0.50	60
w2	3.27	1.87	1.22	0.57	60
w3	1.08	0.53	0.10	0.24	60
w4	2.55	0.62	0.00	0.64	90
w5	1.68	0.53	0.00	0.42	90
w6	2.54	0.78	0.05	0.75	60
w7	1.56	0.59	0.11	0.37	60
w8	0.94	0.43	0.09	0.20	30
s1	1.39	0.72	0.00	0.35	60
s2	1.51	0.61	0.22	0.39	13

Table F.9
Table of Carbon Monoxide Measures In Location LOC-3 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	4.79	2.15	1.09	0.81	68
w2	4.82	1.90	1.05	0.87	100
w3	4.50	1.83	0.23	1.03	60
w4	3.51	1.07	0.03	0.85	76
w5	3.19	0.95	0.05	0.76	79
w6	3.21	0.92	0.00	0.75	101
w7	1.79	0.69	0.00	0.43	101
w8	2.37	0.78	0.07	0.55	71
s1	2.53	1.08	0.13	0.76	25
s2	3.05	0.74	0.00	0.75	100

Table F.10
Table of Carbon Monoxide Measures In Location LOC-4 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.33	2.74	2.20	0.30	34
w2	3.45	2.49	1.71	0.36	50
w3	4.84	2.87	1.98	0.57	29
w4	3.69	1.84	0.98	0.63	36
w5	3.04	1.32	0.65	0.51	40
w6	2.13	1.42	0.96	0.30	49
w7	1.62	0.72	0.34	0.26	49
w8	1.35	0.87	0.40	0.26	39
s1	2.57	1.53	0.62	0.68	10
s2	1.79	0.83	0.26	0.40	50

Table F.11
Table of Carbon Monoxide Measures In Location LOC-4 at Kendal Building During Working Hours Taken Over 8 Weeks In Winter and 2 Weeks In Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.83	1.93	1.22	0.66	60
w2	4.40	2.12	1.35	0.83	60
w3	1.92	0.69	0.16	0.45	60
w4	4.09	0.90	0.12	1.06	90
w5	2.50	0.67	0.00	0.58	90
w6	3.83	1.21	0.01	1.08	60
w7	2.94	0.89	0.15	0.72	60
w8	0.88	0.45	0.14	0.20	30
s1	1.65	0.67	0.00	0.46	60
s2	0.90	0.32	0.07	0.30	13

Table F.12
Table of Carbon Monoxide Measures In Location LOC-4 at Kendal Building During Non-Working Days Taken Over 8 Weeks In Winter and 2 Weeks In Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	4.20	1.95	1.20	0.61	68
w2	4.91	1.76	0.94	0.78	100
w3	3.31	1.25	0.00	0.75	60
w4	2.47	0.59	0.00	0.61	75
w5	2.83	0.52	0.00	0.54	79
w6	2.52	0.52	0.00	0.59	101
w7	1.25	0.36	0.00	0.30	100
w8	1.72	0.37	0.00	0.35	71
s1	1.52	0.43	0.00	0.37	25
s2	2.36	0.31	0.00	0.42	100

Table F.13
Table of Carbon Monoxide Measures in Location LOC-5 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.19	2.52	1.96	0.35	34
w2	3.54	2.30	1.57	0.37	50
w3	4.01	1.98	1.17	0.69	29
w4	3.81	1.41	0.66	0.62	36
w5	3.18	1.12	0.39	0.52	39
w6	2.14	1.22	0.71	0.34	49
w7	1.72	0.66	0.23	0.39	50
w8	1.51	0.83	0.39	0.33	39
s1	1.63	1.23	0.74	0.33	10
s2	1.50	0.79	0.21	0.33	50

Table F.14
Table of Carbon Monoxide Measures in Location LOC-5 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	2.93	1.78	1.27	0.43	60
w2	3.15	1.74	1.11	0.52	60
w3	0.98	0.39	0.00	0.25	60
w4	2.52	0.47	0.00	0.52	90
w5	1.28	0.37	0.00	0.33	90
w6	2.57	0.55	0.00	0.59	60
w7	1.63	0.48	0.00	0.44	60
w8	0.52	0.28	0.07	0.11	30
s1	1.09	0.25	0.00	0.24	60
s2	0.52	0.15	0.00	0.18	13

Table F.15
Table of Carbon Monoxide Measures in Location LOC-5 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	4.50	2.18	1.31	0.75	68
w2	4.67	1.97	1.03	0.84	99
w3	4.51	1.83	0.09	0.99	60
w4	3.14	1.15	0.00	0.86	75
w5	4.23	1.25	0.10	1.05	80
w6	3.59	1.12	0.00	0.90	100
w7	2.42	0.61	0.00	0.59	100
w8	2.15	0.71	0.09	0.49	71
s1	3.30	0.83	0.00	0.89	25
s2	3.06	0.58	0.00	0.67	100

Table F.16
Table of Carbon Monoxide Measures in Location LOC-6 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.33	2.58	2.05	0.33	34
w2	3.73	2.40	1.79	0.41	50
w3	4.77	2.44	0.87	0.80	29
w4	3.44	1.66	0.85	0.64	36
w5	2.41	1.32	0.72	0.47	38
w6	2.27	1.36	0.73	0.37	49
w7	3.39	0.74	0.12	0.52	50
w8	1.62	0.90	0.39	0.35	39
s1	2.51	1.68	0.93	0.55	10
s2	2.07	1.08	0.25	0.49	50

Table F.17
Table of Carbon Monoxide Measures in Location LOC-6 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.41	1.92	1.15	0.56	60
w2	3.52	2.12	1.33	0.58	60
w3	1.72	0.93	0.25	0.38	60
w4	2.59	0.75	0.04	0.63	91
w5	1.81	0.78	0.00	0.47	90
w6	2.15	0.89	0.01	0.65	60
w7	1.21	0.54	0.13	0.25	60
w8	1.00	0.44	0.13	0.20	30
s1	1.76	0.56	0.00	0.56	60
s2	0.76	0.28	0.00	0.28	13

Table F.18
Table of Carbon Monoxide Measures in Location LOC-6 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.82	1.99	1.15	0.59	69
w2	3.97	1.72	0.96	0.65	100
w3	4.98	1.70	0.01	1.00	60
w4	4.76	1.12	0.00	1.13	75
w5	4.16	1.10	0.00	1.08	81
w6	5.71	1.02	0.00	1.10	100
w7	1.66	0.55	0.00	0.45	100
w8	2.46	0.74	0.06	0.56	71
s1	2.02	0.69	0.00	0.59	24
s2	2.33	0.49	0.00	0.54	100

Table F.19
Table of Carbon Monoxide Measures in Location LOC-7 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.16	2.33	1.86	0.35	33
w2	3.95	2.10	1.36	0.46	48
w3	4.83	2.36	1.58	0.64	29
w4	2.85	1.46	0.43	0.52	36
w5	2.22	1.07	0.37	0.54	38
w6	2.00	1.17	0.66	0.33	49
w7	1.50	0.51	0.15	0.28	49
w8	1.80	0.79	0.25	0.40	39
s1	1.72	1.22	0.80	0.28	10
s2	1.70	0.80	0.27	0.35	50

Table F.20
Table of Carbon Monoxide Measures in Location LOC-7 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.78	1.86	1.22	0.55	60
w2	3.57	1.95	1.35	0.59	60
w3	1.70	0.72	0.13	0.41	60
w4	2.93	0.73	0.11	0.77	90
w5	2.76	0.83	0.02	0.64	90
w6	3.26	1.04	0.02	0.94	60
w7	1.63	0.83	0.08	0.40	60
w8	1.23	0.58	0.10	0.36	30
s1	1.12	0.37	0.00	0.33	61
s2	0.51	0.18	0.00	0.20	13

Table F.21
Table of Carbon Monoxide Measures in Location LOC-7 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.98	1.92	1.01	0.56	68
w2	3.89	1.66	0.87	0.61	101
w3	3.89	1.27	0.12	0.76	60
w4	2.86	0.64	0.00	0.62	76
w5	3.35	0.58	0.00	0.60	81
w6	2.94	0.54	0.00	0.62	100
w7	1.15	0.33	0.00	0.28	99
w8	2.02	0.38	0.00	0.34	72
s1	2.14	0.78	0.01	0.61	24
s2	2.44	0.56	0.00	0.59	100

Table F.22
Table of Carbon Monoxide Measures in Location LOC-8 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.59	2.44	1.91	0.41	33
w2	2.80	2.09	1.59	0.30	48
w3	3.93	1.85	0.95	0.71	29
w4	2.90	1.13	0.59	0.48	35
w5	3.35	0.97	0.27	0.53	71
w6	1.80	1.05	0.52	0.31	49
w7	1.60	0.58	0.18	0.33	49
w8	2.28	0.89	0.33	0.53	38
s1	1.70	1.15	0.60	0.36	10
s2	2.44	0.96	0.23	0.44	90

Table F.23
Table of Carbon Monoxide Measures in Location LOC-8 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

LOCATION	MAX	AVG	MIN	STD	N
w1	3.30	1.76	1.20	0.45	60
w2	3.17	1.71	1.15	0.48	60
w3	0.92	0.41	0.00	0.23	60
w4	2.95	0.48	0.00	0.56	90
w5	1.56	0.42	0.00	0.35	90
w6	2.08	0.59	0.00	0.59	60
w7	1.21	0.41	0.00	0.31	60
w8	0.71	0.31	0.00	0.17	30
s1	1.10	0.40	0.00	0.33	60
s2	0.75	0.21	0.02	0.23	13

Table F.24.
Table of Carbon Monoxide Measures in Location LOC-8 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

APPENDIX V

Graphs of Measures at Kendal Building

CONTENTS

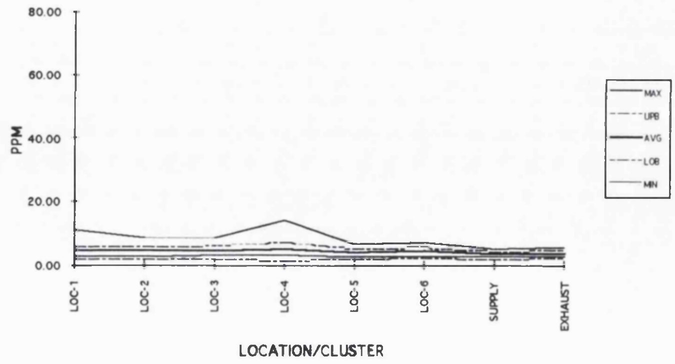


Figure A.1
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

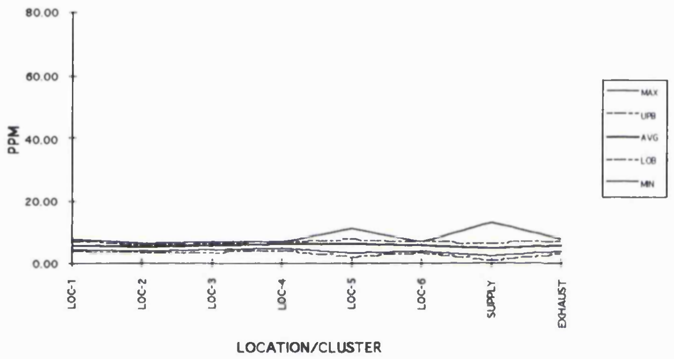


Figure A.2
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

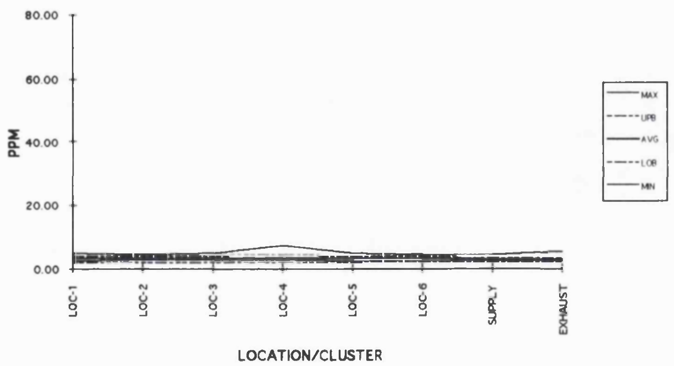


Figure A.3
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

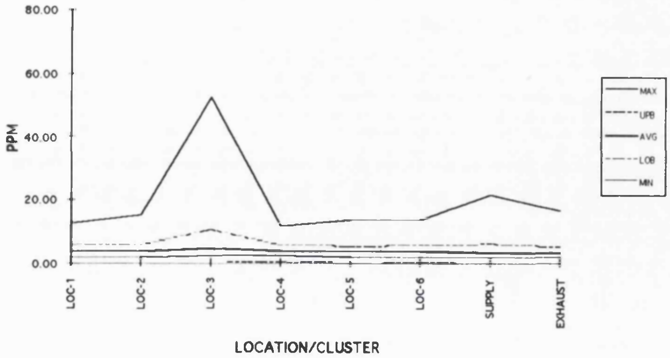


Figure A.4
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

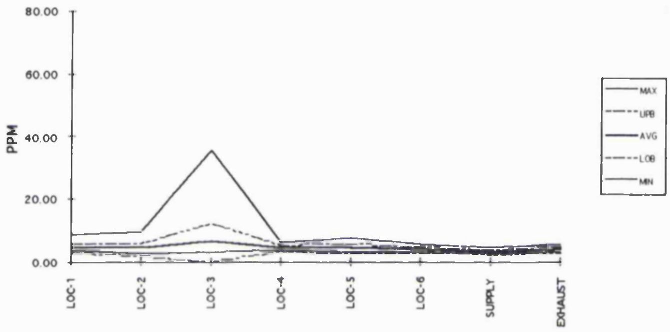


Figure A.5
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

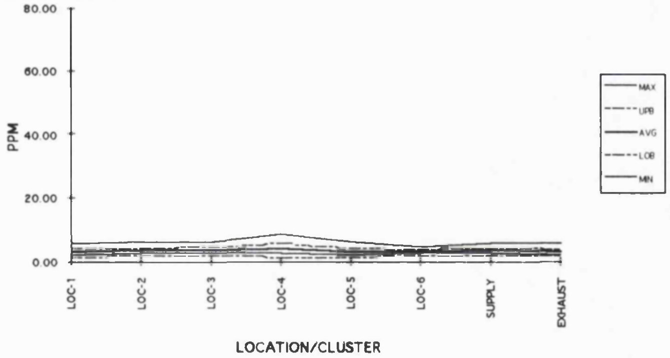


Figure A.6
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

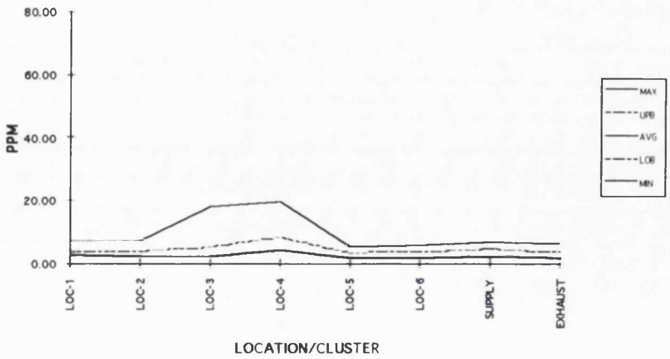


Figure A.7
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

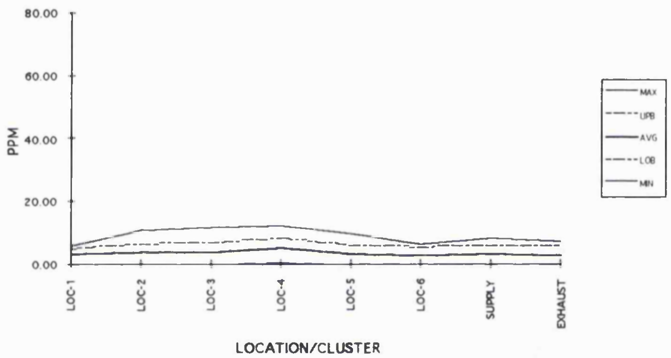


Figure A.8
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

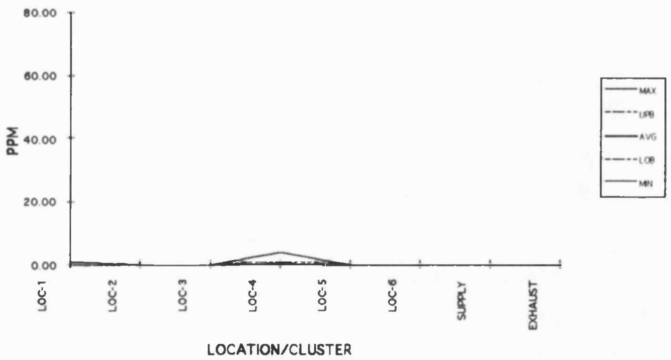


Figure A.9
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

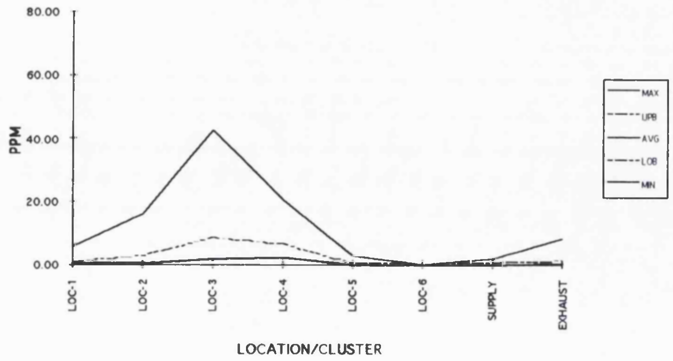


Figure A.10
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

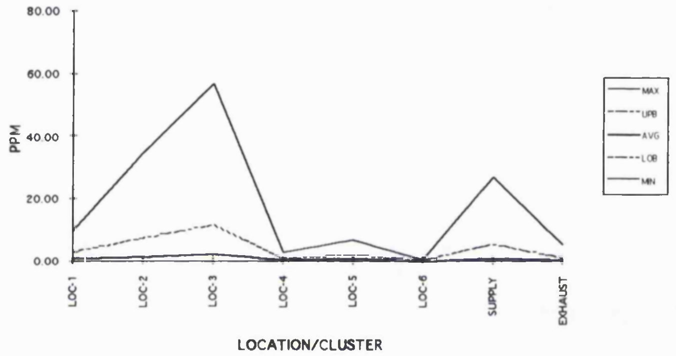


Figure A.11
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

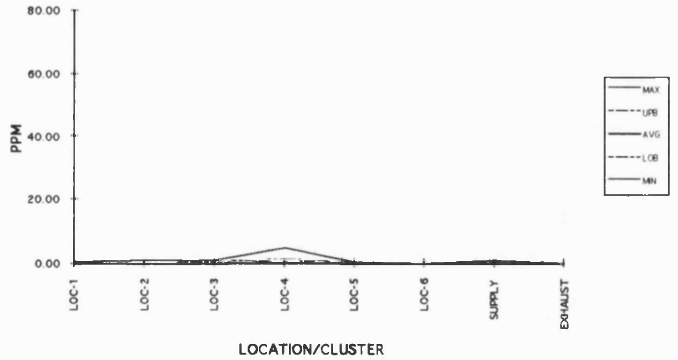


Figure A.12
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

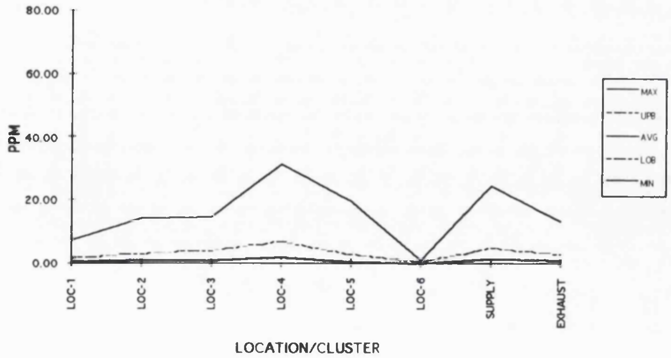


Figure A.13
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

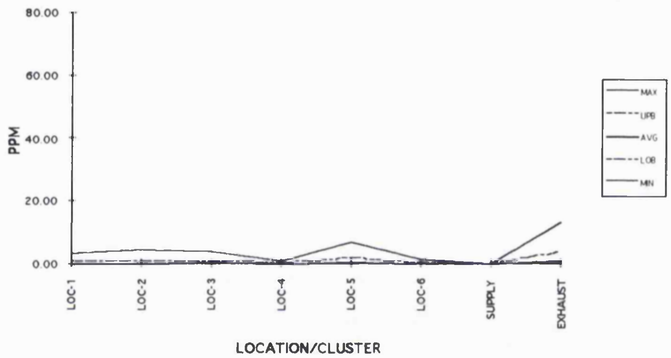


Figure A.14
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

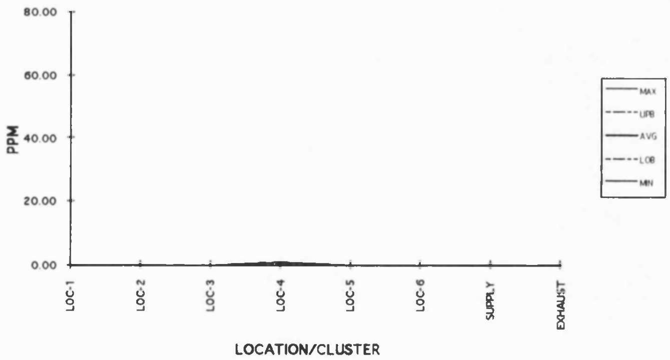


Figure A.15
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

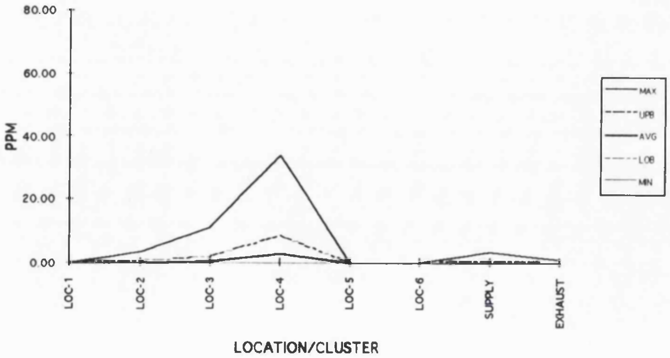


Figure A.16
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

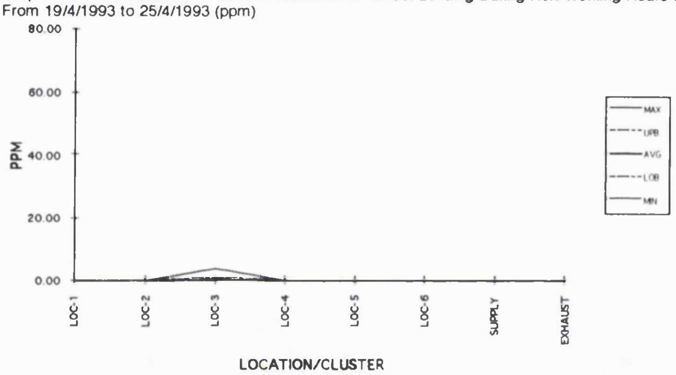


Figure A.17
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

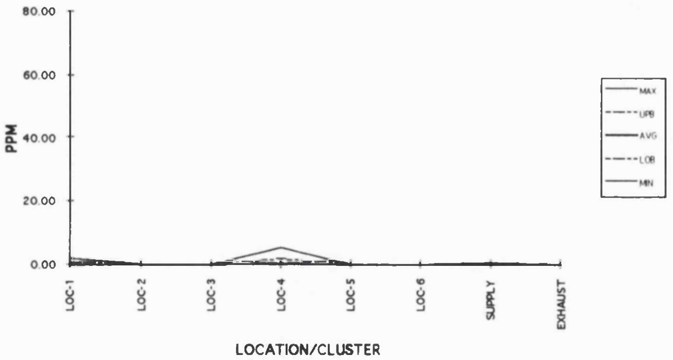


Figure A.18
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

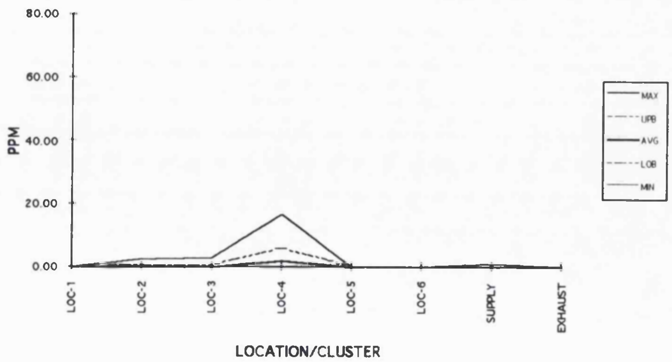


Figure A.19
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

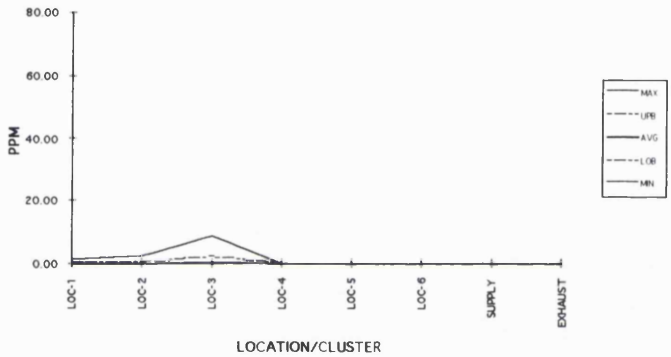


Figure A.20
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

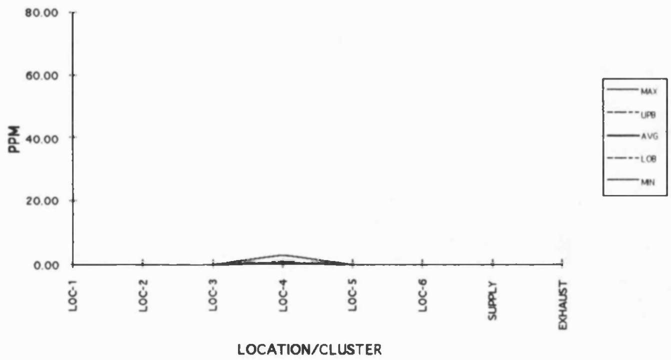


Figure A.21
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

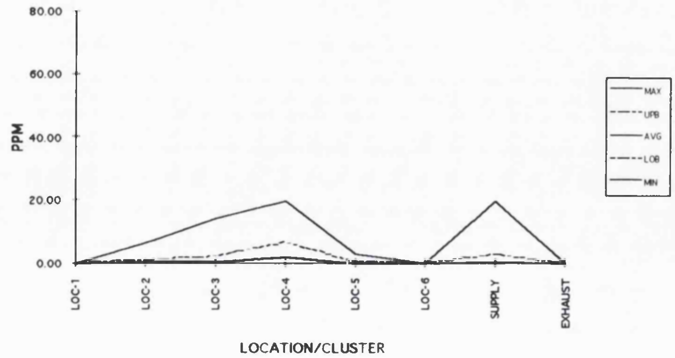


Figure A.22
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

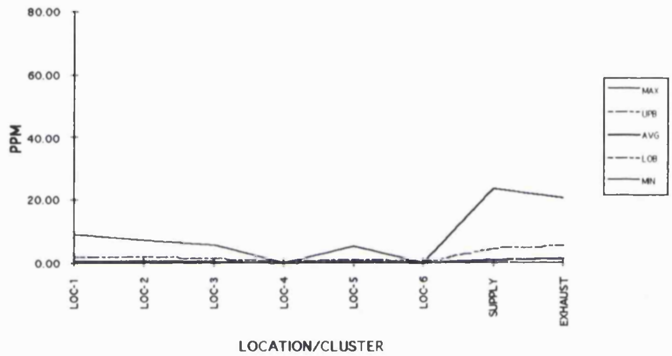


Figure A.23
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

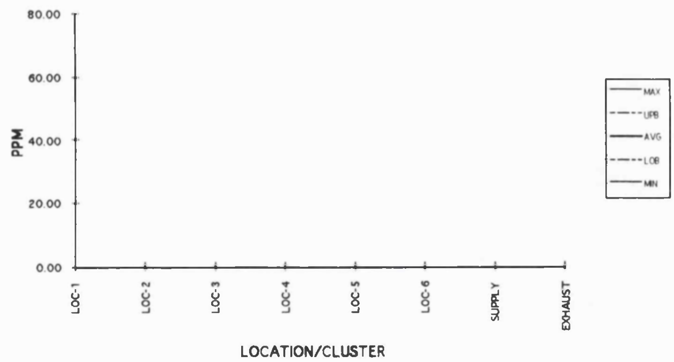


Figure A.24
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

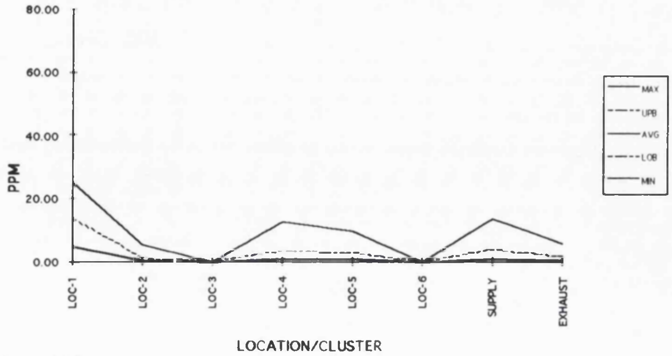


Figure A.25
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

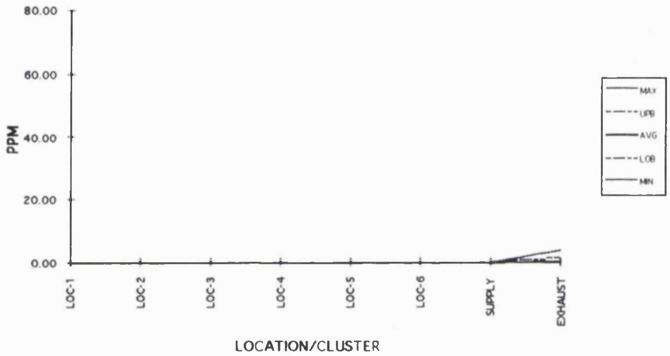


Figure A.26
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

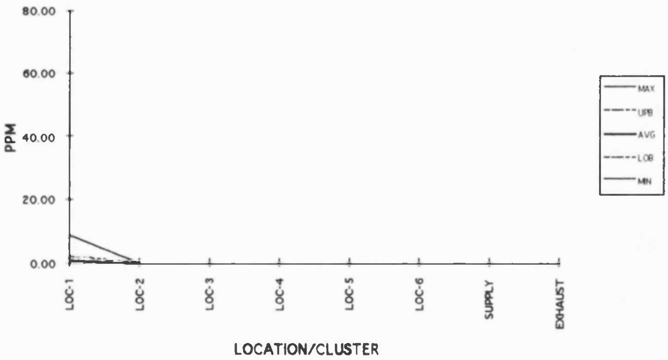


Figure A.27
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

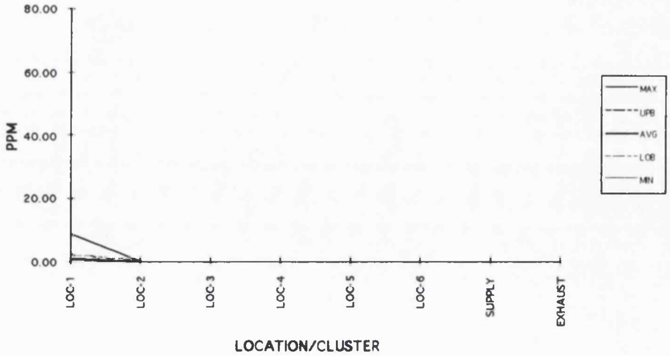


Figure A 28
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

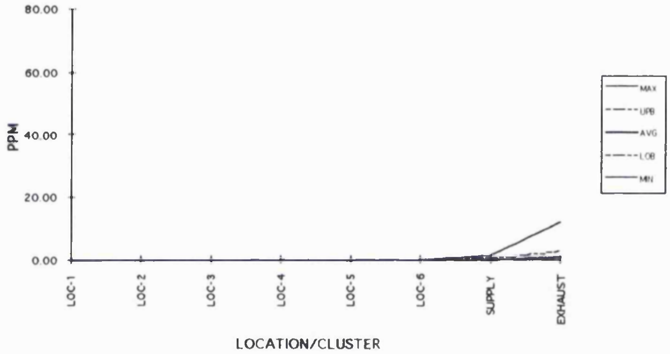


Figure A 29
Graph of TVOCs Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

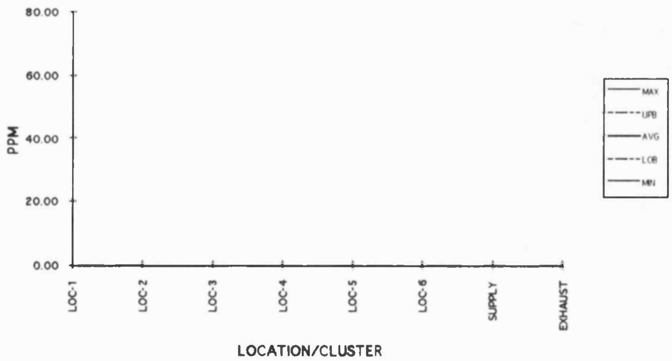


Figure A 30
Graph of TVOCs Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

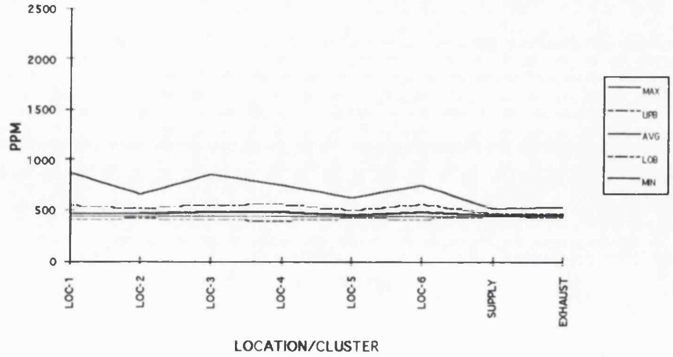


Figure B.1
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

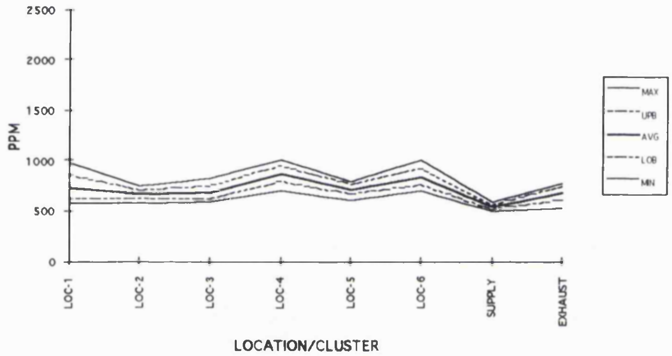


Figure B.2
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

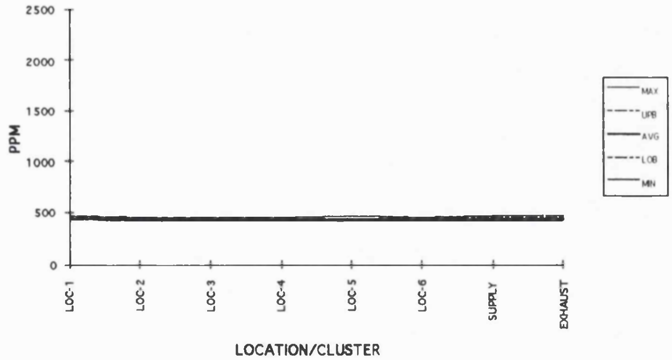


Figure B.3
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

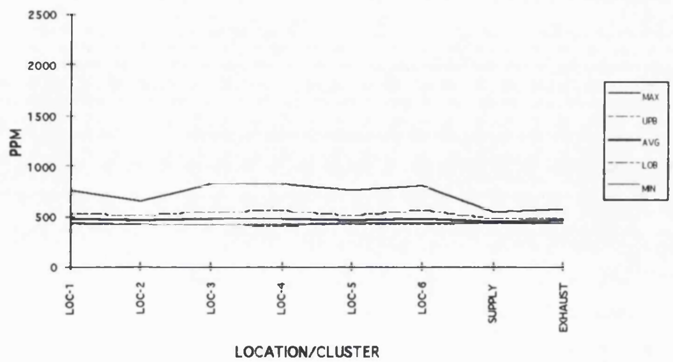


Figure B.4
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

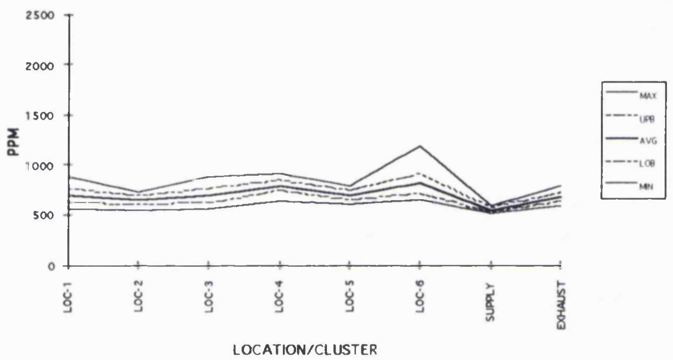


Figure B.5
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

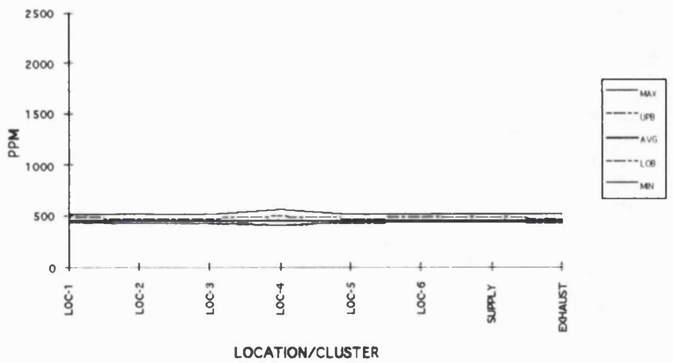


Figure B.6
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

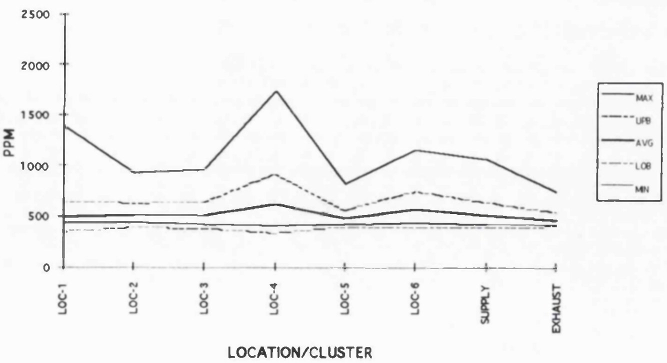


Figure B.7
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

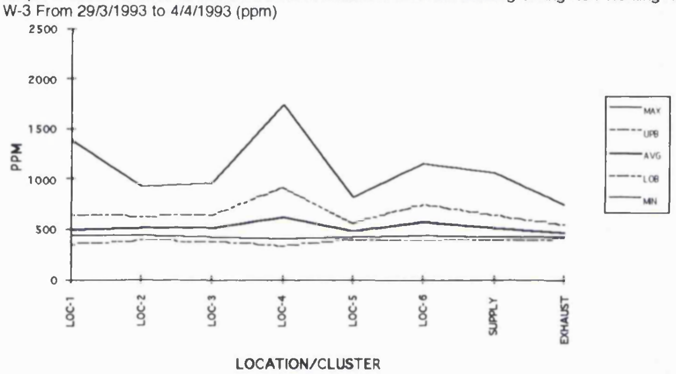


Figure B.8
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

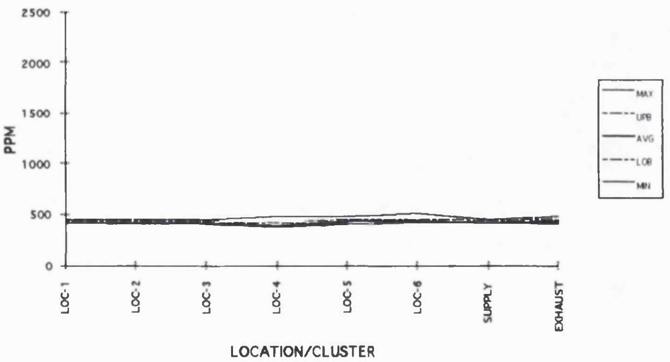


Figure B.9
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

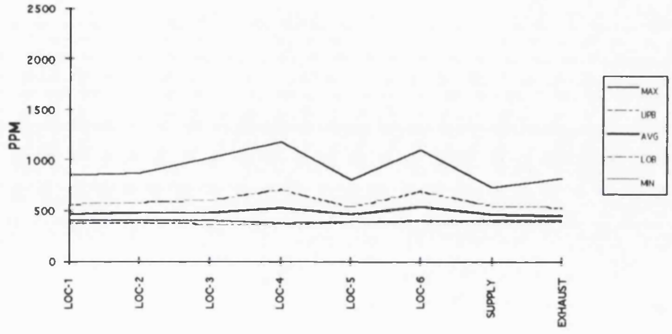


Figure B.10
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

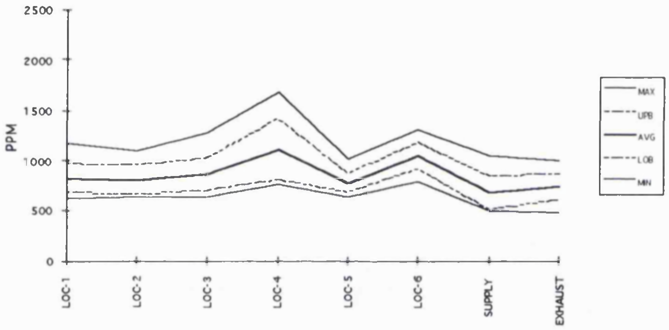


Figure B.11
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

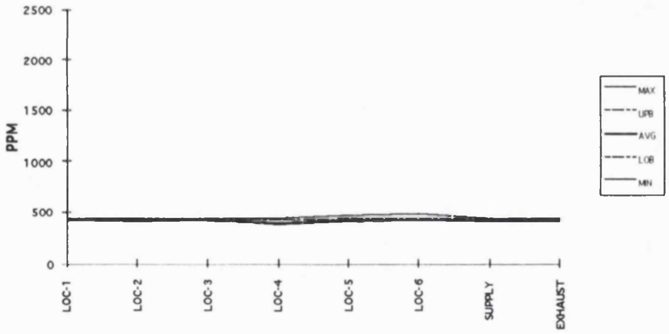


Figure B.12
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

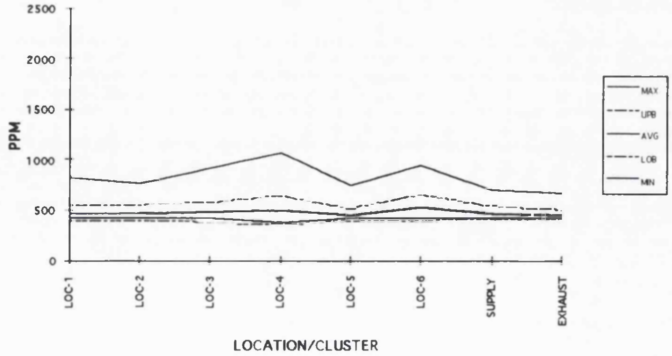


Figure B.13
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

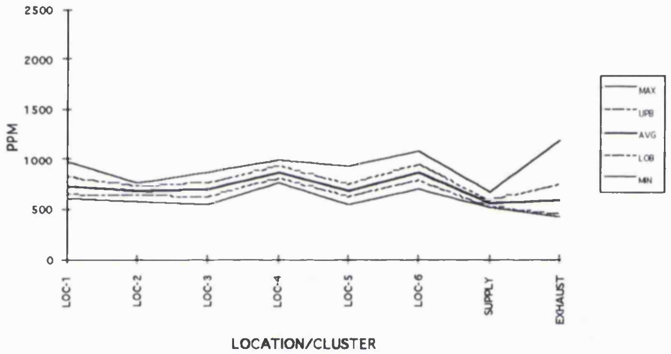


Figure B.14
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

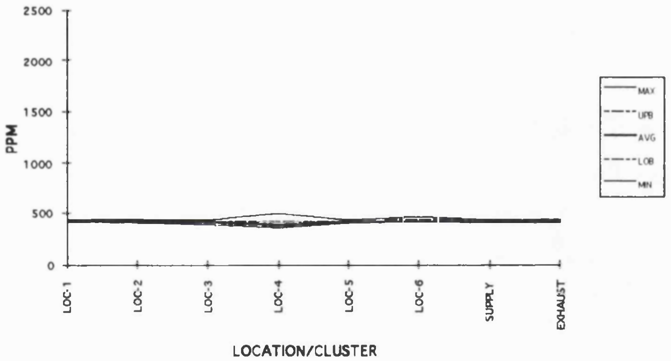


Figure B.15
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

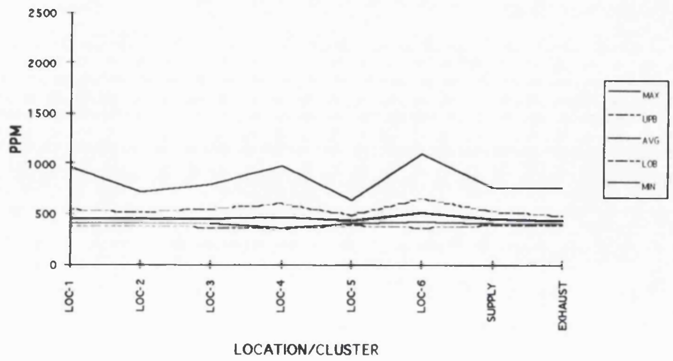


Figure B.16
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

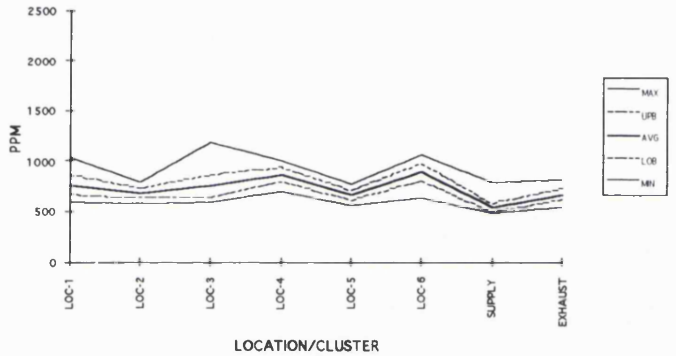


Figure B.17
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

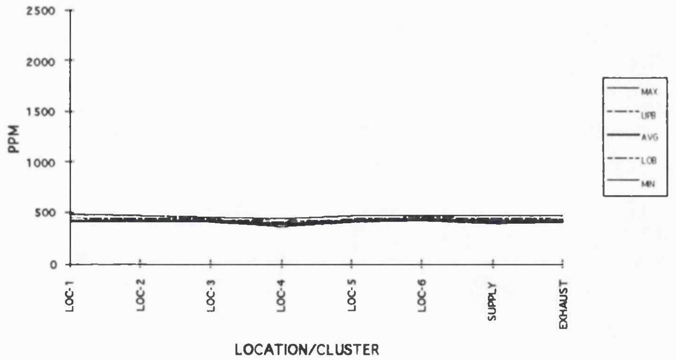


Figure B.18
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

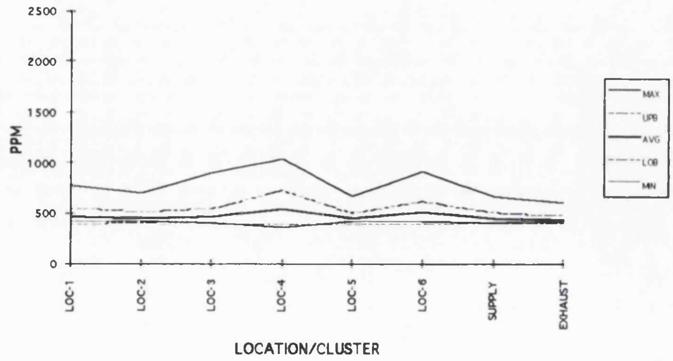


Figure B.19
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

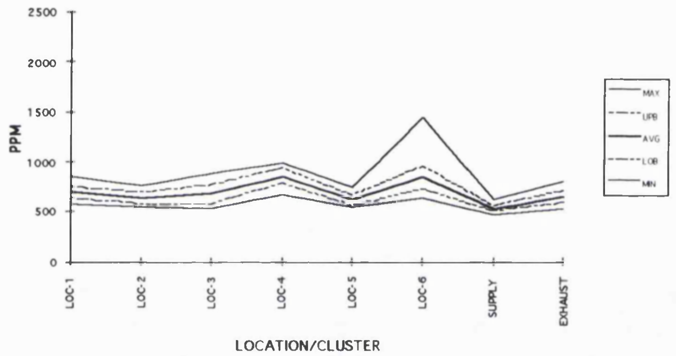


Figure B.20
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

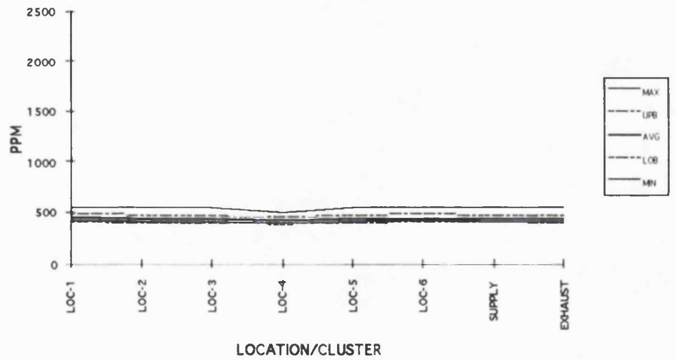


Figure B.21
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

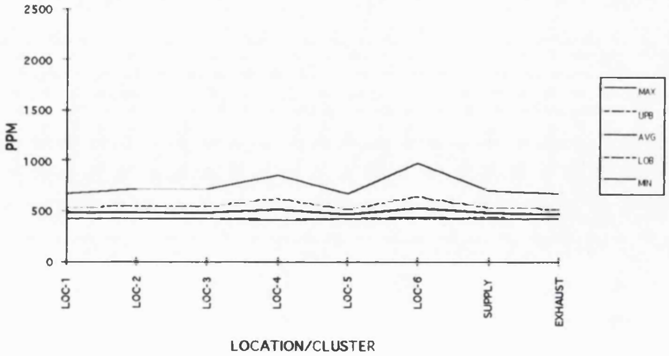


Figure B.22
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

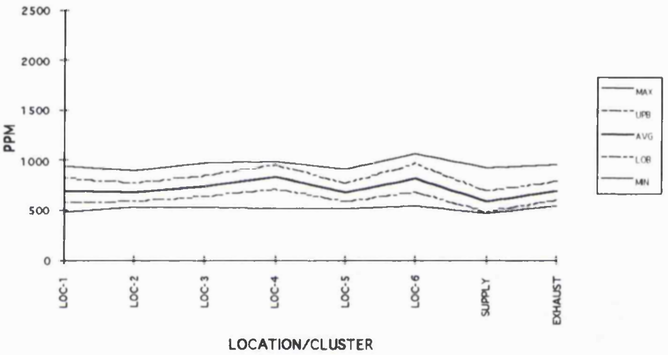


Figure B.23
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

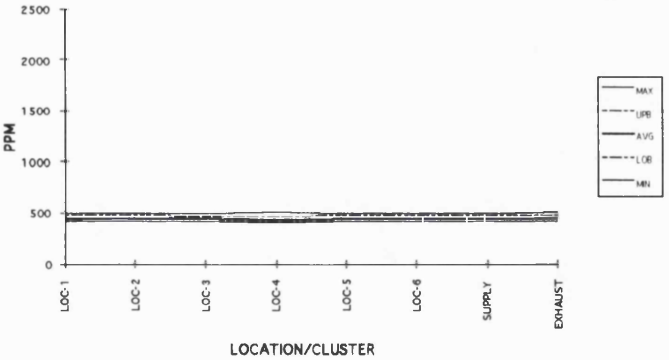


Figure B.24
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

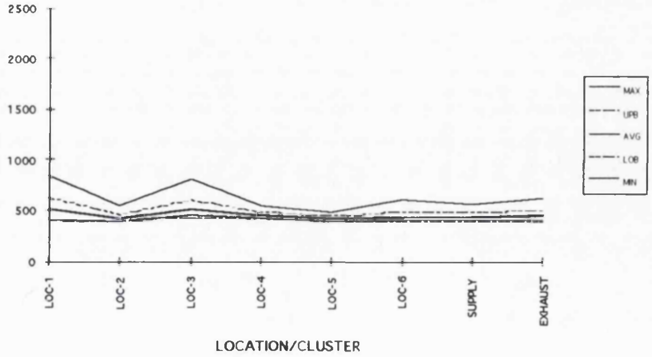


Figure B.25
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

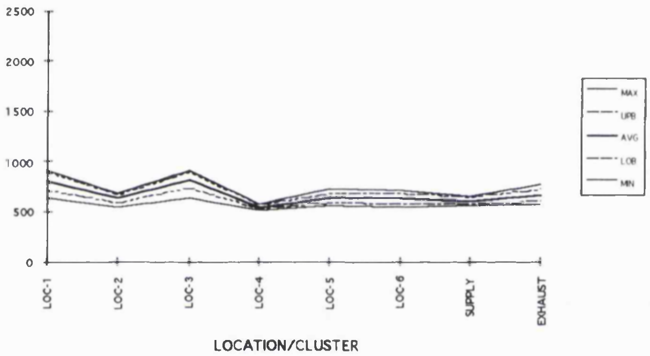


Figure B.26
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

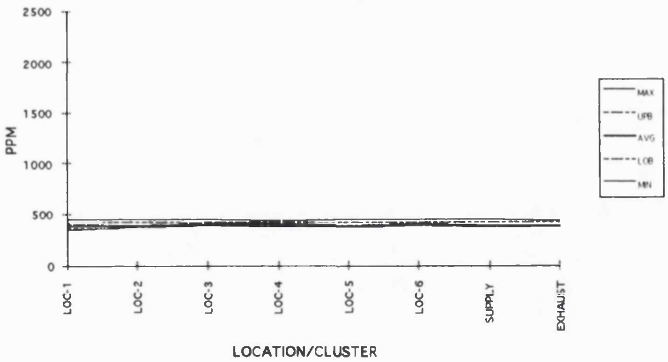


Figure B.27
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

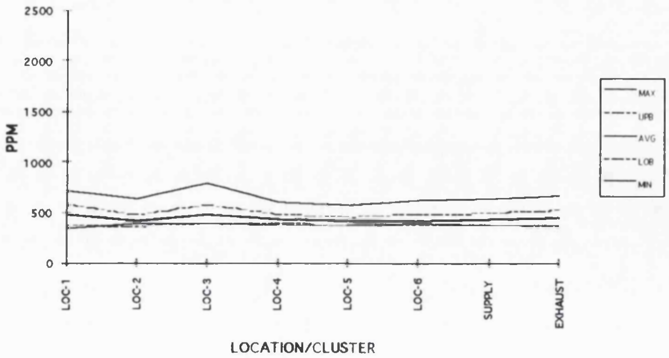


Figure B.28
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

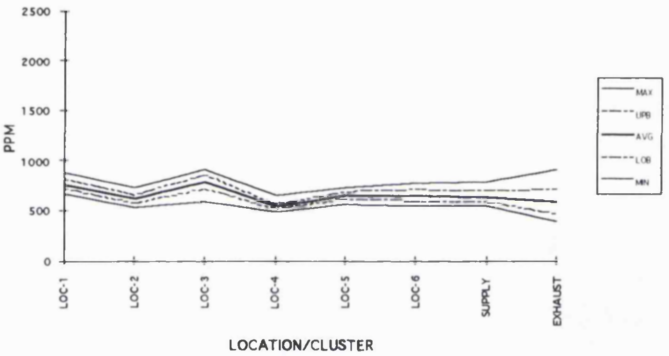


Figure B.29
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

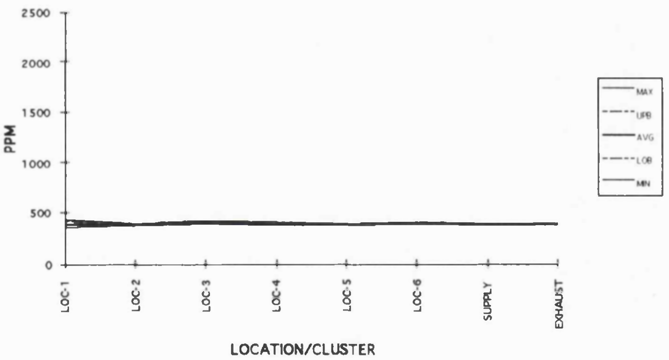


Figure B.30
Graph of Carbon Dioxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

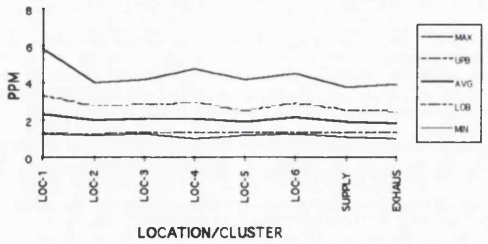


Figure C.1
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

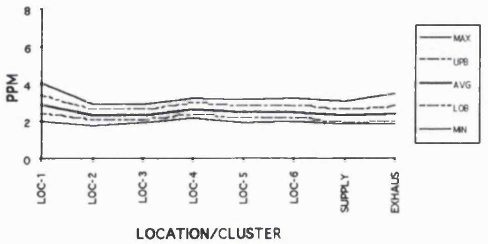


Figure C.2
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

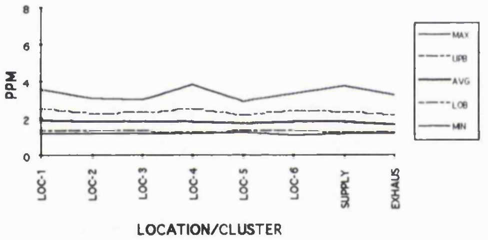


Figure C.3
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-1 From 15/3/1993 to 21/3/1993 (ppm)

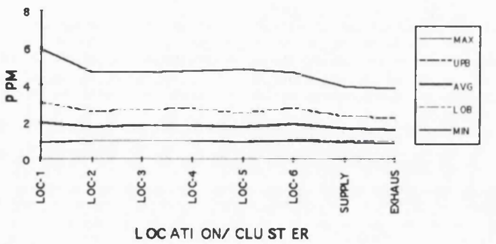


Figure C.4
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

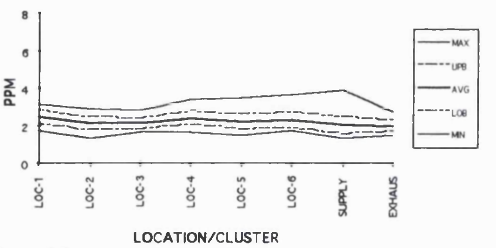


Figure C.5
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

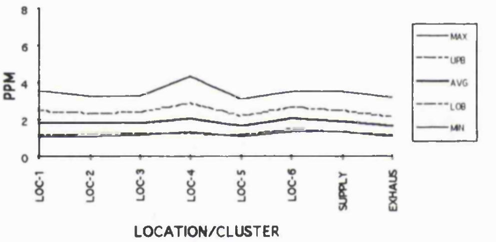


Figure C.6
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-2 From 22/3/1993 to 28/3/1993 (ppm)

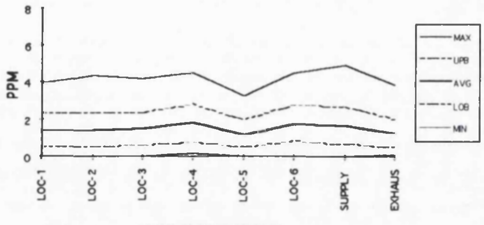


Figure C.7
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

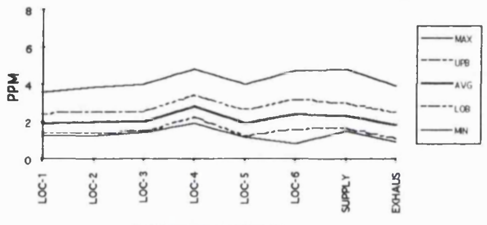


Figure C.8
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

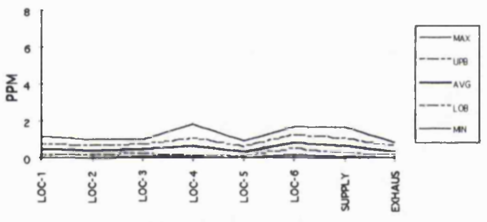


Figure C.9
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-3 From 29/3/1993 to 4/4/1993 (ppm)

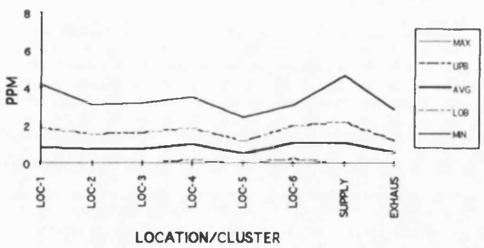


Figure C.10
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

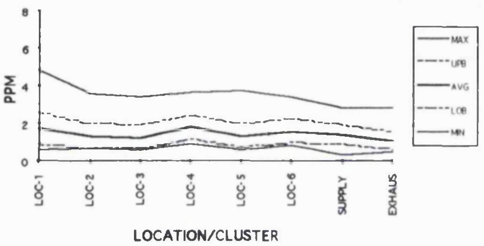


Figure C.11
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

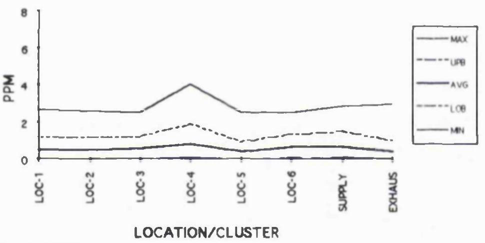


Figure C.12
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-4 From 5/4/1993 to 11/4/1993 (ppm)

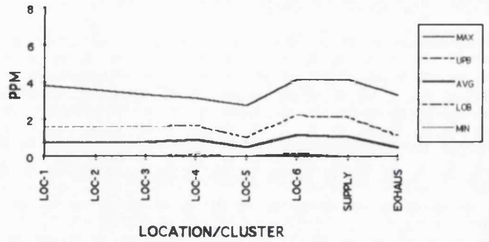


Figure C.13
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

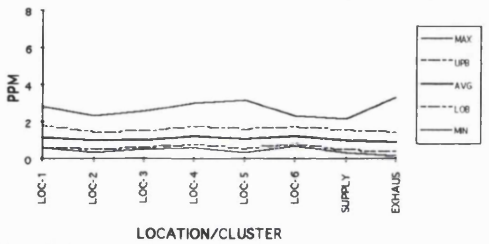


Figure C.14
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

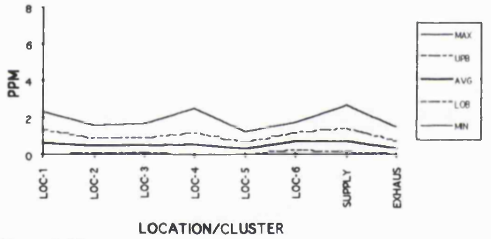


Figure C.15
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-5 From 12/4/1993 to 18/4/1993 (ppm)

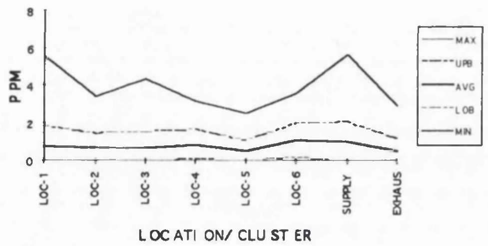


Figure C.16
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

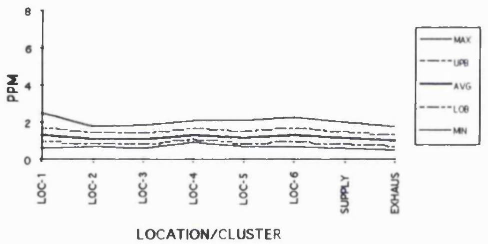


Figure C.17
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

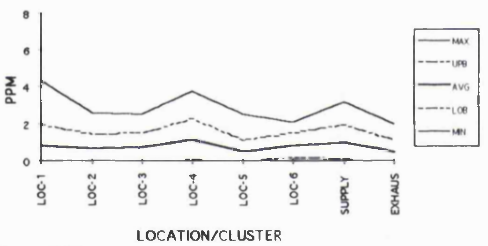


Figure C.18
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-6 From 19/4/1993 to 25/4/1993 (ppm)

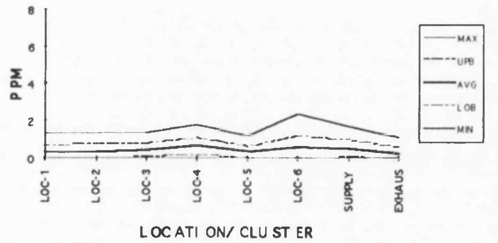


Figure C.19
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

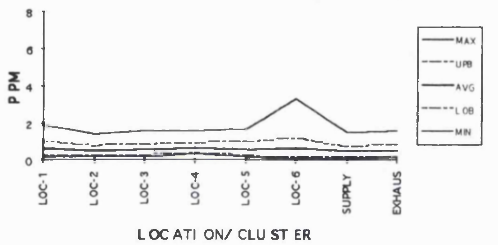


Figure C.20
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

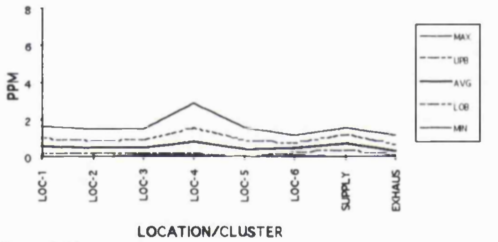


Figure C.21
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-7 From 26/4/1993 to 2/5/1993 (ppm)

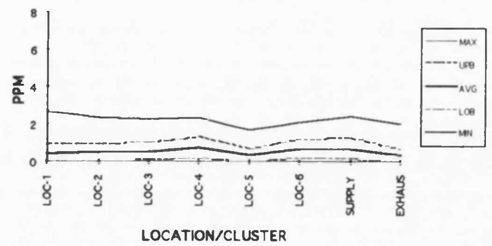


Figure C.22
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

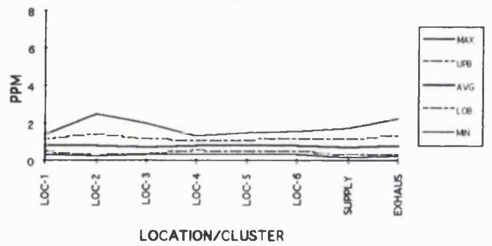


Figure C.23
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

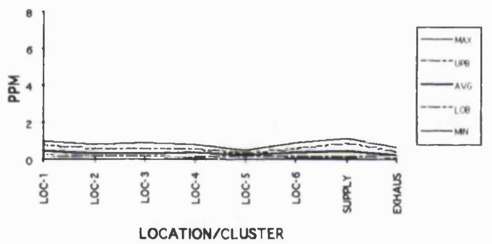


Figure C.24
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Winter Week W-8 From 3/5/1993 to 9/5/1993 (ppm)

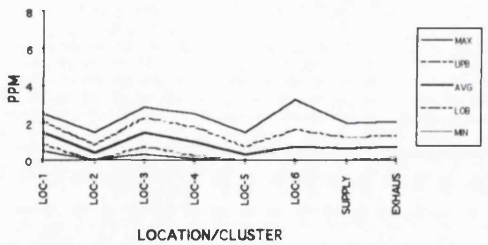


Figure C.25
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

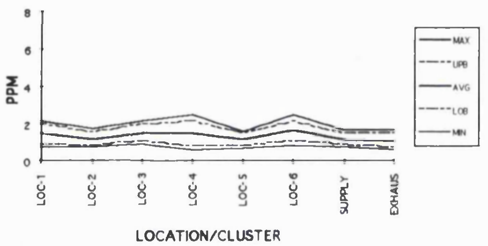


Figure C.26
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

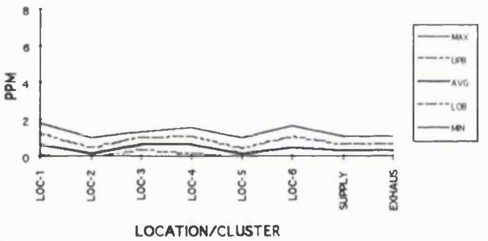


Figure C.27
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-1 From 12/7/1993 to 18/7/1993 (ppm)

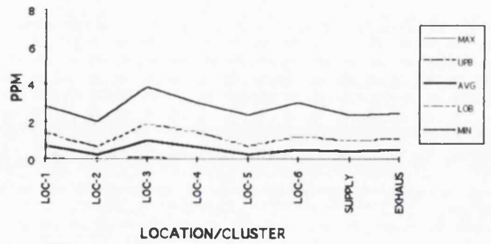


Figure C 28
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Hours of Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

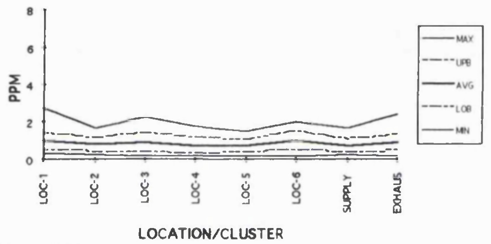


Figure C 29
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Working Hours Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

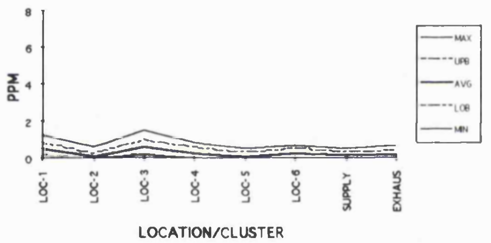


Figure C 30
Graph of Carbon Monoxide Measures in Several Locations at Kendal Building During Non-Working Days Taken in Summer Week S-2 From 19/7/1993 to 25/7/1993 (ppm)

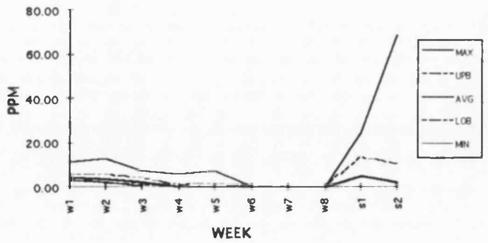


Figure D.1
Graph of TVOC Measures in Location LOC-1 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

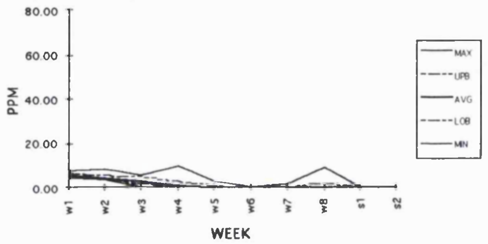


Figure D.2
Graph of TVOC Measures in Location LOC-1 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

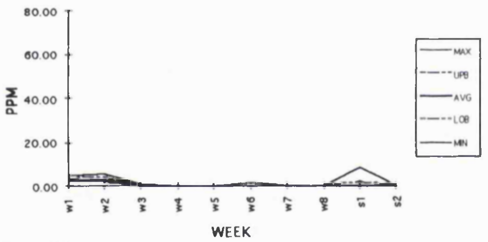


Figure D.3
Graph of TVOC Measures in Location LOC-1 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

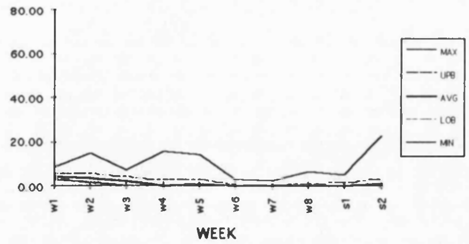


Figure D.4
Graph of TVOC Measures in Location LOC-2 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

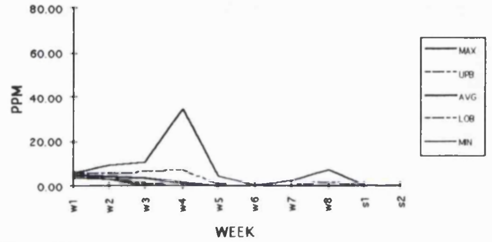


Figure D.5
Graph of TVOC Measures in Location LOC-2 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

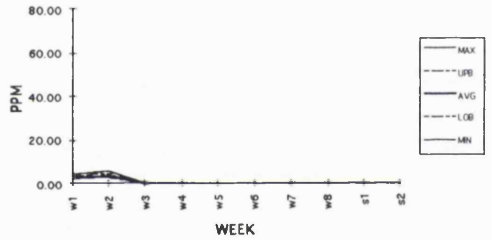


Figure D.6
Graph of TVOC Measures in Location LOC-2 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

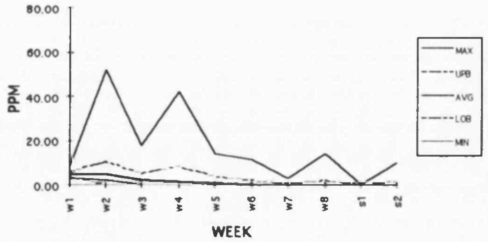


Figure D.7
Graph of TVOC Measures in Location LOC-3 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

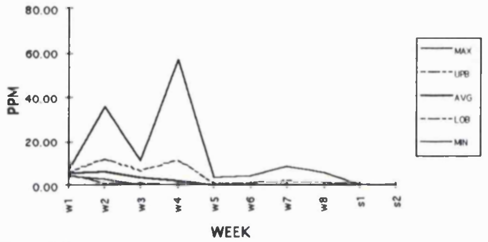


Figure D.8
Graph of TVOC Measures in Location LOC-3 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

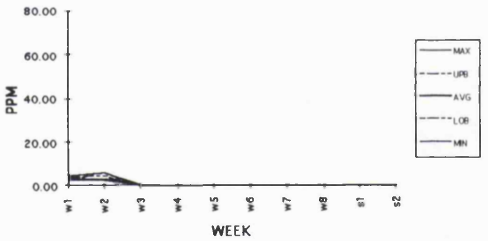


Figure D.9
Graph of TVOC Measures in Location LOC-3 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

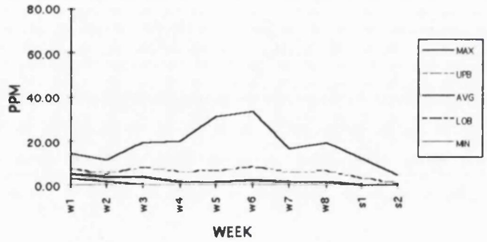


Figure D.10
Graph of TVOC Measures in Location LOC-4 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

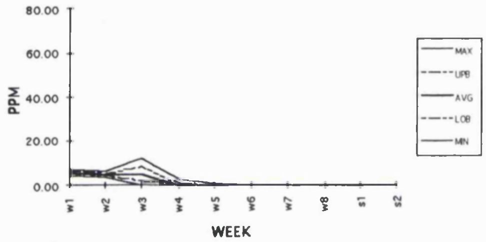


Figure D.11
Graph of TVOC Measures in Location LOC-4 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

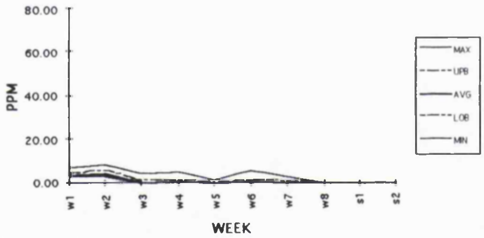


Figure D.12
Graph of TVOC Measures in Location LOC-4 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

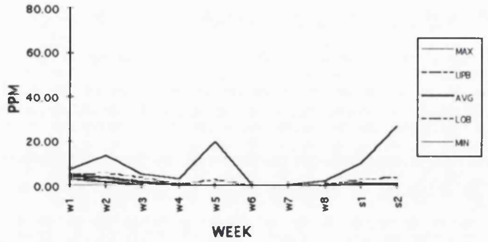


Figure D.13
Graph of TVOC Measures in Location LOC-5 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

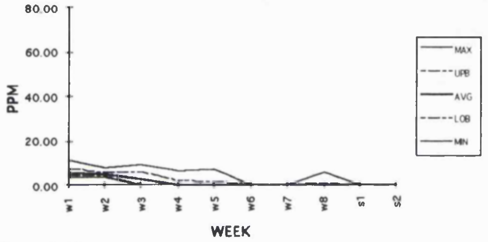


Figure D.14
Graph of TVOC Measures in Location LOC-5 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

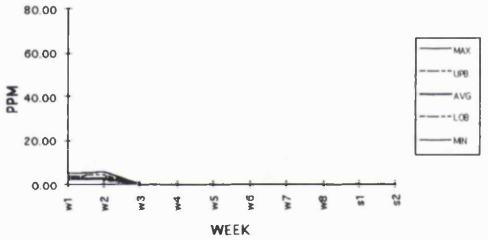


Figure D.15
Graph of TVOC Measures in Location LOC-5 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

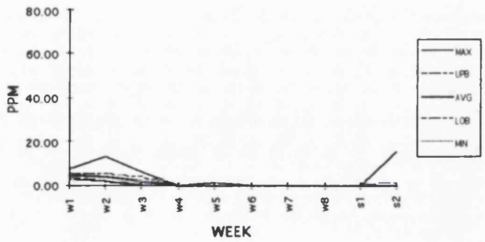


Figure D.16
Graph of TVOC Measures in Location LOC-6 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

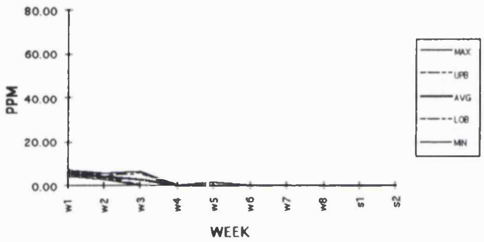


Figure D.17
Graph of TVOC Measures in Location LOC-6 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

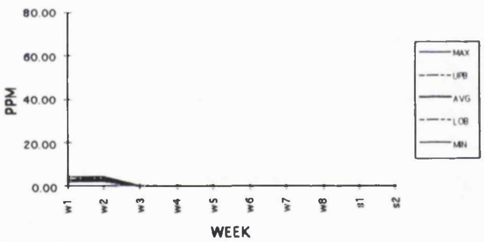


Figure D.18
Graph of TVOC Measures in Location LOC-6 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

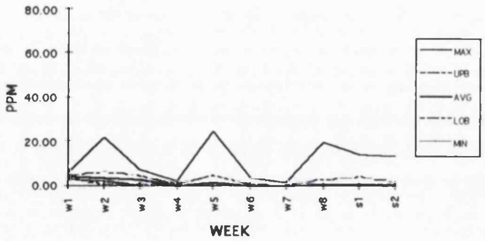


Figure D.19
Graph of TVOC Measures in Location LOC-7 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

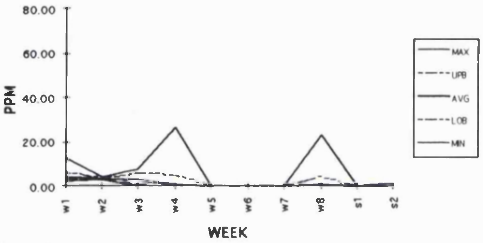


Figure D.20
Graph of TVOC Measures in Location LOC-7 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

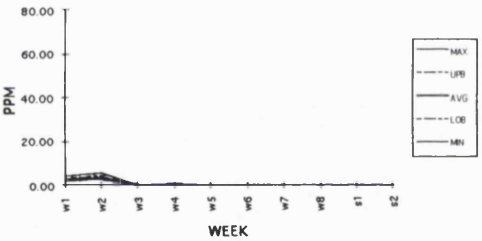


Figure D.21
Graph of TVOC Measures in Location LOC-7 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

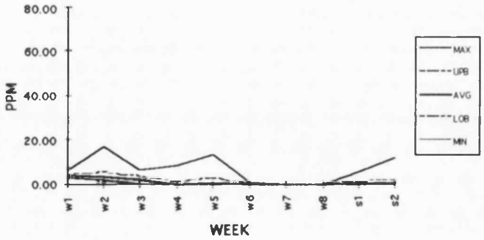


Figure D.22
Graph of TVOC Measures in Location LOC-8 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

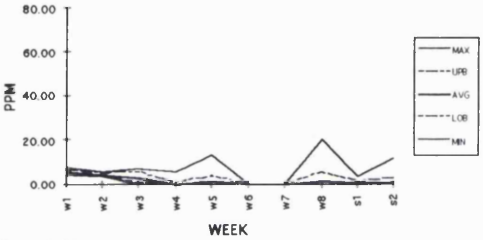


Figure D.23
Graph of TVOC Measures in Location LOC-8 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

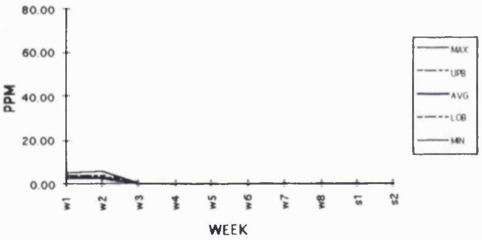


Figure D.24
Graph of TVOC Measures in Location LOC-8 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

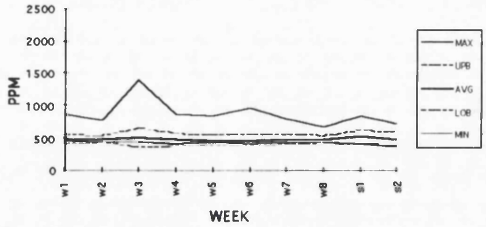


Figure E.1
Graph of Carbon Dioxide Measures in Location LOC-1 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

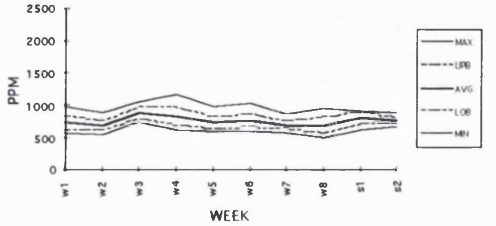


Figure E.2
Graph of Carbon Dioxide Measures in Location LOC-1 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

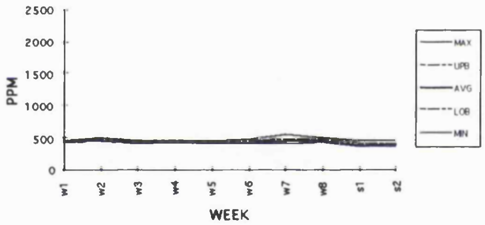


Figure E.3
Graph of Carbon Dioxide Measures in Location LOC-1 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

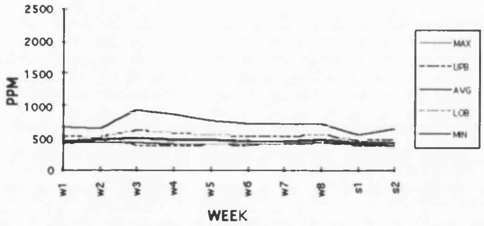


Figure E.4
Graph of Carbon Dioxide Measures in Location LOC-2 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

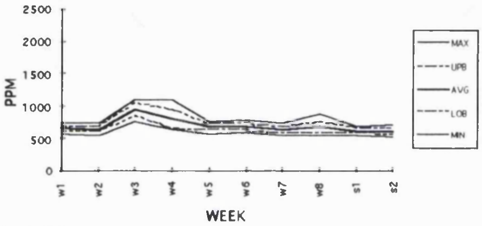


Figure E.5
Graph of Carbon Dioxide Measures in Location LOC-2 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

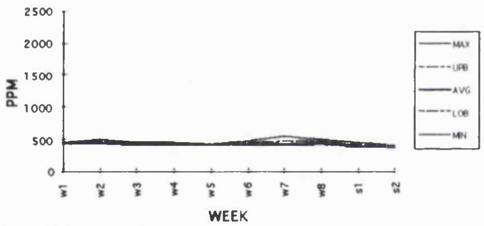


Figure E.6
Graph of Carbon Dioxide Measures in Location LOC-2 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

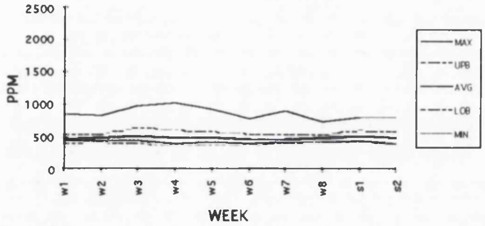


Figure E.7
Graph of Carbon Dioxide Measures in Location LOC-3 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

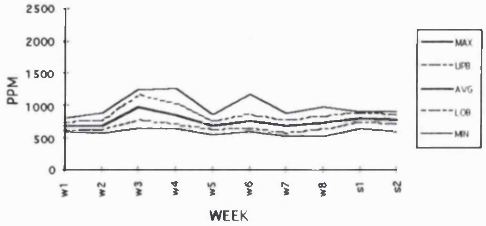


Figure E.8
Graph of Carbon Dioxide Measures in Location LOC-3 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

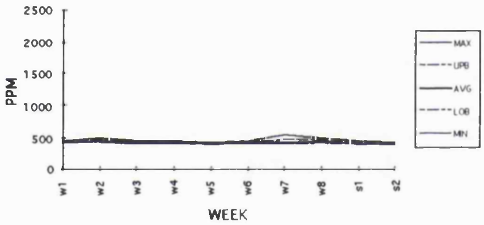


Figure E.9
Graph of Carbon Dioxide Measures in Location LOC-3 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

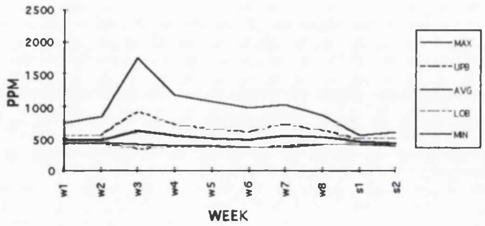


Figure E.10
Graph of Carbon Dioxide Measures in Location LOC-4 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

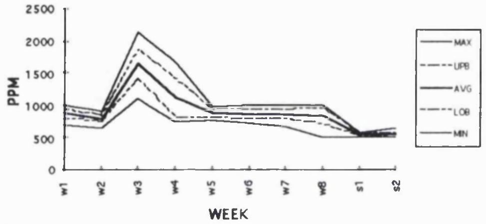


Figure E.11
Graph of Carbon Dioxide Measures in Location LOC-4 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

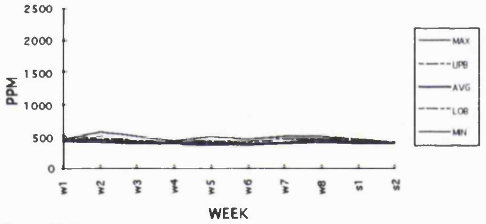


Figure E.12
Graph of Carbon Dioxide Measures in Location LOC-4 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

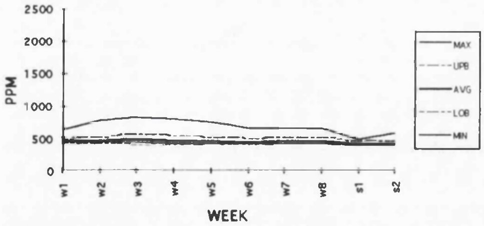


Figure E.13
Graph of Carbon Dioxide Measures in Location LOC-5 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

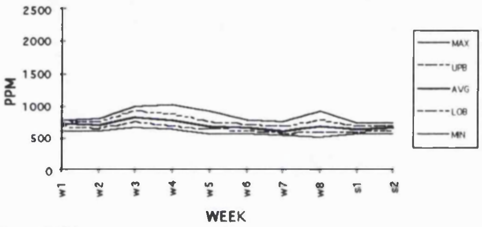


Figure E.14
Graph of Carbon Dioxide Measures in Location LOC-5 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

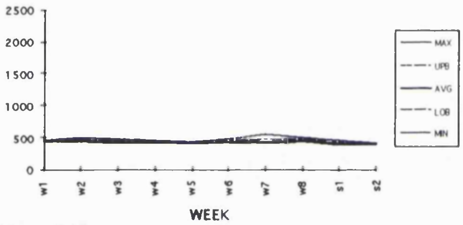


Figure E.15
Graph of Carbon Dioxide Measures in Location LOC-5 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

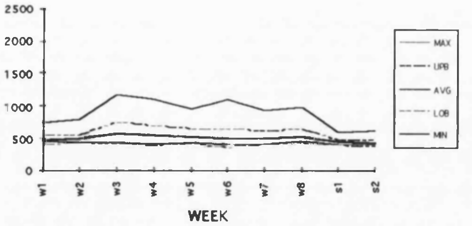


Figure E.16
Graph of Carbon Dioxide Measures in Location LOC-6 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

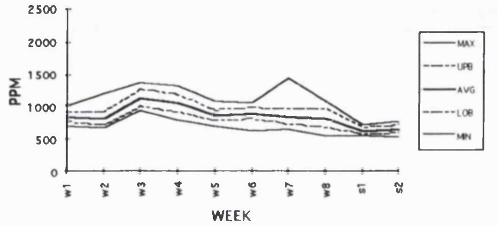


Figure E.17
Graph of Carbon Dioxide Measures in Location LOC-6 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

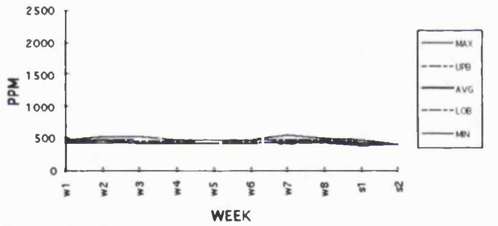


Figure E.18
Graph of Carbon Dioxide Measures in Location LOC-6 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

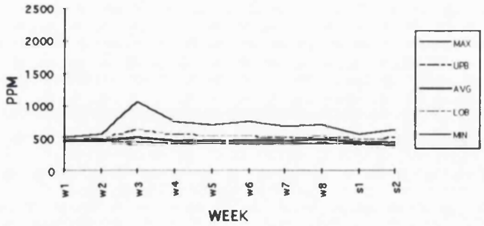


Figure E.19
Graph of Carbon Dioxide Measures in Location LOC-7 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

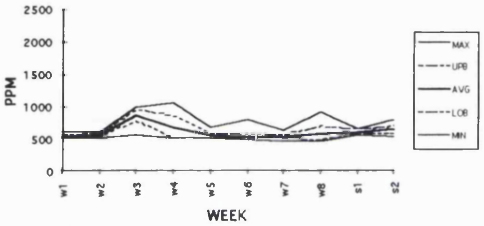


Figure E.20
Graph of Carbon Dioxide Measures in Location LOC-7 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

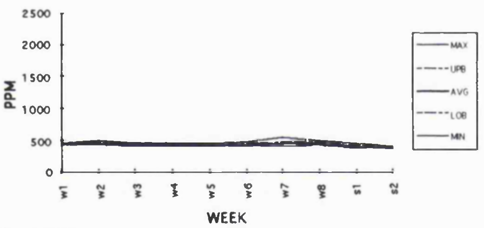


Figure E.21
Graph of Carbon Dioxide Measures in Location LOC-7 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

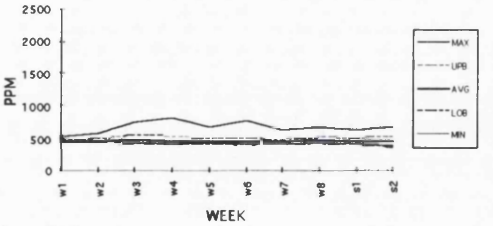


Figure E.22
Graph of Carbon Dioxide Measures in Location LOC-8 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

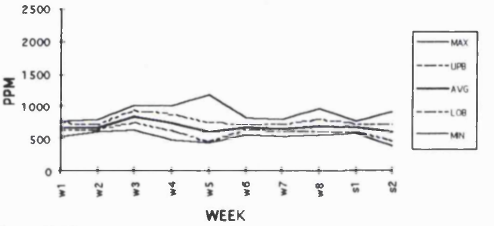


Figure E.23
Graph of Carbon Dioxide Measures in Location LOC-8 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer

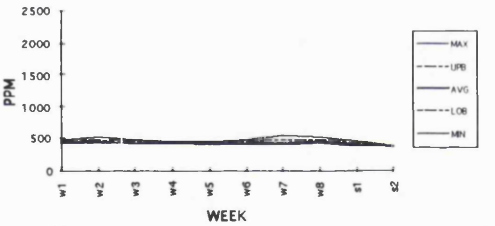
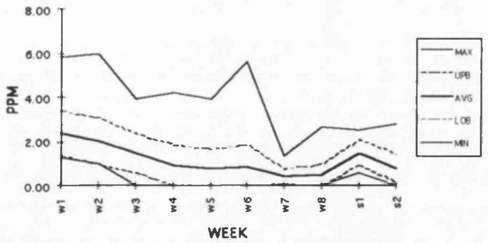
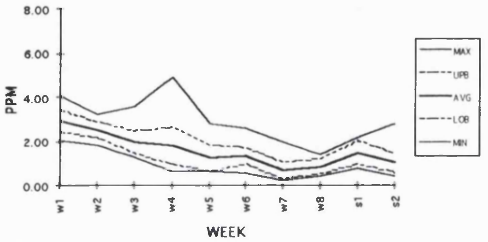


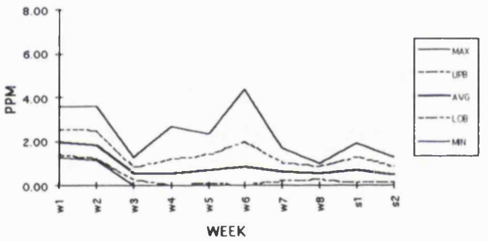
Figure E.24.
Graph of Carbon Dioxide Measures in Location LOC-8 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



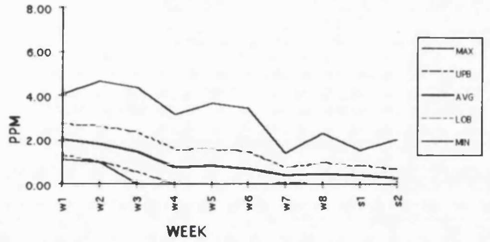
FigureF.1
Graph of Carbon Monoxide Measures in Location LOC-1 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



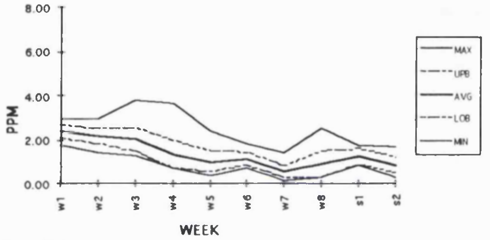
FigureF.2
Graph of Carbon Monoxide Measures in Location LOC-1 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



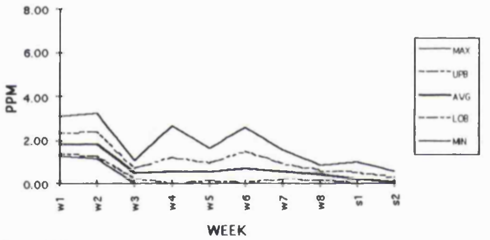
FigureF.3
Graph of Carbon Monoxide Measures in Location LOC-1 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



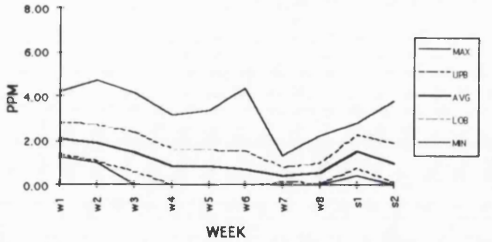
FigureF.4
Graph of Carbon Monoxide Measures in Location LOC-2 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



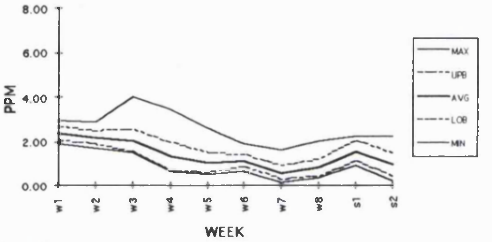
FigureF.5
Graph of Carbon Monoxide Measures in Location LOC-2 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



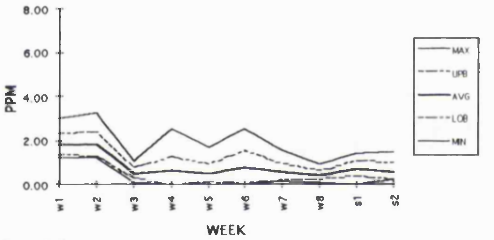
FigureF.6
Graph of Carbon Monoxide Measures in Location LOC-2 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



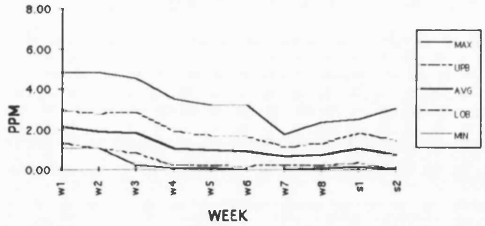
FigureF.7
Graph of Carbon Monoxide Measures in Location LOC-3 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



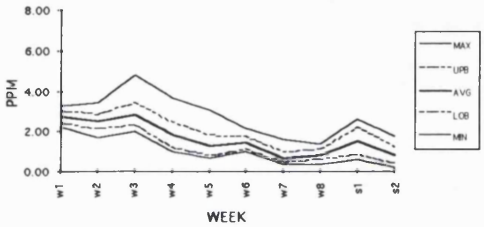
FigureF.8
Graph of Carbon Monoxide Measures in Location LOC-3 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



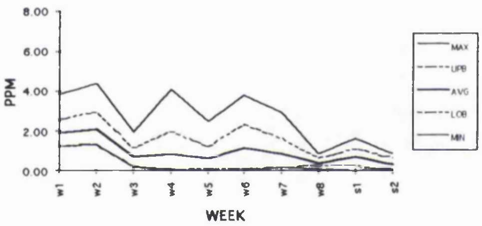
FigureF.9
Graph of Carbon Monoxide Measures in Location LOC-3 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



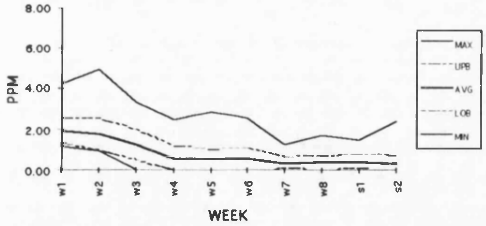
FigureF.10
Graph of Carbon Monoxide Measures in Location LOC-4 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



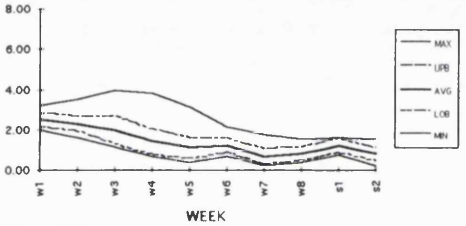
FigureF.11
Graph of Carbon Monoxide Measures in Location LOC-4 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



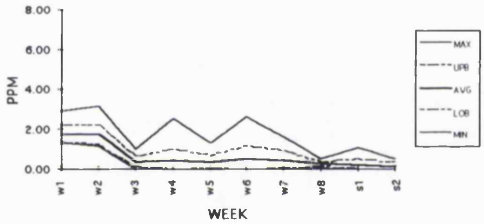
FigureF.12
Graph of Carbon Monoxide Measures in Location LOC-4 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



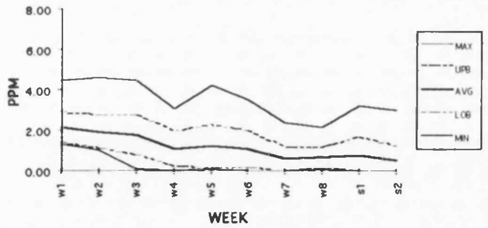
FigureF.13
Graph of Carbon Monoxide Measures in Location LOC-5 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



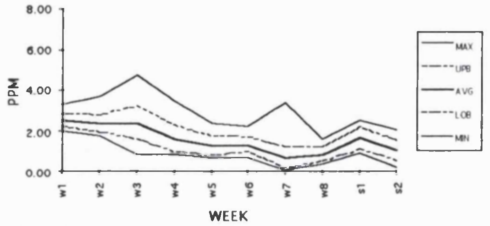
FigureF.14
Graph of Carbon Monoxide Measures in Location LOC-5 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



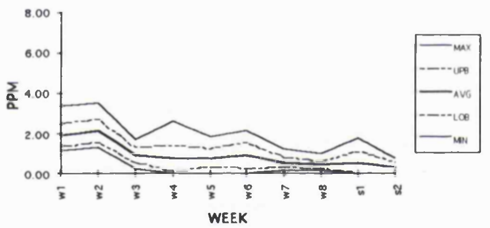
FigureF.15
Graph of Carbon Monoxide Measures in Location LOC-5 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



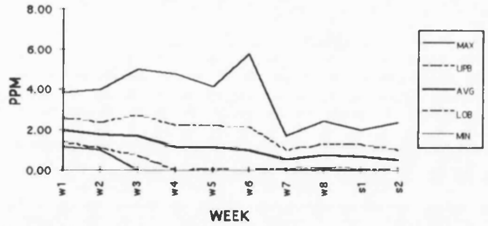
FigureF.16
Graph of Carbon Monoxide Measures in Location LOC-6 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



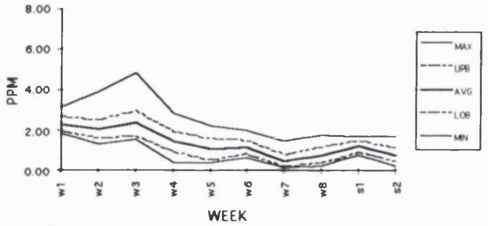
FigureF.17
Graph of Carbon Monoxide Measures in Location LOC-6 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



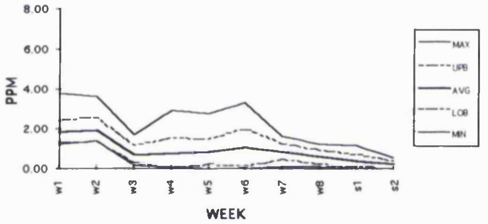
FigureF.18
Graph of Carbon Monoxide Measures in Location LOC-6 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



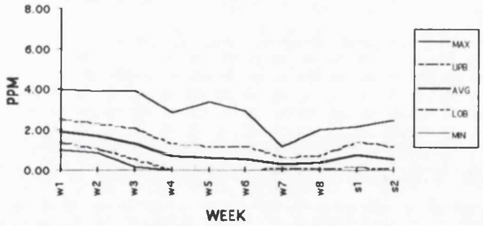
FigureF.19
Graph of Carbon Monoxide Measures in Location LOC-7 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



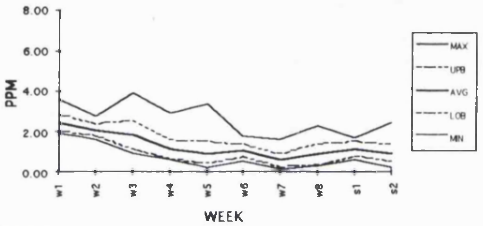
FigureF.20
Graph of Carbon Monoxide Measures in Location LOC-7 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



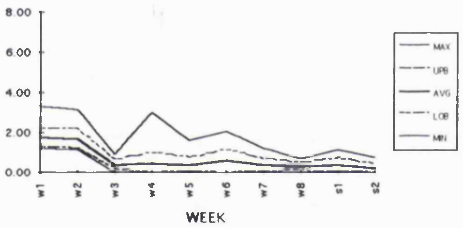
FigureF.21
Graph of Carbon Monoxide Measures in Location LOC-7 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



FigureF.22
Graph of Carbon Monoxide Measures in Location LOC-8 at Kendal Building During Non-Working Hours of Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer



FigureF.23
Graph of Carbon Monoxide Measures in Location LOC-8 at Kendal Building During Working Hours Taken Over 8 Weeks in Winter and 2 Weeks in Summer



FigureF.24
Graph of Carbon Monoxide Measures in Location LOC-8 at Kendal Building During Non-Working Days Taken Over 8 Weeks in Winter and 2 Weeks in Summer

HEALTHY OFFICE ENVIRONMENT STUDY

For The Science & Engineering Research Council and the DTI

94 Victoria Street, London

OCCUPANT'S QUESTIONNAIRE

March 1993

Introduction

Interest in people's health in offices has been growing over recent years as you may have noticed from articles in newspapers and magazines. This study was set up to understand better the factors affecting health and comfort in office environments and to derive some lessons that can be used in the design of future buildings.

As part of our investigations we are carrying out detailed research in a number of buildings, including the one you work in, and it would help us considerably if you would take the time to complete this questionnaire, which is intended to draw upon and make use of your experience as a building user. The wide ranging nature of the questions asked reflects current theory concerning the determinants of people's health at work.

All the answers that you provide will be treated in confidence and used only for the purposes of our research. They will be stored on a computer and their use is governed by the terms of the Data Protection Act 1984.

Your employers or their representative will not have access to the questionnaires but only to the general conclusions conveyed in technical reports on the environmental performance of the building. Individuals will not be identified in these reports.

In answering the questionsplease do so from your own point of view, without consultation with your colleagues. It is important that the answers you give represent your viewpoint rather than that of somebody else.

When you have completed the questionnaire please hold on to it for collection by ourselves tomorrow.

Nigel Vaughan — The Welsh School of Architecture, UWCC, Cardiff
Telephone: 0222 388348

Tadeusz Grajewski — The Bartlett School of Architecture, UCL, London
Telephone : 071 387 7050 x 5908

Please read this before you start

1. Please answer every question, or put a question mark against any that you can not answer.
2. Most questions refer to your WORKSPACE. This is the place where you spend most of your time at work. Typically this is where your desk is situated.
3. Most questions can be completed by ticking shaded areas in a table (see the examples below), or one box in a set of boxes.

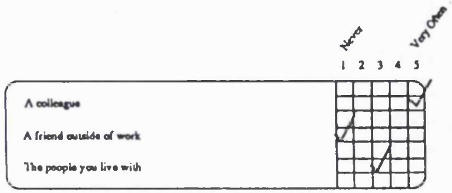
Example 1

Q. How good is the food in the canteen ?

A. If you thought the food was good but that there was room for improvement you might tick :-

Example 2

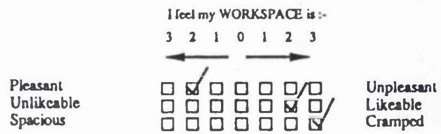
Q. How frequently have you commented to the following people about the building you work in ?



Example 3

Q. By ticking one of the seven boxes in between each word pair, please indicate the extent to which a particular word, in each pair, most describes your WORKSPACE.

A. If you find your workspace (see the instructions for what is meant by this term) reasonably "pleasant", fairly "likeable" but very "cramped" you might tick the boxes as shown :-



Q. Please answer the following questions about yourself :-

- *Name* ☐
- *Job title, band or grade* ☐
- *Which of the following terms most describe your work/job ?* Managerial ☐ Technical ☐ Clerical ☐ Administrative ☐ Professional / Executive ☐ Other ☐
- *Department* ☐
- *How long have you worked in this building ?* years ☐ months ☐
- *How many hours a week do you work in this building ?* hours ☐
- *How many hours a week do you work , including overtime?* hours ☐
- *When did you move to your current desk/workspace ?* Month, year ☐
- *Age* years ☐
- *Sex* male ☐ female ☐
- *Do you smoke ?* yes ☐ no ☐
- *Have you ever been diagnosed by a doctor as having an allergy ?* yes ☐ no ☐
- *How many days have you had off work due to illness in the past 12 months ?* days ☐
- *How often do you engage in the following activities ?*

	Daily	Weekly	Monthly	Less often	Never
Vigorous sports i.e. football, squash	☐	☐	☐	☐	☐
Less vigorous sports i.e. golf, sailing, walking	☐	☐	☐	☐	☐
Passive relaxation i.e. meditation, yoga	☐	☐	☐	☐	☐
Gardening, D.I.Y.	☐	☐	☐	☐	☐
Some other activity for relaxation. Please specify	☐	☐	☐	☐	☐

☐

- *Please describe your journey to work. (hours / miles)* Journey time ☐ Journey distance ☐

	Car	Bus	Train	Motorbike	Cycle	Walk
Method of travel	☐	☐	☐	☐	☐	☐

- *How long have you been in continuous full-time paid employment since last having a break of a year or more ?* years ☐

Q. "Please indicate whether you have experienced any of the following in the past 24 months

Death of a spouse	☐	Prosecuted for a violation of the law	☐
Death of a close family member	☐	Time off work due to a major illness	☐
Divorce	☐	Time off work due to a major injury	☐
Marital separation	☐	Got married	☐
Break-up of long standing relationship	☐	Trouble with a close relative	☐
Marital or partnership reconciliation	☐	Trouble with neighbours	☐
Close family member been very ill	☐	Changed jobs	☐
Big change in financial circumstances	☐	Took out a new mortgage or loan	☐
Pregnancy	☐	Big change in responsibilities at work	☐
A major problem at work	☐	Had a big change in living conditions	☐
Moved homes	☐	Gained a new family member	☐
Partner started or stopped work	☐	Studied for or sat exams	☐
Child left home	☐	Changed the type of work carried out	☐
Major change in eating habits	☐	Major problems with a colleague/boss	☐
Journey time to work increased greatly	☐	Threat of relocation	☐
Changed recreational activities	☐	Some other major incident or change please specify :-	☐
A violent criminal act i.e.mugging	☐		
Your car stolen	☐		
Your home burgled	☐		
Threat of redundancy	☐		

Q. How frequently is the air in your WORKSPACE :-

Air Quality	1 (Never)	2	3	4	5 (Always)
Stuffy					
Fresh					
Stale					
Smelly					
Draughty					
Satisfactory					
Humid					
Dry					

Q. Please tick just one of the terms to describe the odour in your WORKSPACE today :-

Odour Level Today	
No odour	☐
Slight odour	☐
Moderate odour	☐
Strong odour	☐
Very strong odour	☐
Overpowering odour	☐

Approximately how long is it since you last entered the building today ___

Hours _____ Minutes _____

Q. How often have you experienced the following in your WORKSPACE :-

- *For each question, if you ticked to the right of the dark line please answer the other question.*

- *What did you do about the situation ?*

	Never 1	2	3	4	Very Often 5	Asked the Facilities Dept. to do something	Did nothing but accepted the situation	Altered a control myself	Complained to somebody in authority	Complained to a colleague	Did some other action
Your feet being cold when your upper body is comfortable											
One side of your face being warmer or cooler than the other											
Draughts on a localised part of your body											
Stiff neck or shoulders											
Backache											
Overheating in summer											
Overheating in winter											
Underheating in summer											
Underheating in winter											
Difficulty in controlling temperatures											
Dry, stuffy, damp or smelly air											
Inadequate daylight											
Too much daylight											
Some other event or problem : please specify :-											

Q. By ticking one of the seven boxes in between each word pair, please indicate the extent to which a particular word, in each pair, most describes (A) your WORKSPACE and (B) YOURSELF at work.

A. I feel my WORKSPACE is :-

	3	2	1	0	1	2	3	
Pleasant	☐	☐	☐	☐	☐	☐	☐	Unpleasant
Unlikeable	☐	☐	☐	☐	☐	☐	☐	Likeable
Peaceful	☐	☐	☐	☐	☐	☐	☐	Not peaceful
Ugly	☐	☐	☐	☐	☐	☐	☐	Beautiful
Interesting	☐	☐	☐	☐	☐	☐	☐	Uninteresting
Sociable	☐	☐	☐	☐	☐	☐	☐	Unsociable
Hostile	☐	☐	☐	☐	☐	☐	☐	Friendly
Relaxing	☐	☐	☐	☐	☐	☐	☐	Stressful
Unsatisfying	☐	☐	☐	☐	☐	☐	☐	Satisfying
Inviting	☐	☐	☐	☐	☐	☐	☐	Uninviting
Emotionally cold	☐	☐	☐	☐	☐	☐	☐	Emotionally warm
Unusual	☐	☐	☐	☐	☐	☐	☐	Ordinary
Formal	☐	☐	☐	☐	☐	☐	☐	Home-like
Spacious	☐	☐	☐	☐	☐	☐	☐	Cramped
Public	☐	☐	☐	☐	☐	☐	☐	Private
Airless	☐	☐	☐	☐	☐	☐	☐	Airy
Functional	☐	☐	☐	☐	☐	☐	☐	Non-functional
Dim	☐	☐	☐	☐	☐	☐	☐	Light
Cheerful	☐	☐	☐	☐	☐	☐	☐	Sombre
Subduing	☐	☐	☐	☐	☐	☐	☐	Stimulating
Visually warm	☐	☐	☐	☐	☐	☐	☐	Visually cool
Non-glaring	☐	☐	☐	☐	☐	☐	☐	Glaring
Colourful	☐	☐	☐	☐	☐	☐	☐	Colourless
Noisy	☐	☐	☐	☐	☐	☐	☐	Quiet
Hot	☐	☐	☐	☐	☐	☐	☐	Cold
Clean	☐	☐	☐	☐	☐	☐	☐	Dirty
Uncluttered	☐	☐	☐	☐	☐	☐	☐	Cluttered
Natural	☐	☐	☐	☐	☐	☐	☐	Un-natural

B. At work I (am) ...... :-

	3	2	1	0	1	2	3	
Sociable	☐	☐	☐	☐	☐	☐	☐	Keep to myself
Unhappy	☐	☐	☐	☐	☐	☐	☐	Happy
Tense	☐	☐	☐	☐	☐	☐	☐	Relaxed
Mainly sat down	☐	☐	☐	☐	☐	☐	☐	Mainly stood up
On the phone a lot	☐	☐	☐	☐	☐	☐	☐	On the phone very little
Talk a lot	☐	☐	☐	☐	☐	☐	☐	Talk very little
Do computer work	☐	☐	☐	☐	☐	☐	☐	Do no computer work
On my own	☐	☐	☐	☐	☐	☐	☐	Part of a team

Q. By scoring out of 5, please rate your satisfaction with your WORKSPACE on the items listed below :-

	1 (Very Dissatisfied)	2	3	4	5 (Very Satisfied)
Its thermal comfort in winter					
Its thermal comfort in summer					
The ease with which temperatures can be varied					
The amount of daylight entering in winter					
The amount of daylight entering in summer					
The electric lighting					
The ease with which you can control the electric lighting					
Its visual appearance inside					
Its privacy					
Its suitability for the work you do					
Its layout and design					
Its character and 'atmosphere'					
The level of background noise					
The feeling of contact with the external physical environment					
The extent of the view through windows					
Its spaciousness					
Its decoration					
The quality of the air					
The design and layout of the computer workstation you use (if any)					
The degree that the workspace is enclosed					
The ease with which you can communicate					
The layout of the building					
The WORKSPACE overall					
The BUILDING overall					

Q. To what extent do you agree or disagree with the following statements :-

	1 (Strongly Agree)	2	3	4	5 (Strongly disagree)
My work is of value and worth doing					
I largely control and organise my own work					
My work is challenging and stimulating					
My work is innovative and creative					
My work is very predictable					
My work involves a lot of contact with other people and is very sociable					
I feel very fulfilled by the work that I do					
My work is made up of mainly repetitive tasks					
I am very satisfied with my job					
My job involves me in having a lot of responsibility					
My workload is so great that I frequently have to work overtime or at home					
I feel I belong in this organisation and would be very sorry to leave it					
I am valued by my colleagues					
I am valued by my immediate boss					
I am valued by the organisation that I work for					
The work I do makes me bored and leaves me feeling sleepy					
My job is reasonably secure for at least the next year or so					
My work situation is relatively stable and has not involved a lot of change					
I am working as efficiently as I can					
My department could be organised to work more efficiently than it does					
I am given all the information I need to do my job effectively					
My work is self-contained and independent of other groups in the building					
My working environment is lively and stimulating					
My work makes me frustrated and irritable					
My work leaves me exhausted					

Q. For each of the opposing statements below, please tick one of the numbered boxes to best reflect the way you are in your everyday life.

Example *If you are generally on time for appointments, you would tick a numbered box between 7 and 11 on the first question. If you are usually casual about appointments, you would tick one of the lower numbers between 1 and 5.*

Casual about appointments	1 2 3 4 5 6 7 8 9 10 11	Never late
Not competitive	1 2 3 4 5 6 7 8 9 10 11	Very competitive
Good listener	1 2 3 4 5 6 7 8 9 10 11	Anticipates what others are going to say (nods, attempts to finish for them).
Never feel rushed (even under pressure)	1 2 3 4 5 6 7 8 9 10 11	Always rushed
Can wait patiently	1 2 3 4 5 6 7 8 9 10 11	Impatient while waiting
Takes things one at a time	1 2 3 4 5 6 7 8 9 10 11	Tries to do many things at once, whilst thinking what to do next
Slow, deliberate talker	1 2 3 4 5 6 7 8 9 10 11	Emphatic in speech, fast and forceful
Cares about satisfying themselves no matter what others may think	1 2 3 4 5 6 7 8 9 10 11	Wants a good job to be recognised by others
Slow doing things	1 2 3 4 5 6 7 8 9 10 11	Fast (in things like eating and walking)
Easy going	1 2 3 4 5 6 7 8 9 10 11	Hard driving (pushes themselves and others)
Expresses feelings	1 2 3 4 5 6 7 8 9 10 11	Hides feelings
Many outside interests	1 2 3 4 5 6 7 8 9 10 11	Few interests outside work and home
Unambitious	1 2 3 4 5 6 7 8 9 10 11	Ambitious
Casual	1 2 3 4 5 6 7 8 9 10 11	Eager to get things done

Q. To what extent do you agree or disagree with the following statements :-

	Strongly Agree 1	2	3	4	Strongly disagree 5
I frequently wake-up during the night or prematurely in the morning					
I find it easy to go to sleep at night					
I find it easy to say "no" when asked to do work that is not strictly mine					
In the evening I find it hard to stop thinking about the day's events					
Relaxation after work is no problem for me					
I am not easily upset by what people say to me					
Considering my experience and qualifications I am happy with my salary					
I am generally able to cope with the problems life presents me with					
I find it hard to make decisions					
I seldom laugh					
I enjoy a close working relationship with most of the people I work with					
When people upset me I feel unable to argue with them					
These days I have lost my interest in other people					
After eating meals I tend to feel sleepy and a little vague					
I have little appetite for food					
I seldom experience indigestion					

Q. Please tick those boxes that describe the home you live in:-

• *Type of dwelling*		• *Age of dwelling*		• *Characteristics*	
Flat	☐	Before 1870	☐	Centrally heated	☐
Terraced house	☐	Between 1870 and 1919	☐	Fully double or secondary glazed	☐
Semi-detached house	☐	Between 1920 and 1945	☐	Treated recently for worm or rot	☐
Detached house	☐	Between 1945 and 1960	☐	Has a garden	☐
Semi-detached bungalow	☐	Between 1961 and 1980	☐	Has been renovated	☐
Detached bungalow	☐	After 1980	☐	Chimney sealed or no chimney	☐
Other type	☐			Additional insulation added	☐

Q. *The following question aims to ascertain how the building affects communication patterns. Given below is a random list of some of the people who work in this building.*

Please could you identify the people you know by placing a tick against their name; indicate whether you find that person useful to you in your work by placing a second tick in the next column (if you do not find the person useful leave this column blank); and identify the main means by which you communicate with that person by placing an 'F' for face to face interaction, or a 'P' for the phone, or an 'M' for E- mail in the last column.

Leave blank the rows of any people that you do not know.

Example If you know Joe Bloggs, normally interact with him by means of E-mail, and find him useful in your work, you would tick as shown in the first row :-

	Know this person	Useful to you in your work	Main form of communication		Know this person	Useful to you in your work	Main form of communication		Know this person	Useful to you in your work	Main form of communication
Joe Bloggs	✓	✓	M								
Afful, David				Foster, Mick				Orton, Jeremy			
Aitken, James				Fuller, Julie				Patten, Jessica			
Alozie, Connie				Guha, Ananda				Pennycuick, David			
Archbold, Alexandra				Hallinan, Amanda				Perris, Roy			
Armstrong, Julie				Hammond, Brian				Rees, Rhiannon			
Arnold, Irene				Harmer, Elizabeth				Robbins, Simon			
Barrett, Jackie				Harpley, Beryl				Round, Shila			
Barrett, Paula				Harrison, Karen				Scott, Michael			
Bastable, Gerald				Harrison, Trish				Seaton, Andrew			
Beales, Richard				Hollingsworth, Barbara				Seear, Joan			
Bearpark, Andy				Howard, Bill				Simpson, Jeanette			
Bickersteth, Sam				Hudson, Barrie				Skinner, Peter			
Bonner, Jatinder				Hughes, Mike				Smee, Mike			
Braint, Dianna				Ireton, Helen				Smith, Martin			
Bright, Amanda				Janowski, Monica				Sleeper, Joan			
Brookes, Diana				Jenkins, Dick				Stevens, Isobel			
Brown, Pauline				Jones, Julie				Stuppel, John			
Bullock, Ken				Lamond, Alex				Tarbit, John			
Burton, Peter				Langan, Martin				Taylor, Ian			
Chambers, Ivy				Langlais, Natalia				Tranter, Nick			
Chan-Lok, John				Leitch, Rob				Troy, Peter			
Clarke, Owen				Locke, Marian				Turner, David			
Clothier, Charlotte				Longstaff, Dick				Vowles, Margaret			
Coffey, Niall				Machin, John				Waddington, Susan			
Davies, Deirdre				Maguire, Pat				Ware, Victoria			
Davies, Taff				Marshall, Kathy				White, Denise			
de Souza, Carol				McCafferty, Theresa				Wilmshurst, Jon			
Dinsdale, John				McCausland, Martin				Wood, Peter			
Doig, Isobel				Medhurst, James				Wray, Alistair			
Dorrell, Doreen				Morley, Thea				Wright, David			
Firmanger, Lyn				Mullins, Clifford				Wright, Gill			

Q. *Please answer the following questions about the lighting conditions in your WORKSPACE :-*

	1 (Never)	2	3	4	5 (Very Often)
When writing or reading at your desk can you see the writing clearly ?					
Do people's faces appear clear when you look at them ?					
Do you experience any problems with reflections on computer screens ?					
Do the electric lights make any noise ?					
Do the electric lights flicker ?					
Are the electric lights <u>on</u> when you would prefer them to be off ?					
Are the electric lights <u>off</u> when you would prefer them to be on ?					
Is your attention distracted by bright areas outside your main field of view ?					
Do you experience any problems with shadows ?					

Q. *If an object or surface is too bright it may cause you some discomfort even though you may not be looking directly at it. This is called glare.*

Do you experience glare in your WORKSPACE ?

If so please specify where the glare comes from and how frequently it occurs ?

	1 (Never)	2	3	4	5 (Very often)
From a direct view of the sun					
From the sky outside					
From the scene (ground, buildings) outside the window					
From desk tops or other horizontal surfaces in the workspace					
From walls or other vertical surfaces in the workspace					
From electric lights					
From something else (please specify what in the box below)					

392

Q. In the past 12 months, how often have you experienced the following whilst in your WORKSPACE ?

Before answering ... please read the additional 2 questions on the side.

- For each symptom — *If you ticked to the right of the dark line* — *Was the symptom better on days away from work ?*
- For each symptom — *If you had the symptom more than 6 times* — *Approximately how many times did you have it during the year ?*

	Number of Times: 0	1	2	3	4	5	6+	No	Yes	Times (Please state as a number not words)
Tightness of the chest										
Dryness of the eyes										
Itching eyes										
A runny nose										
Lethargy and/or tiredness										
~~Watering eyes~~										
A dry throat										
Blocked or stuffy nose										
Headaches										
Flu-like symptoms but not flu										
A difficulty in breathing										
Hay fever										
Asthma										
Dry skin										
Aching limbs										
Fever										
Contact lens problems										
Backache										
Nausea										
Skin rash										
Noises in your head (tinnitus)										
Other, please specify										

Q. If, in the past 12 months, you experienced any of the following occurrences whilst in your WORKSPACE please indicate, if you can remember, when.

Tick as many boxes as appropriate.

Occurrences \ Occasions	No fixed occasion	Sunny weather	Hot weather	Cold weather	Fog or mist	Strong winds	Cloudy weather	Calm weather	Monday mornings	As the weather changes	Friday afternoons	Other mornings	Other afternoons	Some other time
Tightness of the chest														
Dryness of the eyes														
Itching eyes														
A runny nose														
Lethargy and/or tiredness														
Watering eyes														
A dry throat														
Blocked or stuffy nose														
Headaches														
Flu-like illness (aching limbs, fever)														
A difficulty in breathing														
Workspace : unsatisfactory lighting														
Workspace : poor air quality														
Workspace : too noisy														
Workspace : too hot														
Workspace : too cold														

Q. This questionnaire has sought to build up a picture of your feelings about your workspace. To develop this into a more comprehensive understanding we would need to ask you some further questions, either in the form of an interview or additional questionnaire. Please indicate by ticking any of the boxes below whether you would be willing to take part in such further investigations.

Questionnaire ☐ Interview ☐

Thank you for completing this questionnaire. If you have any additional comments that you feel are relevant to the study please write them down on the reverse of this last sheet.

Q. *In the past 12 months, how often have you experienced the following whilst in your WORKSPACE ?*

Before answering ... please read the additional 2 questions on the side.

● For each symptom

If you ticked to the right of the dark line

Was the symptom better on days away from work ?

● For each symptom

If you had the symptom more than 6 times

Approximately how many times did you have it during the year ?

	Number of Times 0	1	2	3	4	5	6+	No	Yes	Times (Please state as a number not words)
Tightness of the chest										
Dryness of the eyes										
Itching eyes										
A runny nose										
Lethargy and/or tiredness										
Watering eyes										
A dry throat										
Blocked or stuffy nose										
Headaches										
Flu-like symptoms but not flu										
A difficulty in breathing										
Hay fever										
Asthma										
Dry skin										
Aching limbs										
Fever										
Contact lens problems										
Backache										
Nausea										
Skin rash										
Noises in your head (tinnitus)										
Other, please specify										

Q. *If, in the past 12 months, you experienced any of the following occurrences whilst in your WORKSPACE please indicate, if you can remember, when.*

Tick as many boxes as appropriate.

Occurrences	Occasions	No fixed occasion	Sunny weather	Hot weather	Cold weather	Fog or mist	Strong winds	Cloudy weather	Calm weather	Monday mornings	As the weather changes	Friday afternoons	Other mornings	Other afternoons	Some other time
Tightness of the chest															
Dryness of the eyes															
Itching eyes															
A runny nose															
Lethargy and/or tiredness															
Watering eyes															
A dry throat															
Blocked or stuffy nose															
Headaches															
Flu-like illness (aching limbs, fever)															
A difficulty in breathing															
Workspace : unsatisfactory lighting															
Workspace : poor air quality															
Workspace : too noisy															
Workspace : too hot															
Workspace : too cold															

Q. *This questionnaire has sought to build up a picture of your feelings about your workspace. To develop this into a more comprehensive understanding we would need to ask you some further questions, either in the form of an interview or additional questionnaire. Please indicate by ticking any of the boxes below whether you would be willing to take part in such further investigations.*

Questionnaire ☐ Interview ☐

Thank you for completing this questionnaire. If you have any additional comments that you feel are relevant to the study please write them down on the reverse of this last sheet.