A TECHNOLOGICAL SYSTEMS APPROACH TO THE SICK BUILDING SYNDROME

by

R M TRUTER

in fulfillment of the requirements
for the qualification of

MASTERS DIPLOMA IN TECHNOLOGY

at the

TECHNIKON WITWATERSRAND

1993

INDEX

CHAPTER 1: SICK BUILDING SYNDROME: LITERATURE REVIEW 1

1.1 INTRODUCTION 1
1.2 DEFINING THE FIELD OF INDOOR AIR QUALITY AND SICK BUILDING SYNDROME 1
1.3 SYMPTOMS 3
1.4 CAUSES 4
1.5 RESPONSE RATES 5
1.6 PSYCHOSOCIAL FACTORS AND THE WORK ENVIRONMENT 6
1.7 SEASONAL VARIATIONS 6
1.8 REVIEW OF STUDY METHODOLOGIES 6
1.9 MEASUREMENT METHODOLOGIES 8
1.10 SOLUTIONS 9
1.11 CONTROLLING INDOOR AIR QUALITY PROBLEMS 10
1.12 INDIRECTLY RELATED FACTORS WHICH AFFECT INDOOR AIR QUALITY 11
1.13 STUDY DESIGN CONSIDERATIONS 11
1.14 DISCUSSION 13

CHAPTER 2: STATEMENT OF PROBLEM 15

2.1 INTRODUCTION 15
2.2 SBS IN SOUTH AFRICA 16
2.3 THE LOCAL CONTEXT OF THIS PROJECT 16
2.4 HYPOTHESIS AND OBJECTIVES 17
2.5 DEVELOPMENT OF RESEARCH 18

CHAPTER 3: SICK BUILDING SYNDROME AND THE VENTI= LATION OF SEALED BUILDINGS 19

3.1 INTRODUCTION 19
3.2 MECHANICAL VENTILATION 20
3.3 SYSTEM DESIGN AND CRITERIA 22
3.4 ECONOMICS 22
3.5 AIR-CONDITIONING SYSTEMS 23
3.6 DISCUSSION 27

CHAPTER 4: REVIEW OF LEGISLATION PERTAINING TO INDOOR ENVIRONMENTS 30

4.1 INTRODUCTION 30
4.2 THE PRESENT STATUS OF INDOOR AIR STANDARDS AND GUIDELINES 31
4.3 AIR QUALITY 32
4.4 SABS CODE 0400 33
4.5 INTERNATIONAL CODES 33
4.6 DISCUSSION 34
4.7 CONCLUSION 36

CHAPTER 5: PROJECT DESIGN: METHODS AND RATIONALE . . . 37
5.1 INTRODUCTION . . . 37
5.2 QUESTIONNAIRE AND EPIDEMIOLOGICAL STRATEGY . . . 39
5.3 OCCUPATIONAL HYGIENE SURVEY . . . 42
5.4 EQUIPMENT . . . 45
5.5 POLLUTANTS ENCOUNTERED IN THE INDOOR OFFICE ENVIRONMENT . . . 46
5.5 DISCUSSION . . . 58
5.6 CONCLUSION . . . 58

CHAPTER 6: QUESTIONNAIRE SURVEY RESULTS . . . 59
6.1 INTRODUCTION . . . 59
6.2 COMPARATIVE RESULTS . . . 59
6.3 MATCHING OF THE POPULATION . . . 59
6.4 DEMOGRAPHICS . . . 60
6.5 CONCLUSION . . . 67

CHAPTER 7: PHYSICAL AND POLLUTANT CHARACTERISATION OF THE INDOOR ENVIRONMENTS OF STUDY BUILDINGS68
7.1 INTRODUCTION . . . 68
7.3 RESULTS OF MEASUREMENTS OF INDOOR AIR POLLUTANTS . . . 68
7.4 DISCUSSION . . . 81
7.5 CONCLUSION . . . 81

CHAPTER 8: CONCLUSION . . . 83
8.1 INTRODUCTION . . . 83
8.2 CONCLUSION . . . 84
8.3 RECOMMENDATIONS . . . 85
8.4 IMPLEMENTING AN IAQ INVESTIGATION STRUCTURE . . . 86
8.5 BUILDING SYSTEMS MANAGEMENT: THE KEY . . . 87
8.6 LIVING BUILDINGS . . . 90
8.7 DISCUSSION . . . 92
8.8 IMPLEMENTING THE LIVING BUILDING SYSTEM . . . 93
8.9 DISCUSSION . . . 94
8.10 CONCLUSION . . . 94

REFERENCES . . . 96

APPENDICES . . . 101

LIST OF TABLES

CHAPTER 1

Table 1.1 Summary of Definitions of SBS 3
Table 1.2 Comparative Review of Symptoms 4
Table 1.3 NIOSH causes of Indoor Air Quality Complaints 5
Table 1.4 Comparison of Various Methodologies 9
Table 1.5 Long Term Integrating Measurements 12
Table 1.6 Short Term Time Measurements 12
Table 1.7 Symptoms of SBS and Possible Causes 14

CHAPTER 3

Table 3.1 Advantages and Disadvantages of Natural and Mechanical Ventilation 20
Table 3.2 Overview of Historical Recommended Airflow Rates Used in Air-Conditioning Spaces 21
Table 3.3 Perception of Draft or Airflow by Indoor Occupants 22
Table 3.4 Indoor/Outdoor Pollutant Relationships 27

CHAPTER 4

Table 4.1 Regulatory and Non-Regulatory Approaches for Environmental Control 30
Table 4.2 Current Indoor Air Standards 31

CHAPTER 5

Table 5.1 Breakdown of Sample Population 39
Table 5.2 Monitoring Timetable 43
Table 5.3 Equipment Availability 44
Table 5.4 Major Indoor Pollutants, Sources, Concentrations and Health Effects 45
Table 5.5 Health effects of Nitrogen Dioxide (NO_2) 48
Table 5.6 Composition of Mainstream and Tobacco Smoke 55

CHAPTER 8

Table 8.1 Summary of Proposed Organisation Involvement in IAQ Issues 84
Table 8.2 Implementing an IAQ Assistance Programme 85
Table 8.3 Usual Method of Resolving IAQ Complaints 87

LIST OF FIGURES

CHAPTER 6

Figure 6.1 Distribution of job status by building 60
Figure 6.2 Distribution of educational qualifications in both buildings 61
Figure 6.3 Smoking status amongst populations in both buildings 61
Figure 6.4 Open plan versus closed plan offices in building A and B 62
Figure 6.5 General perception of respondents to office environmental conditions 63
Figure 6.6 Occupants perception of the office environment 64
Figure 6.7 Prevalence of symptoms in both buildings 65

CHAPTER 7

Figure 7.1 Typical trend for CO in building A over 24 hours 69
Figure 7.2 Daily profile of Carbon Monoxide in building A for one week 69
Figure 7.3 CO trends in the 1st level parking garage 70
Figure 7.4 CO path from basement parking garage to 28th floor 71
Figure 7.5 Daily profile of Carbon Monoxide in building B for one week 72
Figure 7.6 Time profile of NO_2 in building A 73
Figure 7.7 Time profile for NO_2 over three days 74
Figure 7.8 Daily maximum values of NO_2 measured at the Johannesburg City Hall 74
Figure 7.9 NO_2 concentrations measured in building B 75
Figure 7.10 Time profile of NO in building A 76
Figure 7.11 Time profile of NO in building B over one week 76
Figure 7.12 Non Methane Hydrocarbons measured in building A over three days 77
Figure 7.13 Non Methane Hydrocarbons measured in building B over three days 77
Figure 7.14 Temperature profile on 28th floor of building A 79
Figure 7.15 Wet Kata Index on 28th floor of building A 79
Figure 7.16 Airflow measured on 28th floor of building A 80
Figure 7.17 Temperature trends on the second floor of building B 80
Figure 7.18 Wet Kata Index on 2nd floor of building B 81

CHAPTER 8

Figure 8.1 The Habitability Pyramid 88
Figure 8.2 Normal procedure for construction of a multi-storeyed building 89
Figure 8.3 Normal activities/processes in a building system 90
Figure 8.4 "Typical" system of building management in South Africa 91
Figure 8.5 Components of a living building 92

ACKNOWLEDGEMENTS

Financial assistance for this project has been given by the *National Council of Trade Unions, Anglo American Property Services and the Johannesburg City Council.*

The author wishes to express his most sincere appreciation to his project panel for all assistance and advice given to him during the course of the project: Dr J Schoeman, Prof H Annegarn, Dr M Steinberg, Ms M de Beer, Mr V Yousefi, Prof G N Padayachee.

The author also wishes to thank particularly the following people for their assistance, encouragement and help during the course of the project:

Mrs R Davey
Mrs M de Beer
Mrs M Gainsford
Mr O Held
Mrs S Human
Mr H Krohm
Dr A H Leuschner
Mrs N Nel
Ms G Reid
Mrs L Smith
Mr S Steyn
Mr M Turner
Mrs E van Aswegen

"Buildings do not protect their inhabitants from pollution. To the contrary, the body burden of toxic vapours and dust in the inside may very well exceed the burden of pollution on the outside." [ST77]

EXECUTIVE SUMMARY

A cross sectional survey was conducted in an air-conditioned building and a naturally ventilated building to establish the prevalence of Sick Building Syndrome (SBS) in these Johannesburg buildings. Numerous studies conducted in other countries have found that the prevalence of SBS symptoms are usually higher in sealed air-conditioned buildings than naturally ventilated buildings.

The study was conducted in two stages namely a questionnaire and indoor environmental survey which was conducted in both buildings. The results of the questionnaire survey showed that:

> *All symptom prevalences in both building populations were very closely related, however the SBS symptoms in building B were more common than air-conditioned building.*

The indoor environmental survey measured the following parameters: carbon dioxide, carbon monoxide, nitrogen dioxide, nitric oxide, total nitrogen oxides, total non methane hydrocarbons, respirable dust, asbestos, sound levels. No measurements were above any threshold limit values or relevant scientifically acceptable standards, however in the air-conditioned building levels of some pollutants were higher than the naturally ventilated building.

The study found that the prevailences of SBS type symptoms in the naturally ventilated building were higher than those in the air-conditioned building. The type of building population could also affect the outcome as has been found by researchers in the United Kingdom. The predominant population in the naturally ventilated building consisted of government employees which could have affected symptom prevalence.

UITVOERENDE OPSOMMING

Ten einde te bepaal of Siekgebousindroom (SGS) toestande in twee van Johannesburg se geboue teenwoordig was, was deursneë afdelingsondersoeke in beide 'n lugversorgde asook 'n natuurlik-lugversorgde gebou onderneem.

Verskeie studies wat in ander lande uitgevoer was, het getoon dat die algemeenheid van SGS-simptome gewoonlik hoër is as in verseëlde lugversorgde geboue in natuurlik-geventileerde geboue.

Die studie was gedoen in twee afsonderlike fases, nl. (1) 'n vraelys en (2) binnenshuise omgewingsopname wat in albei geboue uitgevoer is.

Die resultate van die opname het die volgende getoon:

> *Alle voorgekome simptome in beide gebou-populasies was verwant, alhoewel die SGS-simptome in gebou B meer algemeen was as in die lugversorgde gebou.*

Die binnenshuise omgewingsopname was gemeet aan die volgende parameters: koolstofdioksied, nitrogeen dioksied, salpetersuur, totale nitrogeen dioksied, totale nie-mentane hidrokoolstofdioksied, inasembare stof, asbes en klankvlakke. Geen mates was bo die drumpel van beperkte waardes of relevante wetenskaplik-aanvaarbare standaarde nie, alhoewel in die lugversorgde gebou vlakke van sekere besoedelings hoër was as in die natuurlik-lugversorgde gebou.

Die studie toon aan dat die teenwoordigheid van die SGS-tipe sindroom in die natuurlik-versorgde gebou hoër was as die van die lugversorgde gebou. Navorsers in die Verenigde Koninkryk het gevind dat die tipe geboupopulasie die resultaat kon beïnvloed. Die oorheersende populasie van die natuurlik-lugversorgde gebou het bestaan uit staatswerknemers wat die teenwoordigheid van simptome kon beïnvloed het.

CHAPTER 1

SICK BUILDING SYNDROME: LITERATURE REVIEW

1.1 INTRODUCTION

Increasing attention has been directed to the design of new structures and modifications of existing ones to minimise the consumption of energy. This has followed the realisation that public, private residential, and commercial buildings consume about one fourth of the total end-use energy produced in the USA [HU86].

Most office workers spend about one third of their time in an office environment. Due to the energy crisis in the early 1970's, buildings were designed to be more energy efficient. This was achieved by 'tightening' up buildings to reduce heating and cooling costs. Thus buildings are much better sealed and insulated than they used to be. Building engineers have also cut back on the fresh air supply to sealed buildings [HU86]. 'Tightening up' of buildings reduces outside air infiltration and in turn reduces the costs of cooling the building.

Hughes and O'Brien [HU86] state that typical energy reduction strategies include inter alia: the reduction of the outdoor air component of the office supply to a minimum, the reduction of the total air circulation to the minimum value needed to maintain design space ventilation conditions, and the periodic shutdown of ventilation systems components. Hughes and O'Brien [HU86] elaborate on these energy reduction strategies which include the use of sealed windows, lower winter and higher summer room temperatures and centralised control of air-conditioning.

Finnegan and Pickering [FI86] state that ventilation standards have been reduced in the years following the oil crisis (1970's) and that there has been a tendency to supply the minimum amount of air, rather than the recommended amount required.

These new design concepts and modifications to existing structures have failed to appreciate the considerable difference in individual requirements as regards the work environment. Robertson and Burge [RO86] feel that this may lead to ill health and frustration on the part of the office worker. The purpose of this chapter is to acquaint the reader with the literature published to date on this subject and to lay a foundation for the research project described in later chapters. A cross sectional analytical study is developed and implemented to ascertain certain objectives.

1.2 DEFINING THE FIELD OF INDOOR AIR QUALITY AND SICK BUILDING SYNDROME

The term Sick Building Syndrome (SBS) forms part of a field commonly referred to as that of Indoor Air Quality (IAQ) or Indoor Air Pollution (IAP).

IAQ is a multidisciplinary field embracing many professions. No single approach can lay claim to directly solving IAQ complaints. This field involves the following types of environments:

- Home Environments;
- Office and Building Environments;
- Special Environments (Submarines);
- Cinemas/Theatres;
- Sports arenas, Cinemas;
- Shopping Centres;
- Public Buildings;
- Aeroplanes.

Within the field of IAQ certain diseases and symptoms have been associated with air-conditioning systems.

These are categorised by Robertson and Burge [RO86] as:

Physical: Sick Building Syndrome;
Allergic: asthma, humidifier fever, extrinsic allergic alveolitus; and
Infectious: bacterial, fungal, viral.

Finnegan [FI86] describes SBS as a building/s in which complaints of ill health are more common than one might reasonably expect. Burge's definition is perhaps more apt as he defines it as common symptoms associated with the occupation of predominantly sealed buildings [BU87]. Table 1.1 compares the plethora of definitions by various authors.

The World Health Organization as described by Truter, Turner, Ijsselmaiden, Annegarn, Schooney, Steenberg and Padayachee [TR89] has defined Building Sickness as follows:

> *"general nonspecific symptoms of malaise in particular irritations of the eye, nose and throat, lethargy and dizziness. These are experienced by the sufferers during the time they occupy the building and disappear shortly afterwards."*

Apart from this specific definition of building sickness, a number of varied definitions have been documented. These are shown in Table 1.1.

Table 1.1: Summary of definitions of SBS

Author	Definition	Source
Finnegan et al.	- Building in which complaints of ill health are more common than one might reasonably expect	[FI84]
Morris-Hawkins	- Used to describe buildings in which symptoms such as headache, lethargy, skin rashes, eye, nose and throat irritation and respiratory problems are highly prevalent	[MO87]
Robertson	- Office workers who complain of a wide variety of work related health complaints such as eye irritation, nasal blockage, running nose and sore throat, headache and lethargy	[RO86]
Burge	- Term used to describe common symptoms associated with the occupation of predominantly sealed buildings	[BU87]
Abbritti et al.	- Refers to a complex of irritative and general symptoms occurring in particularly susceptable individuals more often than expected	[AB90]
Menzies et al.	- Constellation of symptoms arising among workers in high rise office buildings in which all indoor ventilation is supplied by mechanical means	[ME90]
Ruotselainen and Jaakola	- A similar set of symptoms which are reported by office workers	[RU90]
Skov and Valbjorn	- Is characterised by irritative symptoms of the eyes nose and throat, dryness and irritative of the skin, headache, tiredness and lethargy. These symptoms are experienced as work related	[SK90]
Leaderer et al.	- Generally taken to mean an increase in the frequency of building occupant-reported complaints associable with acute non-specific symptoms in non-industrial indoor environments that improve while away from the building	[LE90]

1.3 SYMPTOMS

A number of different symptoms have been experienced by office workers in air-conditioned buildings. The pattern of symptoms reported usually includes:

- headaches;
- lethargy;
- fatigue;
- sore eyes; and
- irritation of the upper respiratory tract [RO86, TU83].

Robertson and Burge [RO86] have reported that many components of this syndrome were found to be significantly more common in an air-conditioned building as compared to a naturally ventilated building: e.g. rhinitis 28% vs 5%; nasal blockage and dry throat 35% vs 9%; lethargy 36% vs 13%; headache 31% vs 15% and eye irritation 27% vs 5%.

Robertson and Burge [RO86] suggests that watering of the eyes is related to air-conditioning systems. Dry throat, eyes, nose and skin, have in the past been attributed to the low moisture content of air, but Robertson and Burge [RO86] state that the moisture content remained within acceptable limits. Work related lethargy and headache are only recently recognised problems of SBS. The authors also postulate that negative ions have also been suggested as a cause of non-specific symptoms in air-conditioned buildings. Various researchers have reported a variety of symptoms as summarised in Table 1.2.

The World Health Organization (Truter et al.) [TR89] describes the symptoms of building sickness as follows:

- eye, nose and throat irritation;
- sensation of dry mucous membranes and skin;
- erythema;
- mental fatigue;
- headaches, high frequency of airway infections and cough;
- hoarseness, wheezing, itching skin, unspecified hypersensitivity; and
- nausea, dizziness.

Table 1.2: Comparative review of symptoms

Author	Symptoms	Causes	Response	Source
Fidler et al.	Sleepiness, fatigue, stuffy nose, dry eyes headache, "discomfort"	Tobacco, paint, cleaning fumes, miscellaneous chemicals, glues and adhesives	90%	[FI90]
Nelson et al (LOC)	3 Groups 1) Indoor air quality symptoms - headache, fatigue, mucous membrane irritation 2) Respiratory or the like symptoms - clinically defined illness 3) Ergonomic symptoms - pain, stiffness in back, neck, shoulders hands and wrists	Tobacco, paint, cleaning fumes, miscellaneous chemicals, glues and adhesives	81%	[NE90]
Stenberg et al	Fatigue, feeling heavy headed, headache, nausea, difficulties in concentration, itching, burning or irritation of eyes, stuffy or runny nose, hoarse dry throat, cough, dry facial skin itchiness	Not yet available	95%	[ST90]
Turiel et al	Eye irritation, frequent irritation of nose and throat, chest tightness, eye inflammation, infection, skin dryness	Reduced ventilation rates	62% Sample Building 66% Control Building	[TU83]
Burge et al	Lethargy, blocked nose, dry throat, headache, chest tightness, difficulty in breathing	1. Feature of the workers 2. Materials 3. Technology they work with 4. Job specification 5. Building features	92% (range 67% to 100%)	[BU87]

1.4 CAUSES

The National Institute for Occupational Safety and Health (NIOSH) [NI87] completed 446 indoor air quality investigations up to the end of 1986. It has categorised the causes of indoor air quality problems as follows:

Table 1.3: NIOSH causes of Indoor Air Quality Complaints [NI87]

CAUSES	%
Inadequate ventilation	52%
Inside contamination	17%
Outside contamination	11%
Microbial contamination	5%
Building fabric contamination	3%
Unknown	12%

Finnegan, Pickering and Burge [FI84] studied nine buildings, six of which had mechanical ventilation. They showed that in the mechanically ventilated buildings there were a significant excess of work related headaches, lethargy and nasal and mucous membrane symptoms as compared to the naturally ventilated buildings. They suggested several causes for these symptoms, viz: cigarette smoke, increased formaldehyde concentrations, lack of negative ions, airborne microbes, low relative humidity, high office temperatures, "gassing off" from modern building materials, low airflow rates in offices and reduced fresh air intake.

Burge, Hedge, Wilson, Bass and Robertson's [BU87] survey of 4373 office workers in 42 different buildings states that design characteristics of the buildings and its air-conditioning system are associated with substantial differences in the reported frequencies of symptoms present in those working within them.

Finnegan et al. [FI84] debate the advantages of negative ion concentrations on office workers and suggests that sensitivity depends on the skin conductance of individuals. Finnegan concludes that this is an area requiring additional research before any associations can be drawn to its effects on health.

1.5 RESPONSE RATES

Turiel and Hollowell [TU83] had low response rates to medical questionnaire surveys (66%) or 34 out of 54 surveyed. The authors [TU83] also state that the possibility cannot be ruled out that a number of contaminants acting synergistically may be responsible for higher incidence rates of the symptoms in buildings' occupants. This is however difficult to measure.

Robertson and Burge [RO86] recorded response rates of 84% from occupants. Results indicated that SBS symptoms were more prevalent in air-conditioned than naturally ventilated buildings.

Burge et al. [BU87] had a response of 92% and also demonstrated an increased prevalence of symptoms in the air-conditioned buildings. These rates were not substantiated by the indoor environmental analysis.

1.6 PSYCHOSOCIAL FACTORS AND THE WORK ENVIRONMENT

Morris [MO87] states that stress may give rise to health problems and any aspect of the work environment may elicit a stress response in prone individuals. He highlights a point which is often overlooked by researchers - that responses to and perception of the environmental stressors by individuals vary from person to person and are thus difficult to quantify.

If social interactions in the office are predominantly of a positive and encouraging nature, this will have a strong positive modifying effect on how the more directly building related factors will be perceived [SA88].

The factors that express themselves in a sensory awareness are not perceived by all occupants in the same way, and even for an individual occupant the perception of a given factor will vary from time to time.

Furthermore, once an employee perceives that his grievances about his environment have been addressed, the employee feels that the environment does improve. Air quality complaints are exacerbated when management is not responsive to the whole range of job related problems and a management that directs complaints to a third party who cannot act against a complainant [NA86].

1.7 SEASONAL VARIATIONS

Most research conducted on SBS have been in the Northern Hemisphere where meteorological conditions differ vastly from South Africa. Morris [MO87] emphasises that ideally a survey should be carried out for a number of weeks and repeated at different times of the year to eliminate seasonal variations. Robertson et al. [RO86] conducted a survey over 3 separate weeks in 3 separate months to eliminate seasonal variations.

Due to the large world wide variation in seasonal and meteorological conditions, the phenomenon of SBS should not be generalized until these factors have been investigated.

1.8 REVIEW OF STUDY METHODOLOGIES

The approach of Burge et al. [BU87] in conducting a survey of 4373 office workers in 42 different buildings were the following:

- Self-administered questionnaire;
- Organizational questionnaire; and
- Report by a building services engineer on the ventilation system of the building.

They conclude that the study forms a basis for further reports and that the symptoms of building sickness are widespread and are not related to a few problem buildings only. The design characteristics of the buildings and its plant are associated with substantial differences in the reported frequencies of symptoms in those working within them.

NIOSH [NI87] has developed an approach to solve IAQ problems. NIOSH calls its approach a "Solution Orientated" approach. It comprises

- Background Assessment;
- Initial Site Visit consisting of:
  a. Walk-through Evaluation
  b. Personal Interviews
  c. Environmental Monitoring and
- Follow-up Site Visit.

NIOSH makes the following recommendations for the correction and prevention of IAQ problems:

* Ensure an adequate fresh outdoor air supply. Eliminate or control all known and potential sources of chemical contaminants and

* Eliminate or control all known and potential sources of microbial contaminants.

The Total Building Performance Approach [TBPA] [RO88] to indoor environment concerns in schools, was prepared for the Energy Conservation and Building Environment Department of the Board of Education for the City of Toronto. The TBPA replaces what was often a crisis orientated and ad hoc approach to solving indoor environment concerns. By establishing an inter-departmental, multi-disciplinary team (TBP committee), the TBP approach can assist both in solving problems and evaluating the building's functioning.

Once an IAQ problem has been identified, the TBP committee uses the following methods to respond to the problem:

- The initial site visit;
- Following up the initial visit;
- Considering the data gathered;
- Evaluating a discrete solution;
- Archival research;
- Performing an ecological assessment of the building;
- Analysis of IAQ testing and communication of results, and
- Human aspects of the ecological assessment.

The USA National Research Councils Committee on Indoor Air Quality's Report [NA87] lays down the following methods for dealing with IAQ problems:

Firstly, a means for recognising the problem is described, broken into two major areas of likely professional activity namely:

- Architecture, and
- HVAC Engineering.

<u>The following steps are then taken:</u>
- Problem evaluation;
- Evaluation of system performance;

- Comparison with existing conditions, and
- Recommendations [NA87].

Robertson et al. [RO86] initiated a survey by administering an interview type questionnaire in a communal building. The industrial hygiene survey was conducted using the following instruments: globe thermometer; swing hygrometer; kata thermometer; median ion analyser; CO indicator; a photomultiplier and spectrophotometer. Total monitoring took 1 week over 3 separate seasonal periods.

In the survey, Burge et al. [BU87] used a self-administered questionnaire as the only data-collection method to assess the indoor environments of the buildings. The questionnaire was validated by repeating the survey again two weeks later and then one to two years later. There was a close correlation between the results obtained in the two surveys.

In Table 1.4, a comparison of a number of surveys is presented for information purposes. It can be seen that a holistic approach to the subject is necessary to enable a full evaluation of the indoor environment.

1.9 MEASUREMENT METHODOLOGIES

Turiel and Hollowell [TU83] in their research, used the following equipment to measure contaminants:

- Particulates collected on twelve hour teflon filters by automated dichotomous air samplers and then analysed by beta ray attenuation;
- CO_2 - Teflon sampling lines into an infrared analyser;
- CO - Electrochemical device, and
- NO_2 - Passive samplers over a one week period and then analysed spectrophotometrically.

Formaldehyde and total aliphatic aldehyde concentrations were measured by drawing air from one outdoor site and one indoor site through teflon sampling lines into a portable refrigerated bubbler and then analysed by gas chromatography. Organic air contaminants were sampled by drawing air through cartridges containing a porous polymer and then analysed by gas chromatography and mass spectrophotometry [TU83].

In Table 1.4, a summary of the various methodologies is given as an overview.

Table 1.4: Comparison of various methodologies

Author/ Source	Method	Parameters	Scope	Comments
Robertson et al. [RO86]	Epidemiology Occupational Hygiene	Globe temperature. Dry bulb temp. Relative humidity. Moisture content. Air velocity. HCHO Concentration.	Representative Sample	Good design
Burge et al. [BU87]	Self-administered Questionnaire Organisational Questionnaire Engineer's report		Representative samples in buildings	Limited in respect of validity
NIOSH [NI87]	Occupational Hygiene Carbon Dioxide Method	Background assessment. Walk-through survey. Personal interviews. Environmental monitoring.		Very flexible. Usable by many researchers.
Rozenweig and Landras [RO88]	Building Committee Management Approach	Site visit. Follow-up visit. Evaluation. Archival research. ecological assessments. Analysis of IAQ results. Human aspects of ecological assessments	Use of building Committee	Good potential

1.10 SOLUTIONS

Rozenwieg-Witherspoon and Landrus [RO88] conclude that technically, most IAQ problems may be solved by physical actions such as:

- Renovation;
- Re-design, and
- Altered operating practices in the building maintenance.

Problems are not solved in human terms, however, unless those concerned perceive them as being solved. If human factors are insufficiently considered, technical solutions may not alleviate the problem from the occupant's point of view. The most valid and reliable evaluation of remedial physical action is therefore not through the before and after measures of technical criteria alone, but through assessments of the lived experiences of building users.

Spenglar and Sexton [SP83] recommend that the following issues be considered in decisions concerning the need for public action to deal with IAP:

- The role of government may depend on the degree of "publicness" of a particular building;
- Dissimulation between indoor emission sources may be important;
- Some indoor pollutants, such as tobacco smoke, are perceptible to most people, and individual actions to reduce personal exposures may be predicted on sensory stimuli;
- It is necessary to specify whether building occupants are to be precluded from chronic exposures to low level pollution or short term peak exposures;
- Policy makers must balance the benefits of energy conservation measures against the cost of deteriorating IAQ, and
- If it is decided that public intervention is needed, a regulatory approach should not be implemented automatically.

1.11 CONTROLLING INDOOR AIR QUALITY PROBLEMS

A number of options are available. Temporary measures range from implementing cleaning procedures and increasing ventilation rates to closing down and removing personnel from the affected areas or building. The more permanent type of measures include recommissioning of the building, renewing or replacing components and upgrading of procedures and maintenance.

The report entitled *"Policies and procedures for the control of Indoor Air Quality"* compiled by the National Research Councils Committee on Indoor Air Quality USA [NA87], recommends the following action by the administrators and policy makers:

- Testing and quantification should be performed to determine the effect of reduced air quality on productivity - Energy management strategies that could lead to reduction in IAQ should be weighed against potential reduction in productivity that could result;
- Because of the mismatch between the complexity of current building systems and the abilities of managers and operators to understand, adjust and manage system operation, training and education should be developed and encouraged to produce effective accountability for the proper management of the building systems, and
- Federal and local government agencies should build into their capital budgets the funds required to correct IAQ problems and to provide adequate operations and maintenance for acceptable environmental quality.

1.11.1 Office Plants

The National Aeronautical Space Administration (NASA) [WO89] has released preliminary results of a study which examines the removal of organic chemicals from air by certain plants. The method involves using a plant in a container with soil and an integrated system using activated carbon/plant filtration systems.

Experiments with various gases indicate that a reduction of the concentration of various gases takes place during controlled chamber testing. The study concludes that the interaction of the roots and soil is responsible for removing some indoor pollutants and not the plants themselves However, these results have not been verified by other research bodies.

1.11.2 Air Ionisation

Another aspect of IAQ which has generated much interest, is the use of ionisers in relieving the symptoms of SBS.

The British Health and Safety Executive [SY89] concludes in a special report on SBS, that the balance of evidence suggests that they are of little practical benefit for dealing with SBS. Claims by suppliers of negative ion generators that they have great benefits, have been viewed negatively by the US Food and Drug Administration who seized some brands of generators following misleading advertising [SY89].

1.12 INDIRECTLY RELATED FACTORS WHICH AFFECT INDOOR AIR QUALITY

The above-mentioned report of the National Research Council [NA87] further states that it is usually not possible to identify values for factors that will be acceptable to all occupants. Factors that are characterised by such an inability to indicate absolute values, are:

Those directly affecting IAQ;
Those affecting the:

Thermal environment	- temperature, airflow, humidity
Odours	- smoke and other odours
Irritants	- tobacco smoke
	- building materials and furnishings
	- office equipment supplies and cleaning products
	- others
Presence of toxic substances:	
	- Asbestos
	- Radon
	- Formaldehyde
	- Tobacco smoke

Micro-organisms;
Allergies, and
Infectious agents.

Other factors that affect air quality are:
Lighting
Noise
Furniture and equipment
Crowding and personal workspace
Vibration and motion
Psychosocial factors

1.13 STUDY DESIGN CONSIDERATIONS

According to Walsh et al. [WA87] various diverse factors determine the methodology of SBS investigations thus various choices face the investigator. The different approaches are:

- long term integrating measurements of short term and/real time measurements;
- active vs passive devices, and
- area vs personal sampling.

Each of these options is assessed in the Table 1.5 and 1.6 and the advantages and disadvantages are tabulated [WA87].

Table 1.5 Long term integrating measurements

Advantages	Able to integrate short term fluctuations and provide TWA* exposure potential which is often the most important value for health effects consideration. Analytical sensitivity requirements are often less demanding since a larger sample is collected.
Disadvantages	Requires sample and monitor stability.

* *TWA= Time weighted average*

Table 1.6: Short term time measurements

Advantages	Allows a determination of fluctuations which may be of considerable value especially from sources with intermittent release. Able to obtain results in a reduced time frame and allows only a single visit by the survey team. There is also less likelihood of undesired influences.
Disadvantages	Increased sensitivity often required of limited short term sampling. Is difficult to relate a short term measurement with a diurnal, seasonal or long term concentration variation.

1.13.1 Choice of sampling method

When considering which method to use there are two choices facing the investigator: active and passive devices. The advantages and disadvantages of each have been listed as follows [WA87]:

<u>Passive devices</u>

Advantages
- Diffusion samplers are promising devices for long term measurements.
- Less costly than the alternative.

Disadvantages
- Are susceptible to variation in sampling rate due to air movement.

<u>Active devices</u>

Advantages
- Provides an on-site reading of the parameter being monitored.

Disadvantages
- Proper attention to sampling rates is imperative for accuracy.
- Are costly and generally less portable and require more operator training and maintenance.

1.13.2 Determining the measurement technique for IAQ measurements

The following criteria must be considered [WA87]:

- sensitivity: is a demanding parameter where near ambient levels of many pollutants are encountered;
- selectivity: not as crucial in IAQ;
- portability: is a high priority especially for a large instrument;
- study cost: is important especially in big studies;
- complexity: must consider the degree of skill and training required;
- calibration, and
- quality control.

1.13.3 Factors that affect the measurement of indoor environments

The complex nature of indoor environments and the pollutants encountered make measuring a difficult task. An assortment of conditions should be considered. These are [WA87]:

- Air exchange rates: important in assessing the relationship between sources and resulting concentrations of pollutants;
- Temperature: affects the release of some pollutants;
- Relative humidity: affects the release of some pollutants;
- Wind speed;
- Barometric pressure: radon release is affected by building performance, and
- interaction between pollutants (synergistic reactions).

1.14 DISCUSSION

Table 1.1 has given an indication of the wide spectrum of definitions on the subject. There is clarity over various facets of the definitions. Firstly people who work in multi-storey and conditioned buildings are reporting a certain set of symptoms. Secondly, these symptoms improve when away from work i.e. on leave or on the weekend. Thirdly, these symptoms appear more frequently among woman and lower clerical workers. Fourthly, the psychosocial environment plays a role on the symptom set.

There is agreement in respect of some of the symptoms, but different descriptions are given. The primary symptoms appear to be headache, lethargy and a degree of upper respiratory tract irritation. Symptoms such as eye irritation, dry skin, nausea and dizziness appear to be secondary or specific symptoms.

However, because of the non-specific nature of these symptoms, the category may vary according to various factors such as building age and type, building (HVAC) system and maintenance. As suggested in the previous paragraph, it may be possible to categorise the symptoms set to specific causes. This has been attempted in table 1.7.

Table 1.7: Symptoms of SBS and possible causes

Major Symptoms:	Possible causes:
1. Headaches 2. Lethargy 3. Irritation of URT	- Reduced fresh air intake - Reduced air circulation - ETS*, VOC's*
Specific symptoms:	- Specific causes
5. Eye irritation 6. Skin rashes 7. Nausea 8. Dizziness	- VOC's* Formaldehydes,ETS* - Vibration, Noise, ETS* - " " " - " " "

**VOC = Volatile Organic Compounds*
**ETS = Environmental Tobacco Smoke*

Most studies have reported response rates of over 80%. This was normally achieved with the self-administration of questionnaires. This study will opt to use slightly different methods of questionnaire administration and design. It has also adopted a stronger approach to selecting the study population. It is clear from various studies that factors such as stress, morale and the nature of the office environments play a role in eliciting a SBS response in occupants. In this study a broadly based approach will be utilised as far as is possible to consider all the various factors which have been shown to play a role in the Sick Building Syndrome.

CHAPTER 2

STATEMENT OF PROBLEM

2.1 INTRODUCTION

For the past 15 years, the phenomenon known as SBS or Tight Building Syndrome has been investigated in Europe, Canada and the United States. Most researchers conclude that the results show that certain symptoms exhibited by occupants of sealed multi-storey buildings are not imagined but, make up part of the complex syndrome which is still baffling the health and engineering professions.

SBS came to the attention of researchers during the energy crises in the early 1970's. Increased energy costs forced building planners to tighten up buildings and reduce outside air intake capacities. This contributed to building occupants complaining of "stuffy air" in their work environments as operators were unable to provide adequate outside air supply rates.

The number of IAQ complaints increased rapidly through the 1970's and 1980's. Many of these complaints were referred to NIOSH [NI87], which forms part of the Centre for Disease Control, based in Atlanta. Since 1971, 446 IAQ complaints were received and investigated by the Centre for Disease Control [NI87]. Other United States government agencies conducted research in this field and found that pollutant concentrations were often much higher indoors than they were outdoors. Furthermore, when high exposure levels were coupled with the fact that most people spend more time indoors than outdoors, the potential risk to human health from indoor air pollution was presumed to be potentially greater than the risk posed by outdoor pollution [TR89].

The increasing number of complaints prompted extensive research efforts in many different countries.

Using techniques borrowed from occupational hygiene, epidemiology, engineering and science, researchers demonstrated the strongest links between the symptoms of SBS on the one hand, and buildings that are air-conditioned, usually sealed and use open plan office layouts, on the other.

To many of the uninitiated, the term SBS evokes ambiguous responses. Certainly this is to be expected for it is a term that does not correctly define the problem. In a world where controversial terms educe controversial reactions, the misconceptions around the term SBS need to be corrected. SBS complaints are not a new phenomenon. In addition managers reduced fresh air intakes and airflows inside the buildings. These energy conservation measures prompted the response known as SBS.

The most important question is what is acceptable IAQ? Can it be adequately defined?

The American Society for Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has defined it as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" [AS89].

In order to best fulfil this definition two things are required to be done, namely:

a) The indoor environment must be evaluated, and
b) The people in the building must be assessed.

ASHRAE is regarded as the authority on ventilation in the USA. Locally many ventilation engineers use their criteria and standards in designing buildings.

On the surface, it seemed a simple problem. Nearly two decades later this problem remains perplexing to the building and health professions and it is often exacerbated by the attitudes and feelings of those in the air-conditioning industry.

2.2 SBS IN SOUTH AFRICA

In mid 1987, initial efforts to establish the status of SBS research in the country failed to yield much literature. It was found that an extensive project on the IAQ had been conducted at the Carlton Centre by Annegarn and Horne in 1979 entitled "Electrical Properties of the Indoor Atmosphere of the Carlton Centre" [AN79].

No other local published work could be located by the author at the inception of the study. Up to this point no comprehensive survey of the SBS problem had been undertaken in South Africa.

The purpose then of this study was to ascertain the extent of the problem in Johannesburg. The aims of the study are given in Paragraph 2.4.

2.3 THE LOCAL CONTEXT OF THIS PROJECT

Locally, the question is often asked: "Why SBS research in this country? Is it really a problem?" As previously stated, no published research has yet been located in South African journals to date. No results are available for public perusal and thus it seems on the surface that SBS does not present itself as a problem. For surely, this must reflect an absence of any problems.

On the surface, this may appear to be true. The reason is more likely the fact that the public does experience problems but has no one to turn to. To date no other public body has dealt with any SBS studies. Granted, the National Centre for Occupational Health has responded to requests for assistance. This has resulted in occupational hygiene surveys being conducted but few conclusive results are presented.

Is this therefore a true reflection of the situation? Can health officials, responsible for the health of inhabitants, accept the facts and figures as they seem to be?

In response we must also ask whether our indoor environments differ significantly from those of other modern western countries.

The answer to that is not really easy. The air-conditioning systems used are the same, the materials are very similar, and the users are the same. Could it be then that our ventilation rates differ? This is possible. However, the ventilation rates specified by the National Building Regulations Part O [NA88] are similar to the ASHRAE specifications in Guideline No 62-1989 [AS89]. (These will be discussed in more detail in a later chapter).

The local climates in this country vary according to geographical position (ie. Durban, Cape Town). South Africa has a varied climate with different atmospheric conditions and vastly different seasonal variations. Johannesburg is one of the world's highest cities above sea level and these factors place the context of the project in a different arena.

Before any final conclusion is drawn, some investigation needs to be conducted to justify any decision. South Africa has many highly qualified and able researchers who have published research work of world standard. This is especially true in the fields of engineering, health and atmospheric sciences. In other countries, many professions are involved in the field of IAQ. There is thus no justification for the lack of researchers from South Africa in this field. It could be that nobody wants to investigate the problem.

2.4 HYPOTHESIS AND OBJECTIVES

As stated in the introduction, the ASHRAE definitions [AS89] provide a framework and background for defining objectives and a hypothesis. They were set after an in-depth review of the current literature available at the time.

Objectives number one and two form the main aims of the study and three and four will be attained by evaluating the data derived from the project.

2.4.1 Hypothesis

SBS symptoms and illnesses are associated with certain environmental and physical factors occurring in artificially ventilated buildings.

2.4.2 Objectives

1 To compare the prevalence of SBS and related symptoms in workers exposed to artificial ventilation in sealed buildings and in naturally ventilated buildings.
2 To conduct a full Occupational Hygiene Survey (OHS) in the sample buildings.

3 To investigate the association between various environmental measurements made and any SBS related symptoms ascertained in both types of sample buildings.
4 To investigate the association between any SBS and related symptoms and absenteeism in the artificially ventilated and naturally ventilated buildings.
5 To propose a new method to study SBS.

2.5 DEVELOPMENT OF RESEARCH

In order to reach the set objectives the literature survey in Chapters 3 and 4 need to be fairly extensive for the nature of the study undertaken.

However, the comparative infancy of the field in South Africa and the lack of reliable literature means that it is appropriate to give a good background and source of information. Literature published after 1984 was used as a source and obtained from local library networks.

Chapter 3 will give a brief insight into the different types of air-conditioning systems used. To other professions not involved in ventilation engineering it is useful to browse through the chapter on air-conditioning systems.

For the health official, Chapter 4 will give insight into the legislative aspects of the field.

Chapter 5 will describe and discuss the methodology used. Basically a comparison of an artificially ventilated building with respect to reported prevalence of SBS symptoms and air quality parameters.

The results of the project are presented in Chapters 6 and 7.

In Chapter 8 the results of the project are summarised and a new approach to building management is proposed.

CHAPTER 3

SICK BUILDING SYNDROME AND THE VENTILATION OF SEALED BUILDINGS

3.1 INTRODUCTION

The purpose of this chapter is to give the reader an overview of the essentials of air-conditioning and its design. It is not intended to be a reference manual on air-conditioning. The reader can refer to other comprehensive sources in chapter 1. In a number of studies the air-conditioning system has been implicated as a possible cause of the SBS. The main cause of complaints found by NIOSH [NI87] was inadequate ventilation - 52% (n = 446).

The main concern in this chapter is the perception that the air-conditioning system is usually blamed for the SBS problems which occur. Therefore investigations of any SBS complaint require a background knowledge of these systems. This chapter, however, only lays a very basic foundation and more detailed information can be obtained elsewhere.

In most ventilation systems used air is recirculated throughout the building during occupancy. Normally only 10% - 20% of the air component consists of fresh air or make up air, depending on ambient temperatures. Systems are switched off at night and restarted in the early mornings. Air-conditioning is expensive and regular maintenance is required to keep the system in optimum condition.

Concentrations of pollutants vary between the indoors and outdoors. An indoor/outdoor pollutant ratio exists in most indoor environments and hence the necessity to understand the need for correct ventilation. This relationship is discussed in Paragraph 3.6.

In extreme climates the need for climate control is clearly necessary. The northern hemisphere's winters and summers are well known for their large temperature variations. Thus for optimum productivity properly maintained work environments are required. The ventilation of home and work environments takes on many forms and it is impossible to define all types in this chapter.

Ventilation is a process whereby air is supplied and removed from a space by natural or mechanical means [GO89].

Natural ventilation is the most common process used in this country as most homes, factories and work spaces do not require any artificial ventilation due to the temperate and mild environment experienced. In certain work settings mechanical ventilation is necessary to provide local exhaust ventilation for the removal of hazardous substances. In essence, natural ventilation refers to a space which has no means of mechanical ventilation and fresh air is obtained via natural air movements, through windows or any other natural means [NA88].

Natural ventilation allows the occupant of an enclosed space to control or regulate the amount of fresh air entering through window or door spaces as thermal comfort needs vary. The difference between natural and mechanical ventilation is an important distinction as this ability to regulate the indoor environment is removed once the occupant enters a sealed air-conditioned space. The advantage of natural ventilation is that it uses fresh air to dilute any build-up of indoor odours and pollutants.

In Table 3.1 a comparison is made between the advantages and disadvantages of natural versus mechanical air-conditioning.

Table 3.1: Advantages and Disadvantages of Natural and Mechanical Ventilation

	Advantages	Disadvantages
Natural Ventilation	Cheaper Easier to use Uses cleaner air Allows personal control	Depends on good design No deep space ventilation Depends on ambient conditions
Mechanical	Allows pollutant removal at source Enhances thermal comfort Not dependant on ambient conditions	Increased costs to maintain building No personal control

Natural ventilation is assisted by the infiltration of air into the building space and is influenced by the difference of indoor/outdoor temperatures. Infiltration into buildings is also affected by the following factors: wind effects, stack effects and the combined effects of wind and thermal forces, as well as the design and shape of the building.

3.2 MECHANICAL VENTILATION

The term mechanical ventilation (MV) is an umbrella term used to refer to drawing air into a building space, circulating it throughout a defined area via ducting or paths and then removing an equal proportion of the air using mechanical means. The MV does not normally enhance the quality of the air. The term air-conditioning (AC) refers to the simultaneous control of temperature, relative humidity, purity and movement of the air within the limits imposed by design specifications.

AC is a more expensive process requiring a complex system of sophisticated machinery. It relies on the design or operating specifications and is difficult to alter to meet individual requirements or changing ambient conditions. AC is primarily used in sealed multi-storeyed buildings and in other specialised environments. Dissatisfaction is reported by users of these indoor environments and this unhappiness with the AC stems, it seems, mainly from the fact that the user cannot individually satisfy his thermal workspace requirements.

3.2.1 Historical Overview of AC

AC was first used on a large scale in the 1920's in cinemas. In the same decade, self-contained units were introduced. In the 1930's safe refrigerants were used, allowing better use of compressor and system components [AC87].

During the 1940's, air-conditioning became more applied and specific. Air was cooled using water. Later, however, it was to become air cooled. In the late 1950's, air-conditioning units were installed on the roofs of buildings. This allowed units to increase in size and sophistication [AC87].

3.2.2 History of Airflows

Table 3.2 gives a brief insight into the history of recommended airflows. It is necessary to see that they have fluctuated from high to low and are now once again on the increase. Initially AC was designed with a high airflow. As energy costs increased the air volumes per person were reduced. At present airflow rates are being or have been reviewed in most western countries.

Table 3.2: Overview of historical recommended airflow rates used in air-conditioning spaces [AS87]

Years	Airflow litre/second	Comments
1890'S	14 litre per second per occupant	
1930's	5 litre per second per occupant	
1960'S	2 litre per second per occupant	fresh air
Current	9 litre per second per occupant	when smoking occurs

3.2.3 Perception of Draft or Airflow

Current research has pointed to the fact that occupants complain of inadequate fresh air in their offices. The table below gives an indication of occupants reaction to various airflows and can help determine ventilation design criteria for air-conditioning systems (ACS) in office environments.

Table 3.3: Perception of draft or airflow by indoor occupants [AC87]

Room air supply litre/second (l/s)	Reaction	Recommended application
0-7 l/s	Complaints about stagnant air	None
12 l/s	Ideal design - favourable	All commercial applications
12 - 24 l/s	Probably favourable but is approaching maximum tolerable velocity for seated persons	All commercial applications
31 l/s	Unfavourable - light papers blown off desk	
35 l/s	Upper limit for people moving about slowly - favourable.	Retail and departmental stores
35l/s - 141 l/s	Some factory air-conditioning installations	Factory air-conditioning needs higher velocities for spot cleaning

3.3 SYSTEM DESIGN AND CRITERIA

The objective of a comfortable air-conditioning system is to provide a comfortable environment for an occupant or occupants of a building [AC87]. Therefore the thermal comfort of occupants is ensured by consideration of the following environmental indices:

- THE DIRECT INDICES: Dry bulb temperature, dew point , wet bulb temperature, relative humidity and air movement.
- THE RATIONALLY DERIVED INDICES: Mean radiant temperature, operative temperature, humid operative temperature, heat stress index and index of skin wetness
- THE EMPIRICAL INDICES: Effective temperature, radiant temperature, corrected effective temperature, wet bulb globe temperature and windchill index.

Thermal comfort has been defined as "that state of mind which expresses satisfaction with thermal environment"[AC87]. Subjective reactions to airflow are a complicating variable for many ventilation engineers. Differences in personal preferences between male and female occupants often create a difficult task for the ventilation engineer. In order to satisfy the needs of the tenants he has to balance the system to satisfy a broad spectrum of occupants.

3.4 ECONOMICS

Conditioning air may account for 30-50% of the cost of operating a large building [GO89]. Installing an air-conditioning system in a building can be dictated by the following factors [AC87]:

- The tenants needs and requirements;
- The building design and type;
- Heat gains in the building;
- Stopping excessive draft in the building;
- Reduction of street noise and dust entering the building, and
- Ventilation of deep space in building.

Capital costs of air-conditioning per square meter is approximately R120/m^2 [AC87]. In South Africa air-conditioning running costs are approximately R2.50 per m^2. This translates into an owning cost of R7.00/m^2 per month (figures for 1985) [AC87].

The greatest drawback of air-conditioning use is that it requires large amounts of energy. The energy requirement can account for 15% of the electricity bill [GO89].

Designing a building calls for a special balance between architectural aesthetics and budgetary considerations. Present trends in building design in this country have seen more use of glazed buildings which accumulate high heat loads and require the buildings to be cooled by extra efficient and sophisticated AC systems. This in turn increases running costs which the tenant has to pay for.

Running costs have become the single most important factor in the maintenance of multi-storey buildings. As energy costs increase, so do maintenance standards decrease. Maintaining a system calls for regular servicing of equipment and cleaning procedures.

3.5 AIR-CONDITIONING SYSTEMS

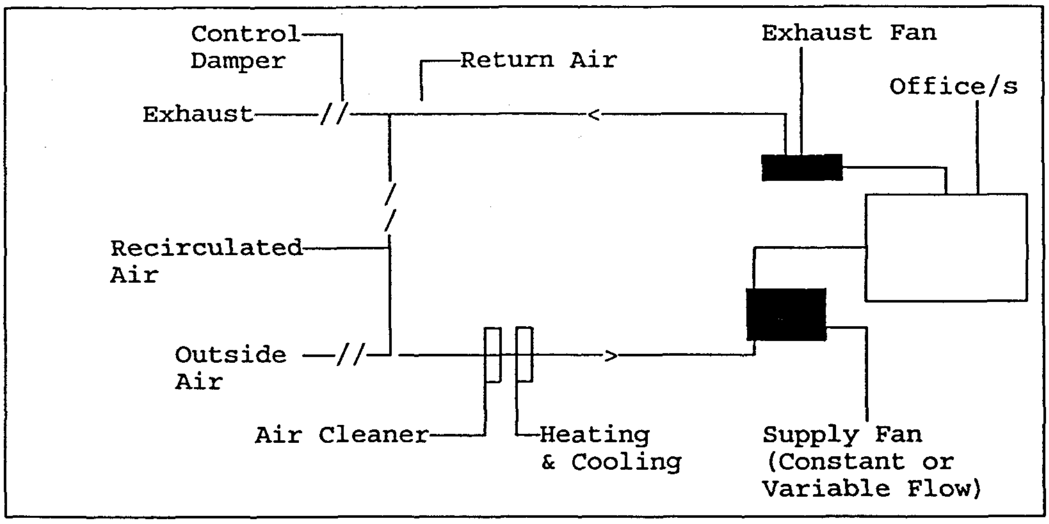
Basic understanding of the various systems used in sealed buildings is important for an insight into SBS. While the notes that follow are not intended to provide a full explanation of air-conditioning systems (ACS) in use, they should give the reader a working knowledge of the concepts of AC.

There are 5 primary ACS used in buildings with each having different variations. These are:
- Central systems;
- All air systems;
- Air and water systems;
- All water systems, and
- Multiple packaged unitary equipment systems.

3.5.1 Central Systems

These systems form the basis for many ACS and have been the most widely used, primarily because of its design. It is an all air system which serves a single zone. It is easy to install and can be used for different pressure air distribution. It is limited by the fact that it requires the heat gains and losses within the ACS to be evenly distributed when a single zone duct system is to be used [AS87].

Figure 3.1: Layout of a typical Central Air System



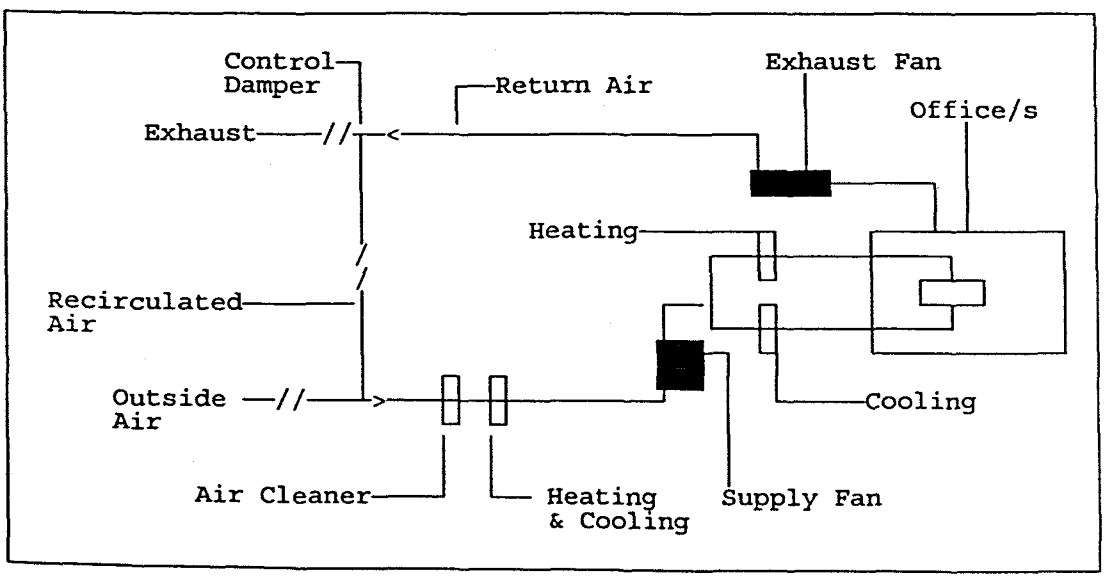
3.5.2 All - Air Systems

These are systems which provide complete sensible and latent cooling capacity in the cold air supplied by the system and thus no cooling is required at the zone. Heating of the air is done via the same air stream of the central system or at the particular zone.

They are classified into 2 categories:

- Single path systems - they contain the main heating and cooling units in a series flow air path and
- Dual path systems - contain the main heating and cooling coils in a parallel flow or series parallel flow airpath [AS87].

Figure 3.2: Layout diagram of a commonly used All Air System
(Constant air volume dual duct HVAC SYSTEM)



The system has the following uses:

- Buildings requiring individual control of conditions and having multiple zones, and
- Special applications where close control of temperature and humidity is needed.

All Air Systems have a number of advantages such as: centralised location of main equipment has greater energy economy; wide choice of uses in different conditions; easily adaptable to heat recovery systems; and is not affected unduly by seasonal changes.

It also has disadvantages: restricts floor space; requires longer fan operating hours when using air for perimeter heating; air balancing can be difficult; accessibility to terminal devices can be difficult; and it can be energy inefficient [AS87].

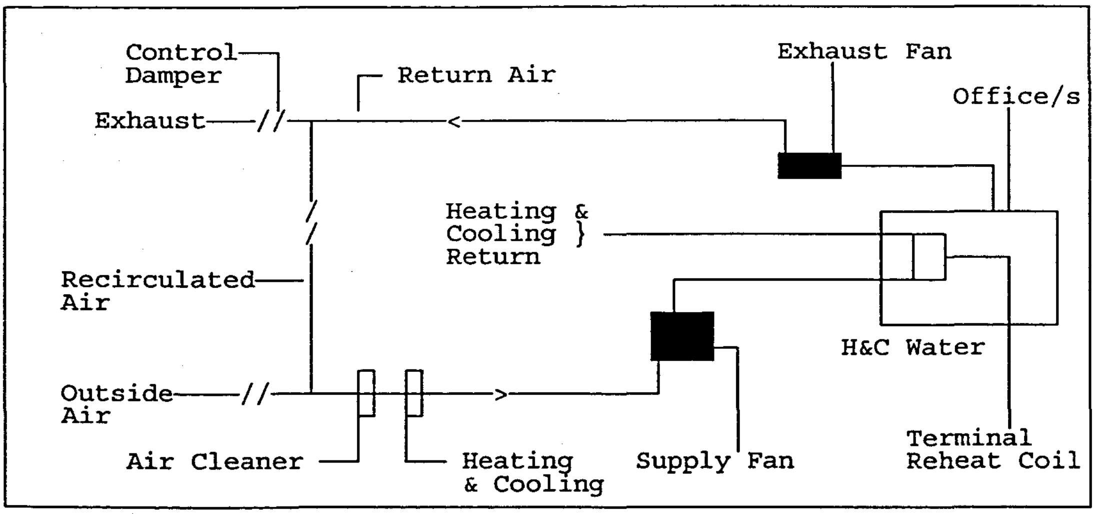
The system has the following uses:
- Work spaces with uniform loads;
- Small working spaces needing precision control;
- Multiple systems for large areas;
- Systems for complete environmental control, and
- As a primary source of conditioned air for other systems [AS87].

3.5.3 Air and Water Systems (AWS)

AWS differ from the previously discussed systems in that air and water are used at the zone or space for cooling. This allows heating and cooling to control the space temperature during all seasons of the year.

AWS have various uses which are more advantageous than other systems. They require less operating space and need less air quantity resulting in cost saving. It can also eliminate the use of a return air system. Good use is made of the air system and gives the system advantageous performance by combining the capabilities of the more versatile all air systems with the water system.

Figure 3.3: Layout of a typical All Air and Water System
(Terminal Reheat Constant Vol. HVAC system)



Its main application is in multiple perimeter spaces where a diversity of sensible loads exists. The system has been used in offices, hospitals and hotels but lends itself very well to multi-storeyed buildings where space saving is an important criterion. It has the following advantages: Individual room temperature control; can satisfy a wide range of load variations; requires a low distribution system space; reduced size of central air handling apparatus; positive outdoor air supply, and increased energy savings [AS87].

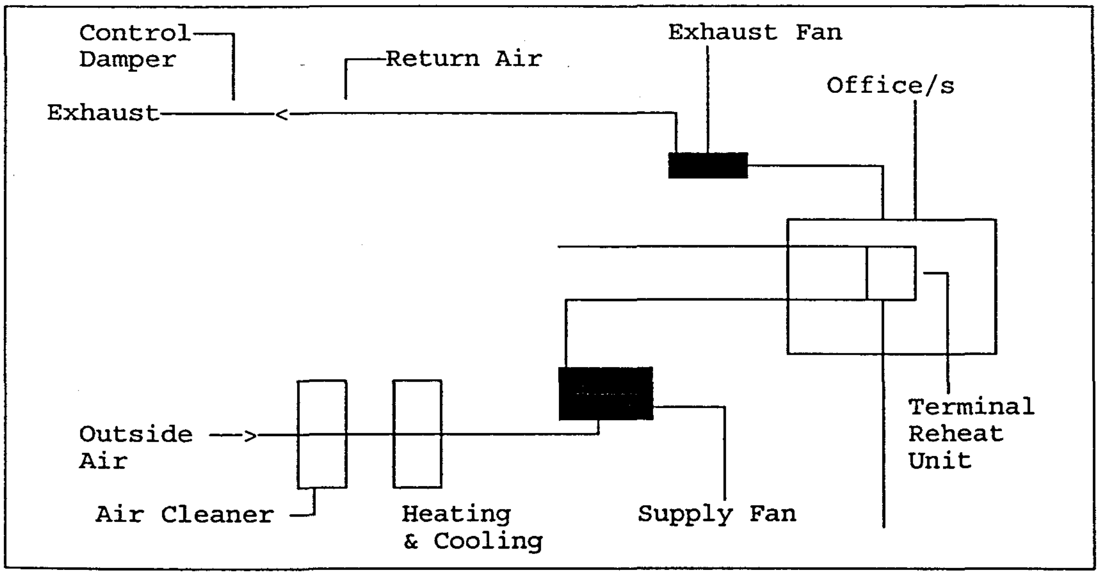
The disadvantages of the system are: application is limited to perimeter space only; requires well informed staff to operate it; controls can be more complex than all air systems; needs frequent maintenance and has limited applicability [AS87].

3.5.4 All Water systems (AW)

AW use unconditioned ventilated air via an opening in the wall or infiltration in combination with fan coil, or valence type room terminals. Cooling and humidification are provided.

AW are flexible for adaptation in many building module requirements. AW do not comply with the definition of air-conditioning as laid down by ASHRAE and fail to meet common ventilation requirements [AS87].

Figure 3.4: Layout of a typical All Water System



3.5.5 Unitary or single air-conditioners (console units)

For the purpose of this study, these units have not received any attention. They are not implicated in the SBS as yet. However, they can cause serious effects if the filters are not cleaned regularly and if the condensate is not removed efficiently.

These systems allow individual room control and air distribution and are not generally encountered in multi-storeyed buildings as a principal system [AS87].

3.6 DISCUSSION

Many variants of ACS are found in sealed office buildings. The most commonly used system is the Variable Air Volume (VAV) system which is an adaptation of an all air system. This system is one of the new generation that uses less energy which is an important criteria today. It has often been reported that SBS cases are more prevalent in buildings where VAV's are used [RO86].

The VAV design incorporates the use of an economiser damper in the plenum of the office space. Once the desired temperature has been obtained, the damper is partially closed and only a minimum of air is provided into the office space.

In the sample building selected for this study the VAV system was used.

The occupant of a sealed building needs to perceive airflow or air movement in order to reach a state of comfort. Hence the problems experienced with the VAV design.

As previously stated in the introduction, there are different types of climate control with various uses and applications. An important facet of air-conditioning is the dilution of pollutants in the office space. As can be seen in Table 3.4, there is an indoor/outdoor pollutant relationship in buildings.

An understanding of the relationship of indoor/outdoor pollutant sources is important. This relationship varies according to different regions and sources of pollutants.

Table 3.4: Indoor/Outdoor Pollutant Relationships [GO89]

Pollutant	I/O Ratio
Sulphur Dioxides (SO_2)	0.3 - 0.5 to 0.7 - 0.9
Ozone (O_3)	0.6 - 0.7
Carbon Monoxide (CO)	Varies according to source
Nitrogen Oxides (NO_x)	Varies according to source
Respirable Particles (RSP)	2:1
Nitrogen Dioxide (NO_2)	2:1
Volatile Organic Compounds (VOC)	1.5 - 1.9
Biogenic (Particles)	Varies according to source

Table 3.4 illustrates the varying indoor/outdoor pollutant relationships that exist in the environment. These factors influence the possible sink effect which affect pollutant concentrations inside buildings. The sink effect has been clearly illustrated in this study as pollutants generated inside and outside the building were detected at the highest floor of the building. Normally ventilation and/or AC should dilute these pollutants. However, the practice of recirculating air with minimal fresh or make up air does not always achieve this aim.

It is thus imperative that the IAQ investigator understand the fundamental aspects of air pollution. This lays a good foundation for an understanding of the complex nature and interaction of indoor air pollutants.

The US Environmental Protection Agency [EN87] estimates that as many as one in three buildings in the US is "sick". The air-conditioning industry as a whole does not accept that AC can affect people's health. Traditionally attitudes reflect an insensitivity to the pertinent health issues which affect occupants of buildings.

AC systems are designed with thermal comfort considerations in mind and fail to provide flexibility for various requirements pertaining to occupant comfort and health. This failure has led to the increase in building related health complaints as discussed in Chapter 1.

A source of the attitude is the lack of cohesive effort on the part of the ventilation industry and architects to design a user friendly building instead of only trying to meet economic requirements. The increase in the construction of glass buildings is testimony to the failure of these two participants to understand the need for correct indoor design first, before designing an aesthetically pleasing outer shell. The occupants spend most of their time inside the building and are not unduly concerned with the outdoor appearances if their comfort is affected thereby.

There are many facets of the AC industry which are good and professional. There is a need for the industry to focus on the real issues of the occupant. These needs are those of the individual user and not of the client only. Little is being done by the industry to focus on developing a better relationship between the user and the air-conditioning industry as a whole.

Design issues should focus on the use of thicker skinned buildings, use less glass and increase shell thermal performance.

This could decrease air-conditioning energy costs and allow more focus on the indoor environmental issues.

CHAPTER 4

REVIEW OF LEGISLATION PERTAINING TO INDOOR ENVIRONMENTS

4.1 INTRODUCTION

At present there is no specific legislation to ensure the enhanced quality of air in buildings in this country. An assortment of legislation can be applied by local authorities and state departments. These will be discussed in this chapter.

When IAQ issues became more prevalent in the early 1970's due to the energy crisis, buildings were designed to become more energy efficient. This was achieved by 'tightening' up buildings to reduce heating and cooling costs. Thus buildings are much better sealed and insulated than they used to be. While these changes led to greater awareness of energy conservation improvement, little was done to ensure the quality of air.

In many industrial countries, as in South Africa, legislation do exist to control smoke emissions [AT83] into the atmosphere when they occur. Furthermore, health legislation [HA77] controls a wide variety of incidents which may cause unhealthy situations through airborne contaminants. Enforcement of this legislation is delegated to local authorities and are enforced by them, while other sections are enforced by central government.

At present however, in South Africa, few health authorities regard indoor air pollution as a possible health hazard. The lack of research and activity in this area is a testament to this. The degree to which indoor air pollution represents a threat to public health has not yet been clearly established but this does not mean that the threat is not understood.

In first world countries the IAQ of private spaces such as offices, schools and aeroplanes escaped the interest of legislators until it was discovered that health hazards existed in these spaces [EN87].

There is strong debate amongst many researchers and legislators regarding the right approach.

The need for control and enforcement in the industrial work setting is generally accepted. Regulation of indoor environments through existing regulation [MA83], however, is not actively enforced, in part due to objections raised for a number of reasons.

Perhaps the main reason is the lack of conclusive evidence that IAQ problems affect the health and productivity of office workers.

There are two objections which may arise. Firstly, can a local authority or government enforce laws within the privacy of the office or home environment? Secondly, should laws be enforced in private office buildings or only in public buildings such as libraries and public gathering places ? These questions can be answered by looking at the existing legislation and their application [TR91].

Various organisations are used as measuring sticks on different levels e.g. EPA Environmental Protection Agency (USA) or the British Health and Safety Executive (HSE) or NIOSH. These organisations are viewed as centres which lead the way in the field of IAQ and provide useful information for researchers in the field. The strategy for dealing with environmental maintenance is not easy and is also very costly. There are a number of possible choices facing the public health official who is faced with solving IAQ problems. Table 4.1 gives an insight into these choices.

Table 4.1: Regulatory and Non-Regulatory Approaches for Environmental Control [GO89]

Regulatory	Definition
Air Quality Standards	- Numerical limits on air contaminant levels eg NAAQS*.
Emission Standards	- Applied to sources in a source category irrespective of existing air quality.
Application standards	- Installment criteria and standards of performance for personnel and product use are set.
Prohibitive Bans	- Regulatory tactics to achieve compliance with air quality standards.
Non-Regulatory	
Health Guidelines Ventilation Guidelines	Reflect true health risk, more easily accepted by professional bodies

**NAAQS = National Ambient Air Quality Standards (USA)*

The application and enforcement of regulatory standards via legislation is usually a difficult task. Standards which are entrenched in the legislative process are often reached after a path of negotiation. Often this causes a compromise between the various departments or interests who set these standards. Whereas the regulatory approach entrenches air quality standards, the non-regulatory approach enables the easier setting of standards and voluntary compliance and participation by industry.

4.2 THE PRESENT STATUS OF INDOOR AIR STANDARDS AND GUIDELINES

International regulatory developments in the field of IAQ are still in their infancy due to the relative newness of the subject. Ventilation standards have been incorporated in various building codes in the USA. In the UK the ventilation rates in air-conditioned buildings have recently been reviewed and increased.

Concern has been expressed by some researchers as to the legitimacy of enforcement of indoor air standards in private buildings. However, in schools, offices, hotels and restaurants where public access is guaranteed, few problems are foreseen [GO89]. An asbestos programme monitored by the EPA has been in existence since 1972 in US schools and will apparently be extended to public access buildings [GO89].

In Table 4.2, a number of indoor air standards already in place and enforced in buildings, are set out.

Table 4.2: Current Indoor Air Standards

Substance/Factor	Enforced by
Formaldehyde	USA, Canada, Sweden, Italy
Asbestos	Most Western Countries, ASHRAE, USA
Ventilation	USR, Canada, UK, ASHRAE
Carbon Dioxide	ASHRAE, USA
Ozone	ASHRAE, USA
Radon	USA, UK
Smoking of Tobacco	USA

ASHRAE = American Society Heating, Refrigeration and Air-Conditioning Engineers

In South Africa ambient air quality standards do exist for use in industry namely the Asbestos and Environmental Regulations of the Machinery and Occupational Safety Act (MOSACT) [MA83].

The legislation that pertains to indoor air quality in SA is:

- The Health Act [HA77]:
  The Health Act delegates functions/ duties to local authorities under Chapter 4 section 20 (1). These functions can be seen as a legislative umbrella for any possible enforcement, should adverse IAQ conditions prevail.
- The Machinery and Occupational Safety Act [MA83]:
  Responsibility for enforcement is delegated to the Department of Manpower
- The National Building Regulations(NBR) [NA88] and SABS Code 0400-1987 [SA87]: Application of the National Building Regulations (NBR)is delegated to local authorities for enforcement.

4.3 AIR QUALITY

The MOSACT Environmental Regulations Section 5 [MA88] specifies that every employer shall ensure that every workplace in his undertaking is ventilated either by natural or mechanical means so that:

- The air does not endanger the workers' safety;

- The time weighted average concentration of carbon dioxide over 8 hours does not exceed a 0,5% by volume of air;
- The carbon dioxide concentration does not at any time exceed 3% by volume of air;
- The prescribed exposure limits for airborne substances are not exceeded, and
- The concentration therein of any explosive or flammable gas, dust or vapour does not exceed the lower explosive limit of that gas, dust or vapour.

The NBR Part O section 01 specifies that the means of ventilation to any specified room should provide air that is "without detriment to health or safety or causing any nuisance" [NA88].

This section requires air that has good quality and sufficient quantity to provide a safe, healthy and comfortable workplace for the worker.

If Part O of the NBR is complied with in any habitable room, and the means of ventilation complies strictly with the outside air requirements, then it is assumed that high levels of toxic airborne substances should not be present in the air of workplaces.

4.4 SABS CODE 0400

The SABS Code 0400 1987 [SA87] prescribes the following control measures for design, installation and maintenance of an air-conditioning system.

Installation and Design
The SABS Code 0400 1987 [SA87] specifies that no air-conditioning system can be installed in a building without the prior written consent of the local authority. The design of an air-conditioning system can only be carried out by or under the supervision of a professional engineer or other approved competent person.

Maintenance
Part 05 [SA87] specifies certain criteria for design, maintenance and security of the ventilation system.

Testing of Air-conditioning systems
Part O of the Code [SA87] requires that the owner of the building "shall at acceptable intervals of time submit to the local authority, a test report indicating that any air-conditioning system installed in terms of the NBR is operating in the designed manner."

The submission of these reports to a local authority places the onus on the owner of the building. The intervals for submission is unspecified but can be decided upon by the local authority. At present, however, this is not enforced by local authorities.

4.5 INTERNATIONAL CODES

A bill (Number HR 3809) was tabled in the United States congress to be called the "IAQ Act of 1987" in December 1987. The purpose of the bill was to authorise a national programme to reduce the threat to human health posed by exposures to contaminants in the air indoors. The bill comprehensively recognised the threat of indoor air exposures to human health and enabled the establishment of a "national programme of research and development concerning the seriousness and extent of indoor air contamination." This bill has recently been enacted and is enabling the US Environmental Protection Agency to conduct a large amount of research on IAQ topics.

The states of Minnesota, Washington, California, Texas, West Virginia, Wisconsin, Ohio and Massachusetts, in the USA have well developed IAQ research programmes. California's programme is the largest although it has no regulatory authority or responsibilities [GO89].

The Pittsburg Health Department [AL88] has adopted a policy concerning indoor air and various documents have already been circulated in the department. The draft specifies an approach for the department when dealing with indoor air problems and complaints. American Society for Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) has published numerous guidelines for its members. A Guideline entitled "Ventilation for Acceptable Indoor Air Quality No 62-1989" [AS89] forms an integral part of their approach. These guidelines specify air quantity rates only and the ventilation rate is assumed to provide acceptable indoor air quality, ipso facto. The UK has not kept pace with the legislative developments of the USA. In Denmark and Sweden research is ongoing and no current legislation was known to be available.

4.6 DISCUSSION

Plans for new buildings are scrutinised for compliance of the design parameters with the criteria laid down in the legislation. At present plans are simply endorsed to state that ACS must comply with Part O of the National Building Regulations [NA87]. The completed building is not checked to determine if the ventilation system does comply.

Subregulation 1 of Section 06 [NA87] requires that any artificial ventilation system is to be tested and the reports submitted to the local authority on a regular basis. This does not happen.

Changes in office layout take place without regard to the requirements for artificial ventilation systems. The new layouts could deviate considerably from the original for which the existing ventilation had been designed. This could lead to problems.

There is insufficient infrastructure of equipment and manpower to carry out routine and acceptance tests within local authorities, although it would be desirable to do so in all cases and incidents which relate to ACS complaints.

Occupants of sealed buildings are becoming more conscious of defects in ventilation systems. Where complaints have been investigated, the results generally revealed a design fault or an oversight in the maintenance programme of the artificial ventilation systems. The assumptions made in the National Building Regulations should be queried.

The relevant authorities could adopt a more comprehensive policy for dealing with new building plans, checking of new plant and routine testing of all artificial ventilation systems and become proactively involved in mitigating indoor environmental problems.

Complaints received by the relevant authorities would be investigated as a part of this policy. A data base can be created which would include the specifications of frequently used equipment, the design criteria applied to plans for new buildings, the regular test report, details of office layouts and changes made in the occupancy of buildings.

As the interest of industry increases, a more comprehensive strategy for dealing with regulatory indoor issues is needed. This strategy should be developed on different levels.

4.6.1 State Involvement

At present three sections of South African legislation which affect indoor environments are applied by three departments. These were discussed in Paragraph 4.1. It must be pointed out that various government departments administer each act and this has led to a fragmented approach. Limited enforcement exists in all of these departments.

4.6.2 Machinery and Occupational Safety Act

The "factory inspectors" presently empowered to enact the regulations of the MOSACT [MA83] are few in number. Limited occupational hygiene work is conducted. Only industrial sites are investigated and visited. Approximately twenty-two inspectors are employed for the PWV area. The environmental regulations of the MOSACT [MA83] could be applied in non-industrial offices with reference to IAQ. However, this would place the inspectorate under a severe work load as the demand for such a service would be high.

The lack of finance in State departments would restrict this need. Reluctance of central government to over-regulate is another added constraint. Ideally suited to providing legislative cover for IAQ research, the Department of Manpower has not yet been involved in general research and development of occupational hygiene and medicine. This could have been solved by delegating section 20 and 21 for the attention of local authorities, who have the manpower and resources to deal with these issues.

In short, the only mechanism which the Department of Manpower could consider is the self-regulatory approach by the ventilation industry, assisted by local authorities.

At present no aspect of ventilation in sealed multi-storeyed buildings is controlled either by central or local government. A more strict application of existing legislation should be adequate to cause the ventilation industry to examine the health and design issues relating to indoor environments and to improve the working conditions of all workers. Costs of such an exercise could be reduced by placing the responsibility on the relevant professions involved in designing ventilation systems, in particular, architects and ventilation consulting engineers. In the UK, the Health and Safety Executive has a special interest in IAQ issues and has actively participated in assisting industry to remedy these problems. The argument against such an initiative here is that there is a small demand for such a service/assistance programme. However, it is obvious that this is only because of lack of knowledge and the absence of such a programme, which does not enable the general public to make use of it.

4.6.3 Local Authorities

Usually all queries relating to ventilation on local authority level are referred to the Health Inspectorate for assistance. In the larger local authorities basic airflow measurements and an assessment of the particular conditions can be made by staff. Further investigation of IAQ complaints is often not carried out, due to various reasons as:

- Lack of progressive management;
- Lack of specific knowledge, and
- Lack of equipment.

Proactive measures at the design and construction stage by local authorities can relieve indoor environmental problems.

Indoor environmental problems can be resolved by an easily used methodological approach. Once initial investigation has been completed, the health officer could refer the complaint to a specialist organisation.

4.7 CONCLUSION

The current legislation pertaining to IAQ in South Africa is not applied adequately to deal with indoor environmental problems. It will not be possible to formulate a single integrated approach for resolving IAQ issues with the current fragmentation of the health care system. Indoor environmental regulation will have to be applied by a single body with a strong mandate in the form of new or reviewed legislation. However, insufficient knowledge exists at this time both locally and internationally to provide a basis for new legislation.

CHAPTER 5

PROJECT DESIGN: METHODS AND RATIONALE

5.1 INTRODUCTION

In any research project the design of the study is possibly the most important factor. Should the design not be well prepared then the validity of the study will be in question. In this study much attention was paid to the type of methodology used by similar studies in the USA and UK so as to keep in line with current indoor air investigations and ensure the validity of the study.

The initial tendency to use occupational hygiene techniques to evaluate indoor environments revealed little to researchers. As usually the levels of indoor air pollutants were far below the threshold limit values used by occupational hygienists [TU83]. Occupational exposures are generally much higher than those measured in the indoor environment. Instead, the tendency is more towards extensive use of epidemiology - questionnaire surveys with a large data set and limited indoor environment measurements. This enables savings in terms of manpower and finances.

This may be useful in other countries, but in South Africa, it may do well to conduct comprehensive surveys of indoor air quality in an initial information gathering effort to ascertain the true situation in respect of air quality and then simultaneously to use a well designed questionnaire.

The local environmental conditions on the Highveld and the height above sea level provide an important basis to assess these indoor environments.

This should not exclude the initial walk-through survey and investigation of the building's air-conditioning system [HU86,RO86]. Many local buildings are similar in design to American buildings. The large amount of glass buildings in the Johannesburg city centre is evidence of this.The appropriate method for solving IAQ problems is the most crucial of all. Added to this choice is the dilemma of matching the right equipment to the right method [NI87].

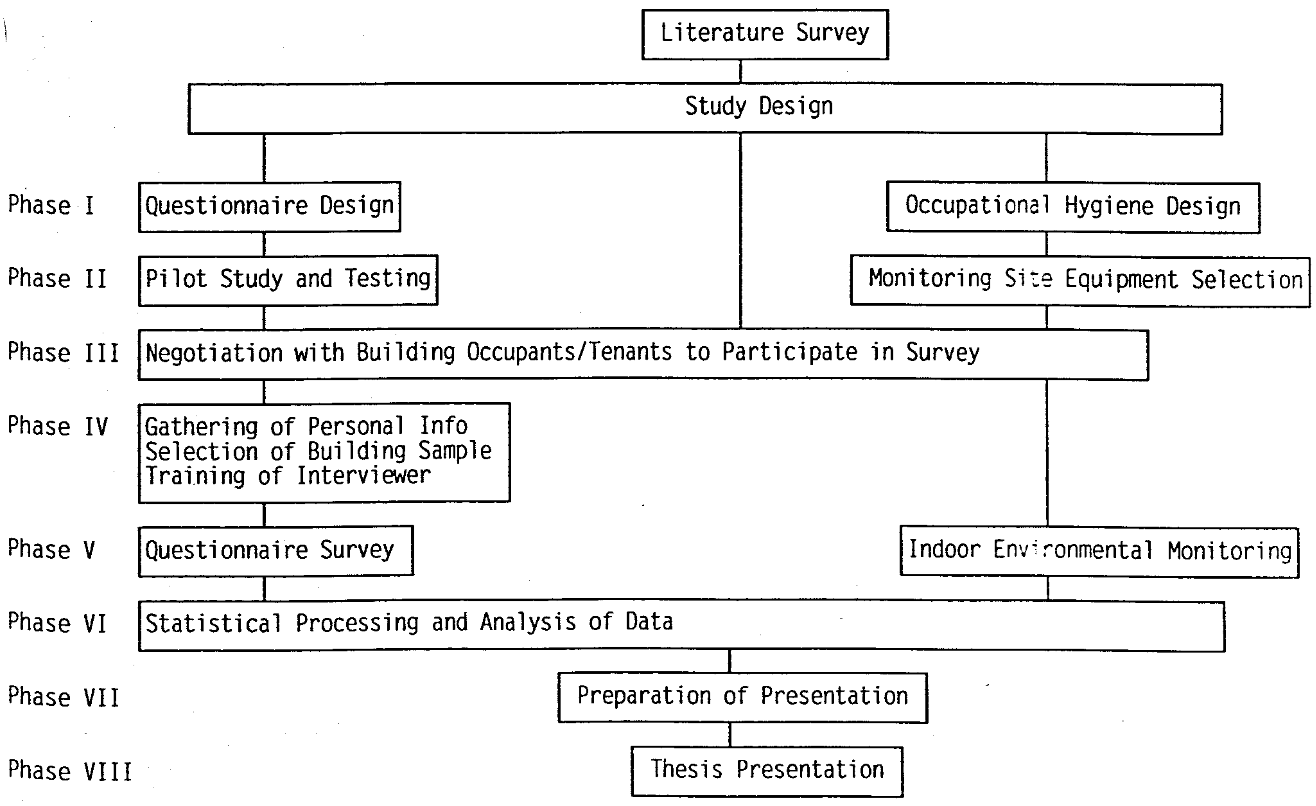
Apart from the ASHRAE [AS89] CO_2 rationale and method for investigating IAQ problems, each investigation will vary and so will the method.

In most cases, a long term monitoring method is preferable, one that monitors for at least seven days in the selected site. This will ensure that a true pattern of the indoor pollutants and thermal parameters will be reflected in the monitoring procedure. The investigator will be able to observe any diurnal variations at the measurement site, as well as to become more acquainted with the particular nature of the building. The use of data logging equipment with the monitoring station is useful, reduces man hours, increases accuracy and enhances presentation. While cost is always the deciding factor, the IAQ investigator has to use equipment which is highly sensitive and reliable. Increased sensitivity will increase the possibility of solving the problem and this is the desired result.

In this study a comparison was made between a sealed multi-storeyed building and an unsealed naturally ventilated building in the city centre. These two buildings were selected from a pool of 35 buildings made available for the study by two major leading property companies. Each building was visited to ascertain what type of building it was and the type of ventilation system used. A profile was made of each building available for the study. Based on these profiles the best profiled building was selected on a weighted score and not on personal preference. After the sample and control buildings were known, it was possible to proceed to visit the tenants of the buildings.

In each building sufficient numbers of office workers were available to investigate the building, and assess the indoor environment using an interview based questionnaire. In addition, literature studies of other major indoor environment studies were reviewed and it was possible to formulate the study design. The study design is detailed in Figure 5.1.

Figure 5.1: Study Design



5.2 QUESTIONNAIRE AND EPIDEMIOLOGICAL STRATEGY

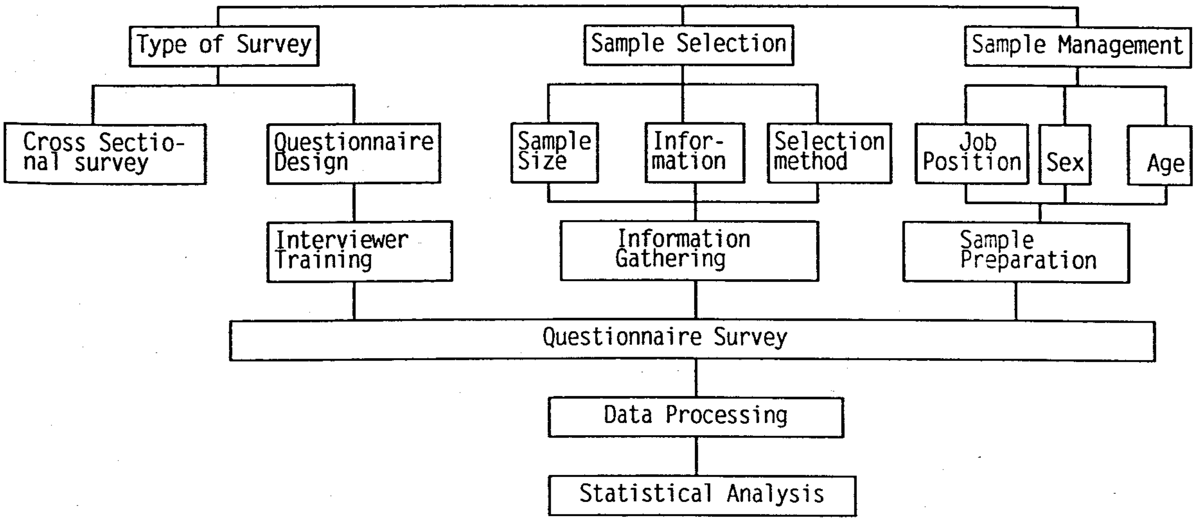
5.2.1 Phase I - Questionnaire Design

Various questionnaires had been obtained from overseas projects for comparative analysis [BU87]. It was felt that the design of these self-administered questionnaires could introduce bias to the sample population as they were direct in the manner in which they questioned the respondents. Questionnaire administration presents the researcher with a number of options, namely:

- Self-administered;
- Interview administered;
- Telephone administered; or
- Postal questionnaire.

The interview administered method was selected as the most suitable method for this study as the direct contact would produce the highest response rate. The questionnaire was prepared in consultation with the senior epidemiologist from the Epidemiology section at the National Centre for Occupational Health. A biostatistician employed at the Johannesburg City Health Department was also involved in the preparation of the questionnaire. Most of the content was original with some of the questions coming from questionnaires in the UK and USA. There were 44 questions in total. The document was prepared in both official languages (see Appendix 2). It was prepared at the Johannesburg City Health Department with a covering letter. The process is shown in figure 5.2.

Figure 5.2: Questionnaire Survey Design and Strategy



- Job Position
  level 1 = Upper and Middle Management
  level 2 = Lower Management and Clerical
  level 3 = Domestic and other staff

- Age - Initially three age groups were used but this was changed to two due to small sample subgroups:
  Level 1 = < 35 years
  Level 2 = > 35 years

- Sex 1 = Male
  2 = Female

Once these matching groups had been determined the sample was selected using randomisation on a computer software programme. Proportional selection was then undertaken to adjust for the differently sized groups which were formed.

When the sample selection was completed, each prospective respondent was informed by personal letter in a sealed envelope of their selection, the date and place of interview.

Training of Interviewers
In order to effectively administer the questionnaires, suitable interviewers were required. Initially three interviewers had been trained and were used in the pilot study. These three interviewers and an additional two were selected for the study. Further comprehensive training in questionnaire techniques was given. All the interviewers were bilingual and female. One interviewer was able to act as an interpreter for several black languages.

5.2.5 Phase V-Questionnaire survey

The sample building (A) was the site for the first series of interviews. This process took two and a half days. The interviews commenced at the tenant occupying the highest floor and then worked down until the lowest floor of the building. This procedure was repeated in the control building (B) over the next two days.

During the interviews very few problems were experienced with any of the participating companies wanting to withdraw from the study. In only a few instances were people either not available or out on business and thus were not available to be interviewed. If respondents were on sick or annual leave then a another respondent was drawn from the back-up sample created for such circumstances. These persons were normally company managers or executives.

5.2.2 Phase II - Pilot Study

A pilot study was organised and the questionnaire was tested with a total sample of 60 people. The results of the pilot study indicated that no serious problems were encountered in the questionnaire design. The monitoring of pollutants was also successful and correct calibration techniques were shown to be an important factor in instrument reliability. The results of this survey are presented in Appendix 3.

5.2.3 Phase III - Negotiations with Building Occupants

Once the questionnaire had been completed discussions to obtain staff lists of personnel had to be finalised with the tenants of the selected sample and control buildings. These lists were used to select respondents and to match age, sex and job position. For more information on the building selection, see the discussion under the title of Occupational Hygiene Survey (Section 5.3).

In total, there were 50 tenants in both buildings. Each tenant was sent a letter addressed to the manager of the company. This letter briefly described the survey and informed the tenant that a visit by the researcher would follow to discuss the proposed study. Except for 3 tenants, all agreed to participate in the study.

5.2.4 Phase IV - Selection of Sample and Population

After obtaining the participation of the building occupants, each tenant supplied personal data pertaining to job, sex and age of all staff employed. This proved a testing job as in every tenant's company staff turnovers made selection of respondents somewhat difficult.

Once all personal data lists had been supplied, it was possible to ascertain the number of persons available for the study.

Table 5.1: Breakdown of Sample Population

	Total number	Sample selected	Actual respondents
Building A	749	200	175
Building B	448	200	147

In order to reduce the number of confounding variables in this type of survey, it was decided to use a control population and match the sample populations for job, age and gender in the buildings. The matching groups were structured as follows:

5.2.6 Phase VI - Processing and Analysis of Data

Shortly after the questionnaire survey had been completed the questionnaires were coded and checked. This process was done a number of times to ensure that there were no errors. After all the questionnaires were complete, they were submitted to the Institute for Biostatistics for statistical analysis. The data was analysed using the BMDP statistical package.

5.2.7 Phase VII and Phase VIII - Preparation and Presentation of Data

After analysis, the results were presented using the Harvard Graphics package. The results of the questionnaire survey are presented in graphical format in Chapter 6.

5.3 OCCUPATIONAL HYGIENE SURVEY

5.3.1 Phase I - Design

At the time of designing the study format, very little information was available to the author. It was thus necessary to do extensive inquiries as to equipment availability. It was found that very little equipment was available for indoor monitoring.

The range of pollutants and physical factors impacting on indoor air quality include the following: particulates, carbon monoxide, nitrous oxide and nitrogen dioxide, carbon dioxide , ozone, volatile organic compounds, airflow and temperatures. The health effects, health standards, and characteristics of those measured are presented in detail later in the chapter. However, the major constraint was the availability of reliable instruments for measurement. The design was further constrained by the availability of instruments from various sources. It was possible to borrow equipment to measure the parameters listed except for the Ozone and Volatile Organic compounds. The measurements obtained with the equipment are deemed to be reliable.

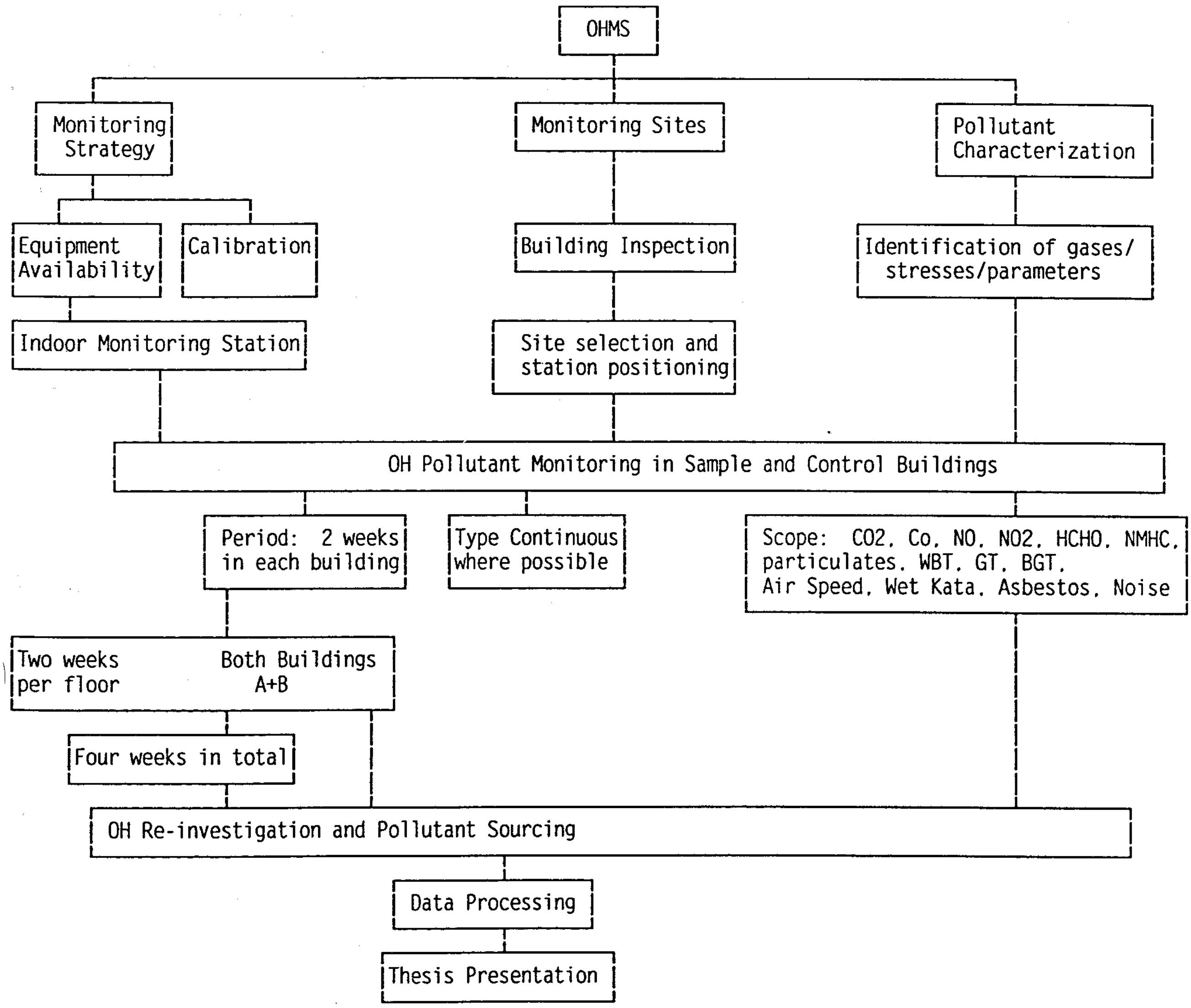
5.3.2 Phase II - Methodology

It was decided to make use of a representative sampling strategy in both buildings. The key to this strategy would be the careful and correct selection of monitoring sites. The following criteria were considered when selecting the sites:

<u>Selection Criteria</u>

- Sampling to be conducted in both open and closed plan offices;
- Sampling site to be situated in an area of normal office activity;
- Sampling site to provide security for the monitoring station;
- Sampling to be conducted for one week at each site, and
- Sampling sites to be on various floors of both buildings.

Figure 5.3: Occupational Hygiene Monitoring Methodology and Strategy



5.3.3 Phase III - Equipment and Monitoring Site Selection

The air-conditioning technician was not informed that the survey was going to take place. This ensured that the air-conditioning system would supply air as normal. An office deemed to be similar in type to all the offices on the floor was selected randomly from a prepared list. The thermal parameters were measured in three separate offices so as to provide an indication of the thermal environment of the floor. The selected office was used to conduct the monitoring over a period of one week (Monday to Sunday). The equipment was placed in a selected area where it was felt that the air to be sampled was similar to that of air that would be inhaled by the office worker. The monitoring equipment was connected to a data logger which recorded the following pollutants - carbon monoxide, nitrous oxide and nitrogen dioxide. The carbon dioxide monitor was connected to a chart recorder.

5.3.4 Phase V - Indoor Environmental Survey

Thermal measurements which included the globe temperature, wet bulb globe temperature, wet bulb index, wet kata index and air velocity were conducted over a four week period in both buildings. The pollutants measured are given in table 5.3. It was not possible to monitor pollutants at the fresh air intakes as there was no equipment available to measure inside and outside the building.

Monitoring procedure

The Occupational Hygiene Survey (OHS) was conducted in both sample buildings. Two floors were to be sampled in each building. The procedures for the sampling and measurements of all parameters was conducted in accordance with recognised scientific and industrial hygiene procedures wherever possible. A layout plan was obtained of the two floors on which monitoring took place. The rooms sampled were representative of typical conditions experienced by the sample population to be tested in respect of the following factors:

- Thermal parameters;
- Airflow standards;
- Standard layout and furnishings of office, and
- Standard usage and density.

Periods of monitoring

Table 5.2 below gives an indication of the time span over which pollutants were monitored. The OHS commenced at the same time as the questionnaire survey. The monitoring took 4 weeks and was conducted as follows:

Table 5.2: Monitoring Timetable

Week I	Sample Building	Floor 28
Week II	Sample Building	Floor 2
Week III	Control Building	Floor 10
Week IV	Control Building	Floor 2

Processing of Data

The CO, CO_2, HCHO, Nitrogen Oxides (NO_x) analyzers ran simultaneously. These analysers ran for 7 days and thereafter the logger was downloaded at the laboratory. The equipment was then set up to run for one week on another floor.

This procedure was repeated until the monitoring period was completed.

The monitoring of HCHO was done using passive badges These were to be changed three times a day. They were taken to an approved laboratory for analysis by gas chromatograph.

Calibration

The analysers were calibrated prior to the survey in accordance with the prescribed calibration procedures for each instrument.

5.3.5 Phase VI, VII and VIII - Analyses and Preparation of Data

Once a sampling phase was completed at the site, the data was downloaded into an IBM personal computer with the Lotus programme. The data was then prepared in a graphic format. The results are presented in Chapters 7 and 8.

5.4 EQUIPMENT

Measurements were limited to available resources and manpower, and were taken using the following equipment:

Table 5.3: Equipment Availability

PARAMETER	METHOD	INSTRUMENT
Airflow in building	Wet Kata Index	Wet Kata Thermometer
Cooling power of air	Wet Kata Index	Wet Kata Thermometer
Dry bulb temperature	Electronic sensor	Tempstress (SCI)
Wet bulb temperature	Electronic sensor	Tempstress
Moisture content -	Electronic sensor	Tempstress
Relative humidity -	Electronic sensor	Tempstress
Respirable dust -	Strategic Sampling	High Volume pump
Carbon Dioxide	Infra-red analyser	Hachmann & Brown meter
Carbon Monoxide	Electro chemical	Ecolyser + logger
Sound measurements -	Sound analyser	SLM = Sound level meter(B&Kjaer)
Luminance	Electronic device	Luxmeter (Sonic)
Formaldehyde	Long term sampling and GC analysis	3M passive badges
Nitrogen Dioxide	Chemiluminescence	Nox Analyser (Monitor Labs)
Nitrous Oxide	Chemiluminescence	Nox Analyser
Nitrogen Oxides	Chemiluminescence	Nox Analyser

KEY:
Wet Kata Index: *A glass bulb alcohol type thermometer which measures the cooling power of the air and low air velocities.*
Tempstress: *an electronic device which uses a thermocouple and measures the necessary thermal indices which affect human performance.*

5.5 POLLUTANTS ENCOUNTERED IN THE INDOOR OFFICE ENVIRONMENT

The following chapter deals with the nature of indoor pollutants measured in the study and gives the reader a brief insight into their physical nature. The relevant standards and the methods which will be used to collect the data in the study are presented.

The range of indoor air pollutants is tabulated in Table 5.4.

Table 5.4: Major Indoor Pollutants, Sources, Concentrations and Health Effects

Pollutant	Source	Concentration	Health Effect
Nitrogen Oxide	Nat Gas*	ave 0.5 ppm	Respiratory effects
Nitrogen Dioxide	Nat Gas		Respiratory effects
Sulphur Dioxide	Wood fires		Respiratory effects
Carbon Dioxide	Human Metabolism	600-2000 ppm	URTI,Headache
Carbon Monoxide	Metabolism	0-10 ppm	Headache, Drowsiness
Formaldehyde	Internal furnishings	0.03 ppm	Irritation of URT
Volatile Organic Compounds	Photocopies		" "
Asbestos	Lagging	<1fpml	Pulmonary Fibrosis
Microbes	Human meta-bolism, ACS	103x106	Humidifier Fever Allergic alveolitus
Ozone	Photocopies		
Respirable particles			Irritation of URT

**Nat = Natural*

5.5.1 Carbon dioxide (CO_2)

Characteristics:
CO_2 is a colourless, odourless, non combustible gas, soluble in water. It is commonly sold in compressed liquid and solid form [NI77].

Sources:
The main source of CO_2 indoors is human metabolism. Another major source is motor vehicle exhaust gases.

Relevant Standards:
The following standards are applicable:

5000 ppm ACGIH TWA Industrial Standard [AC90]
1000 ppm ASHRAE: Recommended Indoor Standard [AC90]

Methods:
The most common monitoring methods involve gas chromatography, electrochemical or infra-red detection. If available, portable gas chromatographs(GC) can also be used. Otherwise, air samples can be collected in bags for subsequent GC analysis (range according to NIOSH is approximately 500 - 150000 ppm). In this study a BAUER non-dispersive infra-red detector was used with a chart recorder.

Health Effects
CO_2 is a simple asphyxiant. Concentrations of 100 000 ppm can produce unconsciousness and death from oxygen deficiency. A concentration of 50 000 ppm can produce shortness of breath and headache [NI77].

5.5.2 Carbon monoxide (CO)

Characteristics:
CO is a colourless, odourless, tasteless gas which is slightly soluble in water. It has a specific gravity of 0.967 and is therefore slightly lighter than air.

Sources:
Environmental tobacco smoke is the principal source of CO indoors. Motor vehicle exhaust gas is another source.

Relevant Standards:
The following standards are applicable:

50 ppm	ACGIH TWA* Industrial Standard [AC90]
400 ppm	ACGIH STEL* Industrial Standard [AC90]
10 ppm	NAAQS* 1 Hr Standard [AS89]
9 ppm	NAAQS* 8 Hr Standard [AS89]
35 ppm	EPA 1* Standard [AS89]

**See Appendix 1 for definition*

Methods:
A Gastech Ecolyzer series 300 continuous system with a lower detection limit of 0.1 ppm was used for continuous monitoring at the selected site. The data was captured using a MI Enviro Logger and Techtran 817 Datacasher cassette system.

Health Effects:
It is an asphyxiant and has an affinity to blood haemoglobin. This affinity is 200 to 250 times that of oxygen. It interferes with oxygen transport to the tissues and results in tissue hypoxia.

CO reaches the alveoli with Oxygen transport where it competes with Oxygen for one of the four iron sites of the haemoglobin molecule. Combining of CO and haemoglobin molecules forms carboxyhaemoglobin (COHb)[GI85].

The known side effects at increased levels of CO exposure lead to reduced oxygen transport to the tissues resulting in tissue hypoxia. CO causes the following known health effects:

Cardiovascular effects (2.9 - 4.5% COHb)
Neurobehavioural malfunctioning (5% COHb)
Fibrinolysis effects (10% COHb)
Perinatal effects.

Blood COHb levels are accepted as being the main physiological marker of CO exposure. However, current thinking amongst the health professions has only concentrated on elevated levels of CO exposure. Concern is now being directed at the health effects of low levels of CO. Available data demonstrates an association between cardiovascular and neurobehavioral effects at relatively low level exposures.

5.5.3 Nitrogen dioxide (NO_2)

Characteristics:
NO_2 is a red to brown gas with a pungent acrid odour. NO_2 is produced during combustion from the combination of nitrogen and oxygen from air.

It is an oxidising agent and causes a wide variety of health effects [EN87]. Atmospheric processes tend to bring the oxides of nitrogen to the nitric acid stage over a period of time [RE85].

Sources:
The primary source of NO_2 is motor vehicles and gas stoves. Gas stoves are, however, not generally used in sealed multi-storeyed buildings in South Africa and shall not be discussed in this section.

Relevant Standards:
The following standards are applicable:

03 ppm	ACGIH TWA* [AC90]
50	ACGIH STEL* value

**See Appendix for definitions*

Methods:
A Monitor Labs NO_2 detector using chemiluminescence analysis with a lower detection limit of 0.1 ppm was used for continuous monitoring at the selected site. The data was captured using a MI Enviro Logger and Techtran 817 Datacasher cassette system.

Health Effects:
Many if the conclusions made about the health effects of NO_2 are based on animal toxicology studies.

Indoors NO_2 levels can decrease pulmonary function[EN87]. Furthermore not much is known of the synergistic effects of other pollutants. NO_2 causes pulmonary function side effects. The table below briefly summarises the known effects of NO_2

Table 5.5: Health effects of NO_2

CONCENTRATION	KNOWN HEALTH EFFECTS
2.5ppm	1. Increased susceptibility to bacterial infections and changes in host defences
	2. Major structural alterations in lungs
	3. Changes in pulmonary function
	4. Changes in lung biochemistry
<1 ppm	1. Decrements in lungs last defences
	2. Lung structural changes (possibly indicative of chronic lung disease)
	3. Changes in lung metabolism

5.5.4 Formaldehyde (HCHO)

Characteristics:
HCHO is a colourless, pungent gas. It is used as fungicide, germicide and in disinfectants and embalming fluids. It is used in glues and is found indoors in pressed woods and carpet glues. It is an important pollutant in indoor environments. It falls under a category of similar gases often referred to as volatile organic compounds.

Sources:
HCHO is prevalent in most sealed environments due to "off gassing" from a variety of sources. The US EPA reports that over 250 Volatile Organic Compounds (VOC) have been measured in homes at levels greater than 1 ppb. The sources of VOC's are [NI83]:

- paints
- stains
- caulks
- shoe polishes
- water replants
- varnishes
- cleansing fluids
- primers
- plastics
- epoxy resins
- vinyl tiles

Most VOC's encountered indoors are higher in concentration than those found outdoors.

Relevant Standards:
The following standards are applicable:

0.1 ppm	EPA indoors [AC90]
0.16	ACGIH TWA* [AC90]
0.1	ACGIH CEILING* [AC90]
1 ppm	OSHA TWA* [AS89]
2 ppm	OSHA STEL*[AS89]

**See Appendix for definitions*

Methods:
3M passive sampling badges were used. This method was the only acceptable and accurate available at the time of the survey. They were analysed by gas chromatography at the 3M laboratory. They reflect the TWA TLV's of the ACGIH [AC90]. Two badges were placed in each building.

Health Effects:
The health effects of exposure to VOC's are known and depend on the dose response relationship. The main effect seems to be a sensory effect but the following neurotoxic effects have been reported: central nervous system depression, tremor, unconsciousness, vertigo, visual disturbances. Molhave et al [MO86] have suggested that low level VOC exposures produced memory impairment and sensory irritation in subjects of Danish homes.

HCHO is a well known irritant of the upper respiratory tract. In sealed environments, it can become trapped as the air is recirculated with only a small amount of top-up air [WA87].

The acute effects of formaldehyde at various levels are listed below.

[] ppm	Effect
0.0 - 0.05	None reported
0.05 - 1.5	Neurophysiological effects
0.05 - 1.0	Odour threshold
0.01 - 2.0	Eye irritation

May cause severe irritation to the mucous membranes of the respiratory tract and eyes. Repeated exposure may cause dermatitis. Inhalation may cause pulmonary oedema.

5.5.5 Nitrous oxides (NO)

Characteristics:
NO is a colourless, incombustible gas, sweet-tasting, and slightly soluble in water.

Sources:
The primary source of NO is motor vehicles and gas stoves. Gas stoves, however, are not generally used in sealed multi-storeyed buildings in South

Africa.

Relevant Standards:
The following standards are applicable:

50 ppm	ACGIH TWA* [AC90]
00	No STEL* value

**See Appendix for definitions*

Methods:
The most common instrumental method is chemiluminescence analysis. A Monitor Labs NO detector using chemiluminescence analysis with a lower detection limit of 0.1 ppm was used for continuous monitoring at the selected site. The data was captured using a MI Enviro Logger and Techtran 817 Datacasher cassette system.

Health Effects:
Exposure to NO may produce irritation of the eyes and mucous membranes. Prolonged low level exposures may produce yellowish or brownish staining of the skin and teeth. Exposure to high concentrations of nitrogen oxides may result in severe pulmonary oedema [NI77].

5.5.6 Non-Methane Hydrocarbons (NMHC)

Characteristics:
NMHC's are higher molecular weight hydrocarbons which play a role in the formation of photochemical smog.

Sources:
They enter the air from car exhaust emissions which contain quantities of unburned hydrocarbons.

Relevant Standards:
The following standards are applicable:

0.4 ppm 1 hour ave. DNHPD*

** Dept. of National Health and Population Development*

Methods:
A HNU Photo-ionisation Detector with a lower detection limit of 0.1 ppm of benzene was used for continuous monitoring at the selected sites. The data was captured using a MI Enviro Logger and Techtran 817 Datacasher cassette system. Due to equipment limitations, measurements of the NMHC were only made on a daily basis.

Health Effects:
When involved in the formation of photochemical smog they have some effect on health.

5.5.7 Asbestos

Characteristics:
Asbestos is a generic term that refers to a group of impure hydrated silicated minerals which occur in various fibrous forms.

They are incombustible and separate into filaments. There are various types of asbestos such as amphiboles(amosite, crocidilite) and chysotile. Asbestos refers to a group of minerals that contain significant properties for use in heat and fire insulation and friction materials. These fibres are small, have a length to width ratio of more than 3:1 and are extremely strong.

Sources:
These products find their way into buildings as a result of construction, alterations, refurbishing and human activities. Asbestos was used widely as a fire retardent in many buildings between the 1950s-1970s. It was also used as an insulator on pipes. Asbestos fibres can be found in many forms in the ambient and indoor environment.

Asbestos fibres can be released into the environment from insulation. American health authorities recognised the threat in 1978 and have stopped its use [EN87]. It is still widely used in South Africa.

Relevant Standards:

1 f/ml	South African industrial standard [MO83]

Methods:
The AIA RTM 1 method was used to collect and analyse the air samples using a dust pump and collection unit.

Health Effects:
The fibres of asbestos are known to cause pulmonary fibrosis and lung cancer (mesothelioma) when individuals are exposed to fibres over a period of time. Continuous exposure over a long period of time can lead to respiratory illness. There are two types:

1) Asbestosis. Fibres inhaled into the lung are usually 0.1 to 100 μm in length. Once in the lung, repeated exposure causes the lung to become progressively disabled with decreasing lung capacity and function. This results in the lung being unable to transfer oxygen to the bloodstream and

2) Mesothelioma is usually associated with exposures to asbestos in the work place and results in asbestos related lung cancer. Mesothelioma is cancer of the lining of the lung [EN87].

5.5.8 Noise

Characteristics:
Noise has been defined as an unwanted sound or as being without agreeable musical quality Sound is defined as an acoustic vibration capable of

producing an auditory sensation. Noise can be further defined as a superposition of sounds of different frequencies and intensities without any phase correlation. Noise seldom comprises a single frequency, it is commonly classified as wide band or narrow band. The human ear can detect sound in the range of 16 Hertz to 20 000 Hertz [IN89].

Sources:
Noise can be generated by any process that emits sound and interferes with the normal environment of man.

Relevant Standards:
Private office 40 dBA SABS Code 0103-1983 [SA83].

Methods:
Noise can be measured with sound level meters.

These are electronic instruments consisting of a precision microphone, a high quality amplifier, a detection system and galvanometer with a dial indicating the sound level. These instruments can be portable or autonomous and must be calibrated according to standards laid by the ISO (International Organisation for Standardisation) [EN87].

Health Effects:
Exposure to noise during work activities can produce physiological and behavioural effects such as fatigue and annoyance.

5.5.9 Thermal Parameters

Characteristics:
The human body's normal temperature is 37.6 o Celcius. The body maintains its temperature by using the processes of convection, conduction, radiation and evaporation. Thermal comfort is a state in which the normal person finds it comfortable to work in. Thermal comfort for occupant buildings can be achieved by regulating the air movement, humidity and temperature.

Sources:
Heat is generated by various sources in buildings, computers, radiant heat from the sun, photocopiers, catering processes and metabolism of human beings.

Relevant Standards:
Summer Optimum 21,7 °C ASHRAE STD 55-1981 [AS81]
Winter Optimum 24,4 °C ASHRAE STD 55-1981 [AS81]

Wet Kata Index 16 TPA Bylaws [TP51]

Methods:
The Tempstress Instrument was used to measure the heat stress. The measurement of the air velocities was first attempted using a hot wire anemometer. After repeated attempts it was found that the airflow coming

from the inlet ducts was too low for reliable results.

Alternative methods are available in other countries but the sensitive equipment was not available at the time of the survey. The method of choice was the Wet Kata Index (WKI), a simple method used in South African gold mines to determine the cooling power of the air. Low air velocities can also be derived from the index using a formula.

The Kata Thermometer is used for the determination of the Wet Kata Index. The thermometer is heated, then removed and allowed to cool in the ambient atmosphere. The period taken for the alcohol to drop between two temperature points 37° to 36°C points, divided by a factor gives the Wet Kata reading. This reading effectively unites the wet bulb temperature and air velocity into a unit known as the WKI. Once the WKI is derived the air velocity can be approximated using a table provided or with a formula. Air velocities below 0-1 m/s will not give reliable readings [MI72].

A WKI of approximately 7 is used in the South African gold mines as an acceptable guide or limit. This figure represents conditions which will expose mine workers to acceptable limits of heat stress.

<u>Health Effects:</u>
Thermal parameters influence work productivity and in turn wellbeing. Exposure to high temperatures can lead to heat stress which can produce serious health effects.

5.5.10 Particulates and other combustion products

<u>Characteristics:</u>
Airborne particulate matter, represents a broad spectrum of matter which is chemical or physical in nature and may consist of liquids, aerosols or solid particles [EN87]. They are classed in two broad size categories with an aerodynamic diameter as follows:

Coarse particles	3 μm - 15μm
Fine particles	< 3 μm

The relationship of particle size and chemical type for ambient particles is well known but this is not generally true of indoor particles [EN87].

<u>Sources:</u>
Outdoor particles are generated from a variety of sources such as industrial processes, mining, construction and combustion. The main source of respirable particles in buildings are tobacco smoke, wood or coal stoves (if still used), outside air, occupant activities, aerosol sprays, mineral and synthetic fibres and biological materials.

Relevant Standards:
These standards refer to particulate matter less than 10 μm.

75 $\mu g/m^3$ annual geom. mean	Primary US EPA Std-NAAQS*
260 $\mu g/m^3$ maximum 24 hr	Primary US EPA Std-NAAQS*
60 $\mu g/m^3$ annual geom. mean	Secondary US EPA Std-NAAQS*
150 $\mu g/m^3$ maximum 24 hr	EPA NAAQS
0.15 mg/m^3 PM10 24 hr	EPA NAAQS
350 $\mu g/m^3$ TSP 24 hr	EPA NAAQS

**See Appendix for definitions*

Methods:
Gravimetric sampling was conducted to obtain the amount of total suspended particles in the air of the buildings. It was not possible to size the particles at the time of the survey. The calibration of the flow rates was conducted before and after each monitoring period.

Health Effects:
Inhalation of particulate matter can cause adverse health effects. The EPA lists the following effects:

- Irritation of the airways resulting in decreased airflow;
- Altered mucocilliary transport;
- Changes in alveoli macrophagic activity, and
- Broncho-constriction arising from chemical or mechanical stimulation of irritant neural receptors in the bronchi [EN87].

Environmental tobacco smoke (ETS) is a major contributor to pollutants in the indoor environment. It is also harmful to non-smokers. The health effects on smokers have received more attention than on non-smokers.

The health effects of tobacco smoke or smoking on smokers have been well documented and investigated. Research has been carried out on passive smoking and indoor concentrations of ETS.

Exposure to ETS depends on the following factors:

- Where located in respect to the smouldering cigarette;
- The extent and form of ventilation, and
- Number of cigarettes smoked per unit time [WA87].

Studies have linked involuntary smoking with increased risk of developing lung cancer. Many investigations into the health effects of ETS have been conducted with controversial results. These studies have been criticised for incorrect statistical methodologies. Despite the variable epidemiological evidence, ETS has been recently characterised as a respiratory carcinogen.

The carcinogenic effects of ETS are not only limited to the lungs but to other parts of the body namely [SA87]:

- Brain;
- Breast;
- Endocrine system, and
- Female genital system.

Investigations have concentrated more on respirable particles emitted from tobacco smoke which is discussed subsequently. These effects however are still treated as controversial until further substantiated.

The United States Surgeon-General's report of the Health Consequences of Involuntary Smoking [US86] concludes that :

- Involuntary smoking is a cause of disease including lung cancer, in healthy non-smokers;
- The children of parents who smoke compared with the children of non-smoking parents have an increased frequency of respiratory infections, increased respiratory symptoms, and slightly smaller rates of increase in lung functions as the lung matures, and
- The simple separation of smokers and non-smokers within the same air space may reduce, but does not eliminate, the exposure of non-smokers to ETS.

Smoking of tobacco indoors can significantly contribute to the pollutant load of combustion products [GO89]. The EPA states that ETS contains 3800 constituents in mainstream smoke. Of the total, 300-400 have been measured in sidestream smoke.

Non-smoking adults who work for several years in smoking offices have similarly impaired lung function, similar to that observed in light smokers. The short term effects of ETS on non-smokers are burning eyes, nose, throat, headache and nausea. Passive smoking is the inhalation of sidestream smoke or second hand smoke. Sidestream smoke has a higher pollutant load than mainstream smoke.

Tobacco smoke produces many pollutants indoors and makes a major contribution in the form of particulate matter. This is illustrated in Table 5.6.

Table 5.6: Composition of Mainstream and Tobacco Smoke [WA87]

Characteristic or compound	Concentration, µg/cigarette smoke		
	Mainstream smoke (1)	Sidestream smoke (2)	Ratio 2:1
General characteristics			
Duration of smoke production	20	550	27.5
Tobacco burned	347	411	1.2
Particles, no/cigarette	1.05 x 10	3.5 x 10	3.3
Particles			
Tar (chloroform extract)	29.8	44.1	2.1
	10.2	34.5	3.4
Nicotine	0.92	1.69	1.8
	0.46	1.27	2.8
Benzo(a)pyrene	3.5 x 10	1.35 x 10	3.9
	4.4 x 10	1.99 x 10	4.5
Pyrene	1.3 x 10	3.9 x 10	3.0
	2.70 x 10	1.011 x 10	3.7
Fluoranthene	2.72 x 10	1.255 x 10	4.6
Benzo(a)fluorene	1.84 x 10	7.51 x 10	4.1
Benzo(b/c)fluorene	6.9 x 10	2.51 x 10	3.6
Chrysene,Benz(a)anthracene	1.91 x 10	1.224 x 10	6.4
Benzo (b/k/j)fluoranthrene	4.9 x 10	2.60 x 10	5.3
Benzo(e)pyrene	2.5 x 10	1.35 x 10	5.4
Perylene	9.0 x 10	3.9 x 10	4.3
Dibenz(a,j)anthracene	1.1 x 10	4.1 x 10	3.7
Dibenz(a,h)anthracene, ideno (2,3-ed)pyrene	3.1 x 10	1.04 x 10	3.4
Benzo(ghi)perylene	3.9 x 10	9.8 x 10	2.5
Phenols (total)	0.228	0.603	2.6
Cadmium	1.25 x 10	4.5 x 10	3.6
Gases and vapors			
Water	7.5	298	39.
Carbon monoxide	18.3	86.3	4.7
	-	72.6	-
Ammonia	0.16	7.4	46.
Carbon dioxide	63.5	79.5	1.3
NO	0.014	0.051	3.6
Hydrogen cyanide	0.24	0.16	0.6
Acrolein	0.084	-	-
	-	0.825	-
Formaldehyde	-	1.44	-
Toluene	0.108	0.60	5.6
Acetone	0.578	1.45	2.5
Polonium-210,pCi	0.04-0.10	0.10-0.16	1.4

a) *Unless otherwise noted.* b) *Filtered cigarettes.*
c) *3.5mg in particulate phase; rest in vapour phase.*
d) *5.5mg in particulate phase; rest in vapour phase.*

In children of smokers, passive smoking has been associated with increased frequency of cough, phlegm and wheeze. Much more extensive work is necessary on the effects of ETS on non-smokers, especially in indoor environments. What is known, however, is that passivesmoking can affect non-smokers [SA87]. In the indoor environment, various option for controlling tobacco smoke are available. Increased attention needs to be directed by ventilation engineers to reduce ETS exposure in the indoor environment.

5.5 DISCUSSION

The study design of the project is similar to other studies conducted overseas. The EPA Library of Congress study which is one of the largest to date has incorporated a similar approach. Some researchers do not conduct indoor monitoring but prefer to conduct only extensive questionnaire surveys. Some use a simple survey of the thermal environments even though many studies have shown that the OHS often reveal little in respect of pollutant concentrations. In this study it was important to obtain indoor pollutant data from a South African building and relate it to other studies conducted overseas.

The measurement of psychosocial factors thought to contribute to SBS are key factors which must be included in the questionnaire design. Consultation with the relevant professional will enable these aspects to be assessed in the study.

5.6 CONCLUSION

A correctly designed study is the most important criteria when deciding on the usefulness and validity of data obtained in it.

An examination of methodologies used in studies in America and Europe shows that an indoor environment study and questionnaire survey are the single most important tools for obtaining reliable results.

Furthermore, the study design will assist the investigator in reaching the objectives set and in testing the hypothesis.

Study design flaws can invalidate data. Normally they are found only after the study is completed. Designing the best method is therefore the ultimate aim.

To date there is no single solution to the problem of SBS. This is probably due to the fact that there is no single cause and research has shown indoor environments to be very complex and one of the most difficult to quantify. The difficulty for the air-conditioning technician and building management is to assure the complainant/s that action taken will solve SBS problems.

It is clear that occupants and building management also need to take steps to improve the aesthetic appearance of offices. The so-called Hawthorne effect may still have merit for a certain subset of building occupants. It is just possible that "SBS" problems may be a symptom of bad management of staff. By this is meant that SBS complaints are perhaps an involuntary way for staff to get management's attention.

CHAPTER 6

QUESTIONNAIRE SURVEY RESULTS

6.1 INTRODUCTION

ASHRAE's definition [AS89] of acceptable IAQ refers to the response of building occupants expressing their dissatisfaction or satisfaction with the building. In order to prove the hypothesis and meet the objectives set for this project, the questionnaire survey played an important role.

The prevalence of SBS symptoms can only be correctly measured with a epidemiologically designed questionnaire. Two key areas were relevant to satisfy the criteria for ASHRAE's definition [AS89]:

1) Dissatisfaction with the building, (80%) and
2) Indirectly manifested as the prevalence of SBS symptoms as defined by the current literature.

In this phase of the study, objectives number one and three as well as the hypothesis would be tested. Objective two (see Section 2.4) is discussed in the next chapter.

This section reports on the methodology, rationale and results of the questionnaire survey. It will also discuss the outcome in terms of the objectives and current overseas results.

The investigation of IAQ related complaints has often been done using a self-administered questionnaire as discussed in Chapter 1. In this study an interview administered questionnaire was evolved as discussed in Chapter 5. In the results that follow reference will be made to two buildings. They are:

Building A : Sample building and
Building B : Control or reference building

6.2 COMPARATIVE RESULTS

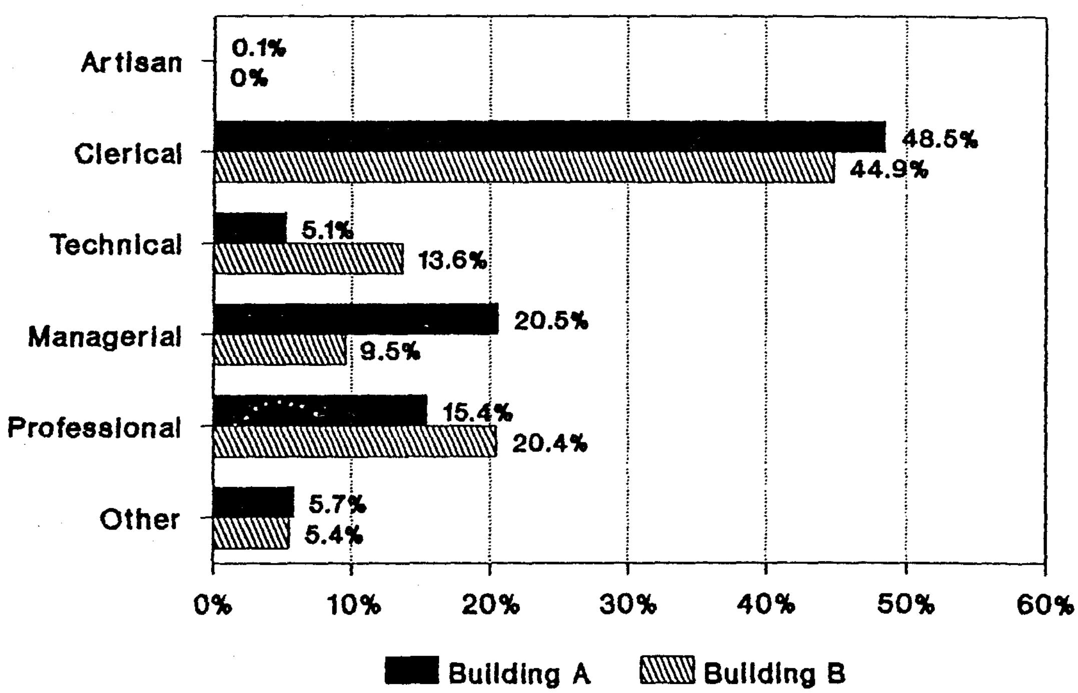
As previously stated, this study was designed as a cross sectional survey between two buildings with similar populations, but with different forms of ventilation. The comparison of the two populations to obtain prevalence rates of a subset of criteria was the main objective of the survey, as discussed in Chapter 5.

6.3 MATCHING OF THE POPULATION

In Chapter 5 the study design incorporated the matching of the selected populations. The practice of matching is used as a type of a restraint on the selection of the population and eliminates the differences between the two groups. By eliminating the differences in the two groups, the investigator is able to work with two similar groups and the results are useful for statistical analysis. The matching used was successful when comparisons are drawn.

There were similar percentages of clerical staff in both buildings [Building A:48.5% (n=85), Building B:44.9% (n=66)]. In building B technical staff were more prevalent [13.6% (n=20)] than in building A [5.1% (n=9)]. See Figure 6.1.

Figure 6.1: Distribution of job status by building



Generally the matching of job positions were similar as the job positions were matched in three categories.

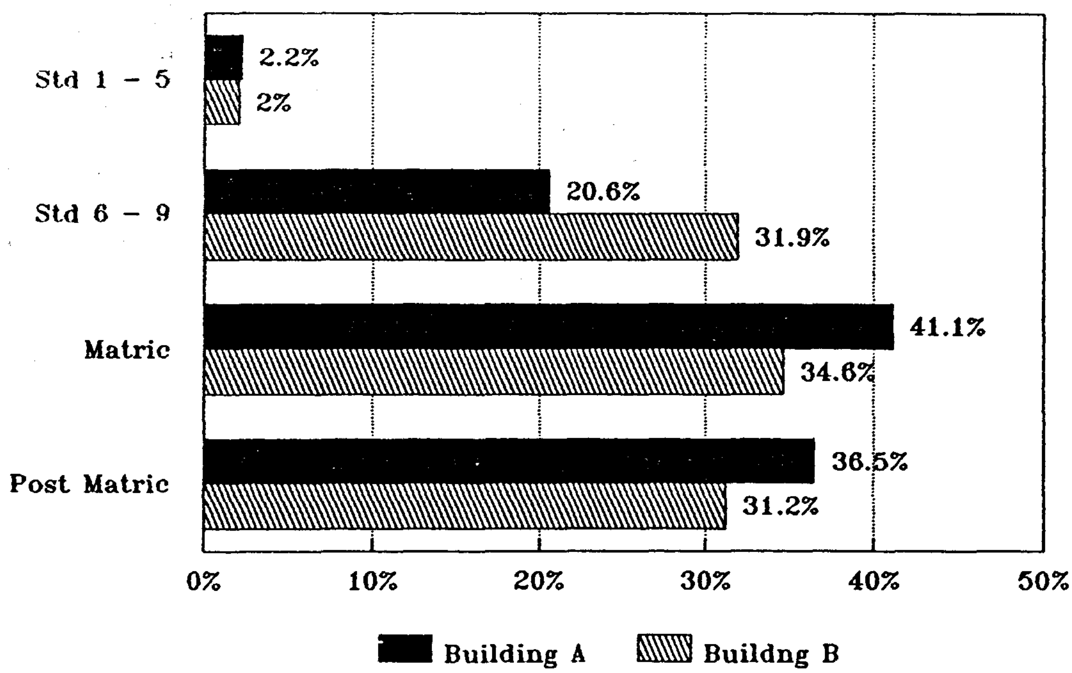
The numbers of females in both buildings was higher than males. The male/female ratio was (1:1.6) in building A and in building B (1:1.4).

6.4 DEMOGRAPHICS

The education levels of respondents in building A was higher than building B. The number of respondents with a matriculation in building A was 41.1% (n=72) and in Building B 34.7% (n=51). See Figure 6.2.

The number of parents in building A was 64% (n = 112) and building B 63% (n = 92).

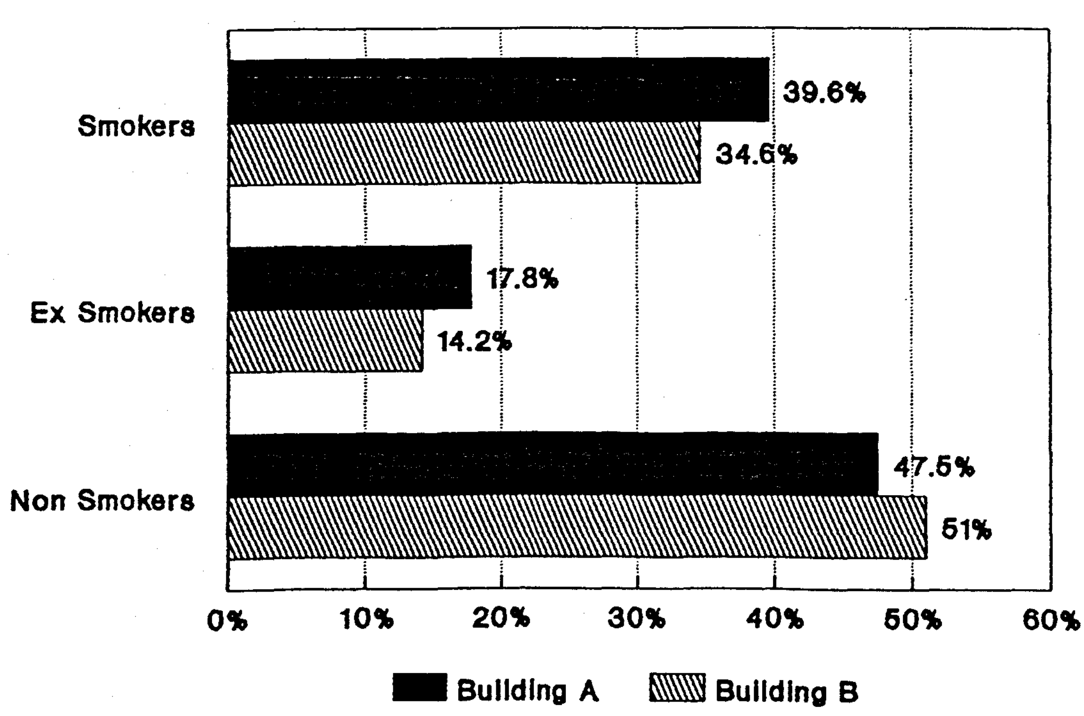
Figure 6.2: Distribution of educational qualifications in both buildings



6.4.1 Smoking Information

There was no significant difference between the smoking status of subjects in building A and building B (p=0.3049). In both buildings more subjects were non-smokers. [Building A : 47.5% (n=74) and building B : 51.0% (n=75)]. See Figure 6.3.

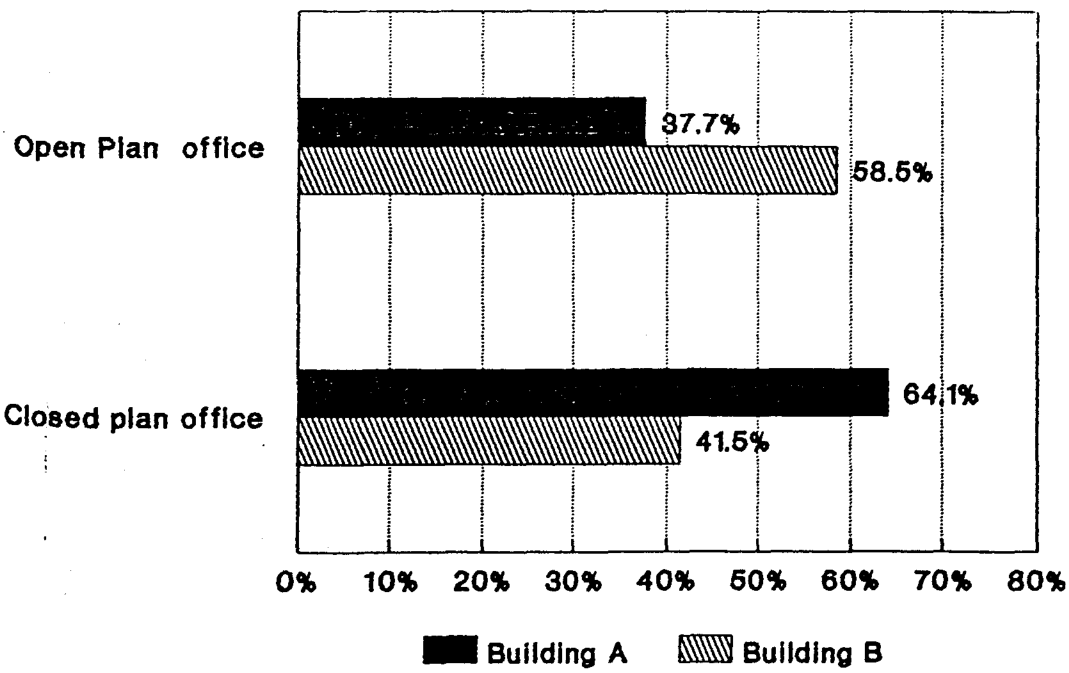
Figure 6.3: Smoking status amongst populations in both buildings



6.4.2 Job and Office Information

In building A, significantly more respondents had closed plan offices [64.1% (n = 107)] than open plan offices [37.7% (n = 66)]. In building B the opposite was true, more respondents having open plan offices [58.5% (n = 86)] than closed plan offices. There was a significant difference between the open plan offices and closed plans in both buildings (p = 0.0004). See Figure 6.4.

Figure 6.4: Open plan versus closed plan offices in building A and B



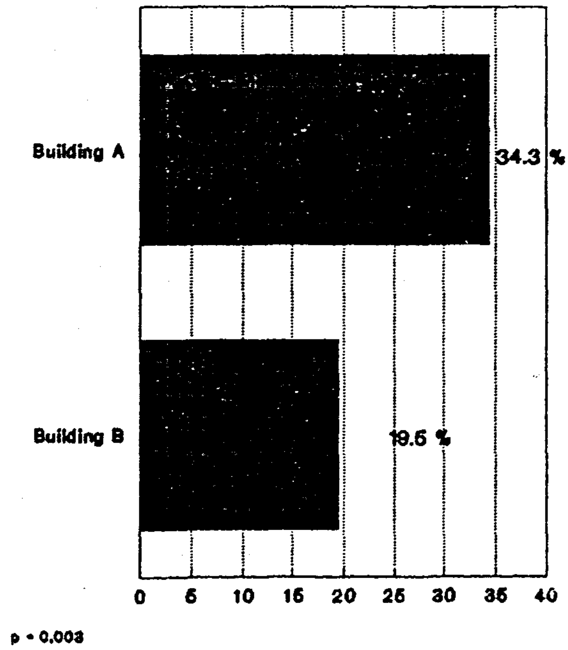
A higher proportion of respondents in building A [69.7% (n = 122)] were users of video display units (VDU) than in building B [53.8% (n = 79)]. There was a significant difference between building A and building B (p = 0.005). Only 17.1% (n = 30) of VDU users in building A and 8.1% (n = 12) in building B had anti-glare screens on their VDU's and there was a significant difference between building A and building B (p = 0.002).

6.4.3 Office Environmental Information

This part of the study was most important as it indicated the opinion of the respondents to the indoor environmental conditions in their offices.It also assists in defining the study in terms of ASHRAE's definition [AS89].

In building A 34.3% (n = 60) and in building B 19.6% (n = 28) of the respondents felt that the indoor environmental conditions affected their ability to work (p = 0.003). See Figure 6.5.

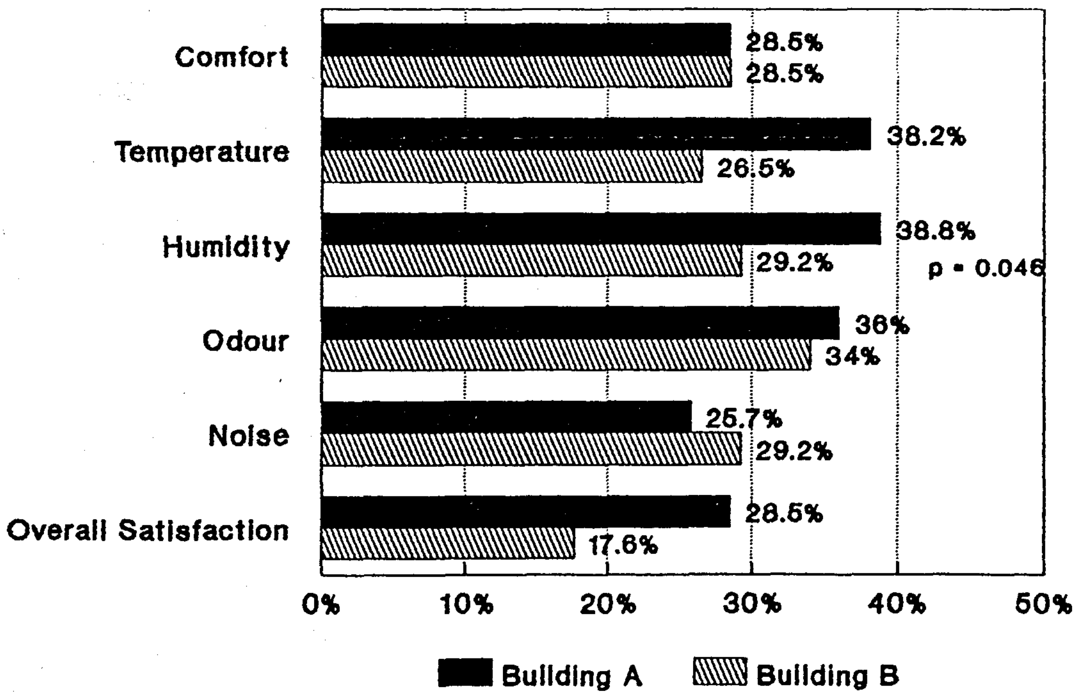
Figure 6.5: General perception of respondents to office environmental conditions



More respondents in building A (38,2% n=67) were dissatisfied with the temperature in their office than in building B (26,5% n=39). Respondents in Building A also expressed dissatisfaction with the humidity in their building (38,8% n=68) while in building B only 29,2% (n=43) expressed dissatisfaction. See Figure 6.6.

The perception of the indoor environments of both buildings indicated that most respondents were satisfied with their environment [Building A:71,4% (n=125; building B 82,3% (n=121)]. There was no significant difference between the overall satisfaction of respondents in building A and B. See Figure 6.6.

Figure 6.6 Occupants' perception of the office environment



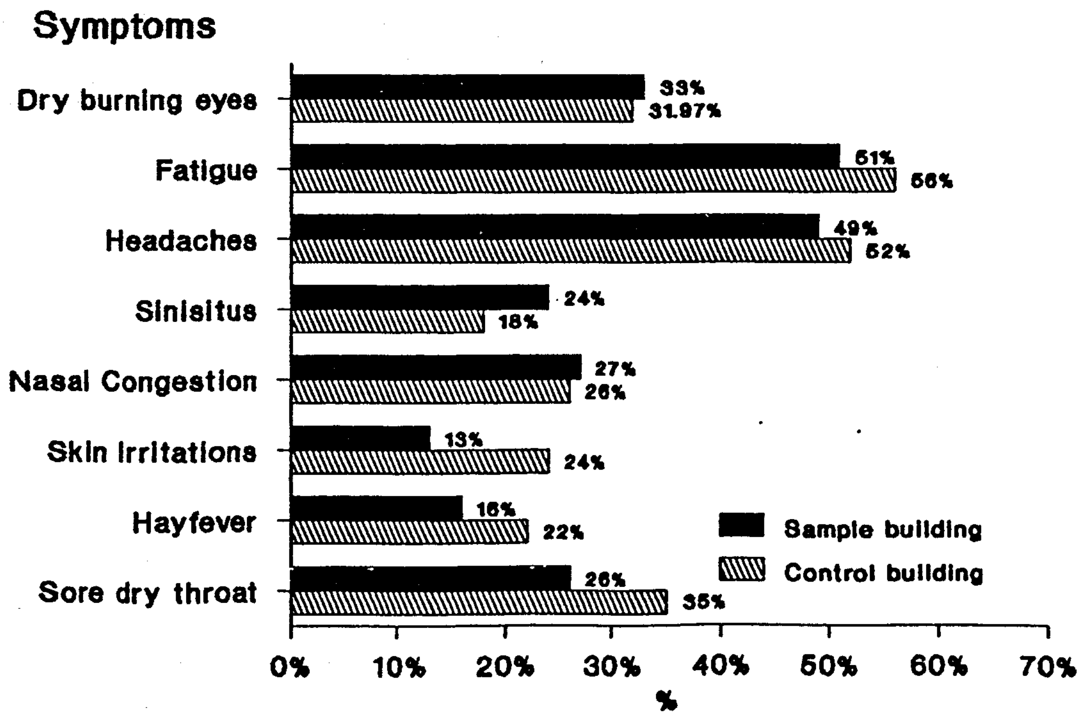
6.4.4 Symptom prevalence

The prevalence of a subset of symptoms in a sealed building can be used to determine whether the majority of occupants in the building are experiencing building related health complaints.

The thirty one symptoms listed in the questionnaire were general symptoms which are normally prevalent in the general population. The subset of symptoms ascribed to the SBS were included in the list of symptoms. The prevalence of most of the listed symptoms were well matched in both buildings. Abdominal pain was the only general symptom with a significant difference (p=0,002).

Three of the nine SBS symptoms had a higher prevalence in building A than in building B.

Figure 6.7: Prevalence of symptoms in both buildings



6.4.5 Discussion: Symptom Prevalence

ASHRAE states that 80% occupants of sealed buildings should express satisfaction with the thermal environment of the building (ASHRAE STD 62-1989).

With this statement, ASHRAE [AS89] is putting the onus on the building occupants to decide whether the indoor environment is satisfactory or not. The ASHRAE subjectivity test is a fair manner of reflecting occupant opinion. The means of obtaining this opinion, however, is not directly specified. It is fair to assume that using a questionnaire will enable the opinion to be expressed.

Therefore, questionnaire surveys should be used as the litmus tests in sealed buildings. Except in a few instances, this is not done at all in sealed Buildings.

Questionnaire surveys are frowned upon by the air-conditioning industry. The rationale is that enquiring from the occupants will bring forth a large amount of "symptoms" which did not exist prior to the survey. While this may be true in the initial surveys, the symptom prevalence should decrease or stabilise after periodic office environmental surveys.

The results of the medical information of this survey reflect interesting facts:

- All symptom prevalences in both building populations were very closely related, however, the SBS symptoms in building B were more common than in building A;
- the populations were not biased before the study or by the questionnaire in any direct manner;
- questionnaire design has an important bearing on questionnaire results, and
- the use of questionnaires in determining SBS prevalence does not necessarily provoke an outbreak of "mass hysteria".

A full list of symptom prevalences is provided overleaf.

ALL SYMPTOMS BY BUILDING

Symptom	Building A		Building B	
1. Aching Joints	18.86%	(n=33)	19.05%	(n=28) (ns)
2. Back Pain	37.14%	(n=65)	33.33%	(n=49) (ns)
3. Bladder Infection	6.86%	(n=12)	6.80%	(n=10) (ns)
4. Chest Congestion	17.14%	(n=30)	22.45%	(n=33) (ns)
5. Chest Pains	8.00%	(n=14)	10.88%	(n=16) (ns)
*6. Contact Lens Problems	4.57%	(n=8)	4.08%	(n=6) (ns)
7. Disorientation	1.71%	(n=3)	3.40%	(n=5) (ns)
*8. Dizziness	16.57%	(n=29)	17.69%	(n=26) (ns)
*9. Dry and Burning eyes	33.71%	(n=59)	31.97%	(n=47) (ns)
*10. Fatigue/Tiredness	50.86%	(n=89)	55.78%	(n=82) (ns)
*11. Drowsiness/Lethargy	29.14%	(n=14)	22.45%	(n=33) (ns)
*12. Headaches	48.57%	(n=85)	52.38%	(n=77) (ns)
13. Sinusitis	24.00%	(n=42)	17.69%	(n=26) (ns)
*14. Nasal Congestion	26.86%	(n=47)	25.17%	(n=37) (ns)
15. Nausea	8.57%	(n=15)	10.88%	(n=16) (ns)
16. Nose Bleeds	7.43%	(n=13)	16.33%	(n=24) p=0.020
17. Palpitations	6.29%	(n=11)	15.65%	(n=23) p=0.011
*18. Skin Irritations	12.57%	(n=22)	23.81%	(n=35) p=0.013
19. Hayfever	16.00%	(n=28)	21.77%	(n=32) (ns)
*20. Sore Dry Throat	26.29%	(n=46)	34.69%	(n=51)
21. Insomnia	19.43%	(n=34)	17.69%	(n=26)
22. Unusual Taste	6.29%	(n=11)	6.80%	(n=10)
23. Digestive Problems	13.14%	(n=23)	16.33%	(n=24)
24. Abdominal Pain	11.43%	(n=20)	24.49%	(n=36) p=0.002
25. Ear Problems	8.00%	(n=14)	12.24%	(n=18) (ns)
26. Skin Problems	19.43%	(n=34)	21.77%	(n=32) (ns)
*27. Flu Like Symptoms	45.71%	(n=80)	48.30%	(n=71) (ns)
28. Anxiety	17.71%	(n=31)	27.21%	(n=40) (ns)
29. Nervous Conditions	10.29%	(n=18)	21.09%	(n=31) p=0.11
30. Asthma	2.86%	(n=5)	2.04%	(n=3)
31. Difficulty in Breathing	8.00%	(n=14)	7.48%	(n=11)

*Key: *SBS symptoms*

As discussed above the higher prevalence of symptoms in building B could be ascribed to various factors. Another possibility relates to the building population. The predominant population in building B consisted of government employees. It is possible that this population could have a lower socio-economic status and thus a higher prevalence of symptoms or other psycho-social factors could influence their high symptom prevalence.

6.5 CONCLUSION

The results of the questionnaire survey have not shown a higher prevalence of SBS symptoms in building A than building B. The reverse is true in this case.

In retrospect, this result can be attributed to various factors. Firstly, neither populations had previously been biased to the project. The project was planned without the knowledge of the building population. Secondly, the design of the questionnaire can have a significant effect on the outcome of prevalence rates. The questionnaire does not reveal any information pertaining to the subject of SBS.

Thirdly, as mentioned previously, the building population could also affect the outcome. The predominant population in building B consisted of government employees. In subsequent surveys, conducted in other buildings in Johannesburg, a self-administered questionnaire with more directly styled questions has returned much higher response rates to SBS symptoms. It is therefore possible that the questionnaire design can bias populations and have an influence on prevalence rates.

Burge et al [BU87] have postulated that buildings which present symptom prevalences as in this study indicate that they would fall within a continuum of buildings.

In this study, the questionnaire design affected the outcome of the survey. In order to test this assumption a second questionnaire survey could be undertaken. This second survey could use a self-administered questionnaire. This would add a longitudinal aspect to the study. Such a step needs to be planned as a separate study and will not be covered in this report.

In summary, the questionnaire remains a valuable tool for indoor environments. The subjective opinion of the building population is imperative as it informs the management whether the building is perceived by the occupants as "sick" or not. Care must be taken, however, in designing the correct approach for obtaining best results.

Was the air-conditioned building a sick building? The answer to that question is Yes and No. The prevalence of drowsiness, lethargy and fatigue could possibly be linked to the findings of the occupational hygiene survey in Chapter 7.

The strict matching regime could have resulted in "over matching" of the sample. This practice then removes all differences between the groups and allows direct comparisons. While matching is a good practice it can be over-emphasized.

CHAPTER 7

PHYSICAL AND POLLUTANT CHARACTERISATION OF THE INDOOR ENVIRONMENTS OF STUDY BUILDINGS

7.1 INTRODUCTION

The traditional approach to solving this phenomenon known as SBS has been to measure the quality of the air in the building using the occupational hygiene approach. Some of the measurement methods used were from the Occupational Hygiene field but mostly from traditional ambient air pollution monitoring methods. These methods are able to inform the researcher of the quality of the air in the building and heat stress indices to which the occupants are exposed. Secondly, they give a profile of the pollutants in the building and enable the researcher to draw valuable conclusions from them.

The possible causes of SBS can be found in the quality of the air and the related psychogenic and engineering factors influencing the occupant. This chapter fulfils one of the main objectives which was to conduct the OHS in both selected buildings.

The monitoring of pollutants was conducted simultaneously with the questionnaire survey. In this survey, all of the pollutants were measured using continuous sampling methods and data loggers. The pollutant concentrations given are hourly averages. Only the important results are given in this chapter as a large amount of data was collected and it is not all displayed in this document. It is, however, available on computer disk should it be required for further analysis.

As it was not possible to measure pollutants in a large number of buildings, two representative buildings were selected from approximately 40 made available to the project. The selection process has already been described in Chapter 5.

Measurements of the pollutants commenced on 12th September 1989 and continued for two weeks in building A. The equipment was then moved to building B for two weeks. The weather throughout the monitoring period was hot, cloudless and windless.

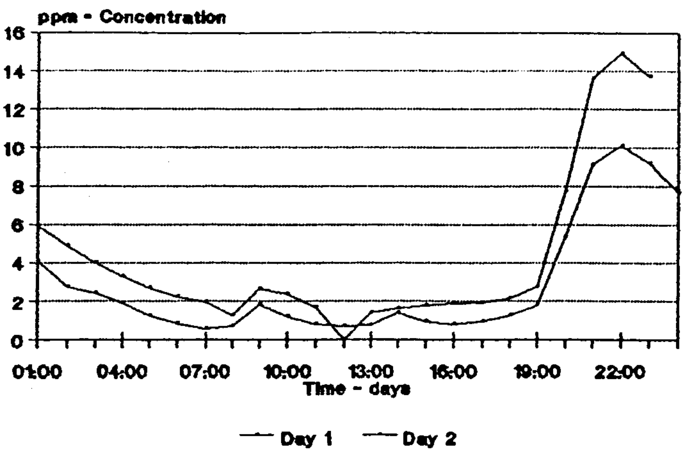
7.3 RESULTS OF MEASUREMENTS OF INDOOR AIR POLLUTANTS

7.3.1 Carbon monoxide (CO)

Results: Building A (Air-conditioned building)
As described in Chapter 5, monitoring of pollutants was conducted on the 28th and 2nd floors of building A.

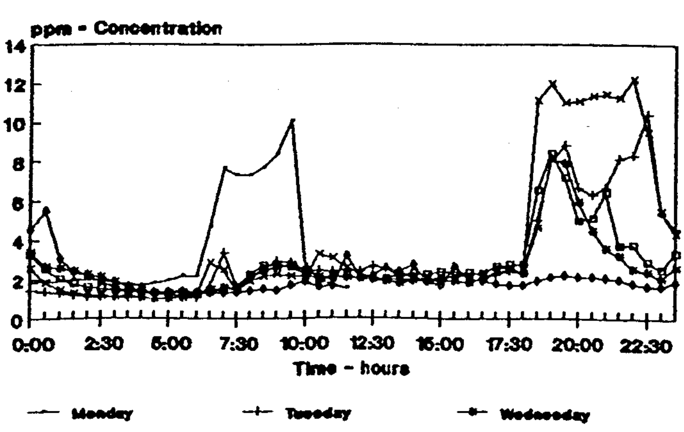
Monitoring of CO produced interesting results. CO levels increased in the morning between 8:00 and 11:00 when the bulk of the office personnel arrived for work (Figure 7.1). The CO would then drop slightly at 11:00 and 12:00 and increase again around lunch time.

Figure 7.1: Typical trend for CO in building A over 24 Hours



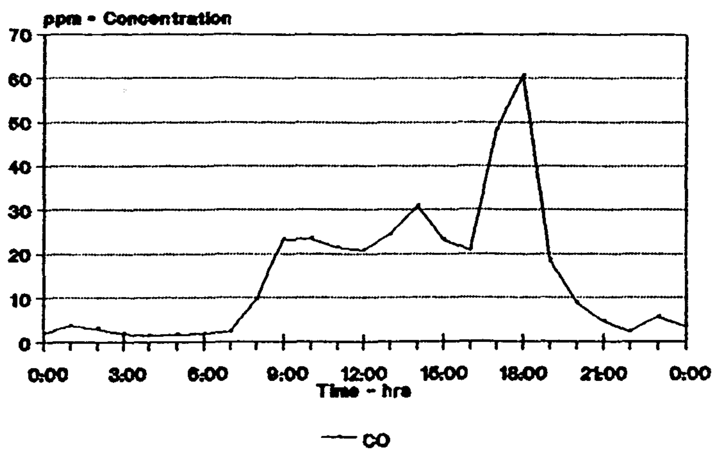
It would decrease until 16:00 when office personnel would leave work for home. Measurements of CO on the 22 nd floor revealed that the CO would increase to a high of 14 ppm, at about 22:00, and thereafter the CO levels would decrease until the morning at about 08:00. The highest recorded nightly concentration was 24 ppm on the second floor of building A. The daily fluctuations in the CO and NO_2 indicated that a pollutant source was causing these increases. These increases coincided with the daily peak hour traffic into the city and the building between 08h00 and 09h00. A lag phase of approximately one hour existed between the peak hour traffic and the measurement at the sampling site. The daily profile of CO over 1 week is presented in Figure 7.2.

Figure 7.2: Daily profile of Carbon Monoxide in building A for one week



To better clarify the reasons for high evening peaks of the CO, monitoring equipment was placed in the parking garage which was situated in the basement of building A (Figure 7.3). The equipment was placed in the security guards' office and the CO concentrations were monitored at the main exit to the garage.

Figure 7.3: CO trends in the 1st level parking garage



Investigation revealed that the basement parking garages were linked to the rest of the building by the fire escape which had openable doors. The fire escape is directly linked to all floors to comply with fire control regulations. The fire doors were usually left open on the first level parking garage as the service lift was situated in the fire escape. It was also found that workmen would load equipment via the service lift.

After ascertaining the levels of the various pollutants in the parking garage, it was found that the air-conditioning system in the building automatically switched off at 18:00. It was concluded that the basement was not being adequately ventilated hereby allowing noxious fumes to accumulate in it.

Once the building's air-conditioner was switched off, the positive pressure gradually reduced. This allowed the fumes to move up the fire escape and service lift shafts in the evening.

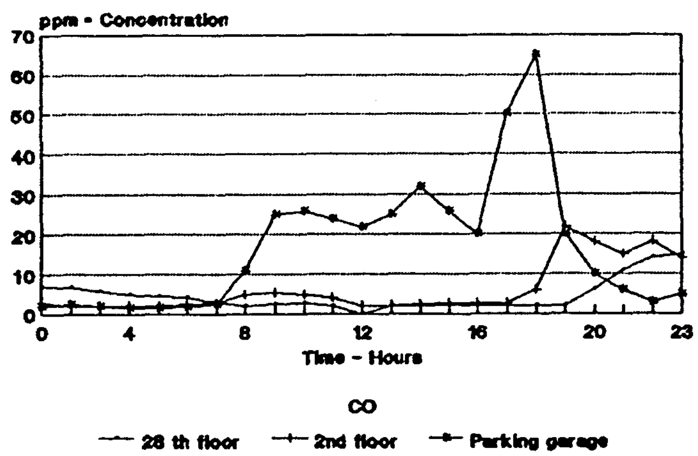
Subsequent measurements conducted on the 2nd floor of building A indicated that the CO and NO_2 peaked at approximately 19:00 whereas it had peaked on the 28th floor at 22:00.

It was also noted that nuisance odours created in the basement (drains) were propagated to the 28th floor of building A even during office hours. It is therefore possible that exhaust fumes were able to enter the building but were dissipated by the operation of the air-conditioner during the day.

After discussion with the building engineer it was decided to allow the basement parking exhaust fumes to run on a 24 hour basis and not only until 18:00 in evenings. Subsequent monitoring indicated that this had reduced the infiltration of vehicle fumes into the building, as the CO peaks previously displayed were no longer observed at the monitoring sites.

In Figure 7.4, the path of CO from the basement parking garage to the 28th floor is shown. When the ACS was switched off in the offices , a pressure difference was created in the building which allowed the egress of exhaust fumes into the offices of the building. Measurements on the 2nd floor of building A indicated that the CO concentration peaked at approximately 19:00. The levels of the CO in the parking garage have declined from 65 ppm to approximately 25 ppm which was the peak at the 2nd floor monitoring site. When the CO was measured at the 28th floor, the CO concentration has declined to 14 ppm by 22:00 and then decreased to below 2 ppm in the early hours of the morning.

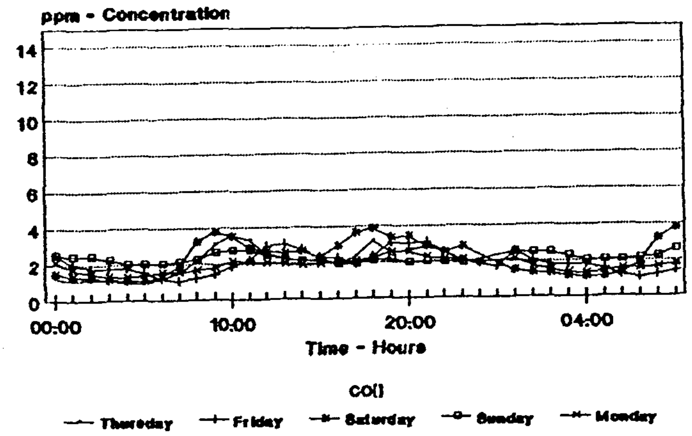
Figure 7.4: CO path from basement parking garage to 28th floor



Results: Building B (naturally ventilated building)

The large daily variations observed in building A were not as pronounced as in building B. CO levels remained at approximately 2 ppm during the night and a daily increase of CO to 4 ppm (Figure 7.5) was noted when traffic volumes increased in the morning and afternoon. No significant indoor pollution events occurred while monitoring in building B at both floors. However, when compared to levels seen in building A, they were relatively insignificant.

Figure 7.5: Daily profile of Carbon Monoxide in building B for one week



In comparison, the levels were higher in the evenings in building A due to ingress of the CO fumes from the parking basement. Whereas building B reflected the daily traffic peaks as it was naturally ventilated. These levels were never above 4 ppm.

7.3.2 Carbon dioxide (CO_2)

The results reflected the expected trends which showed an increased level during the day and reduction at night. These trends were due to the metabolic process from occupants.

Table 7.2: Average Carbon Dioxide concentrations in building A and building B

Results: Building A Concentrations

Average daily (8:00 - 18:00)	440 ppm
Average nightly(18:00 - 07:59)	350 ppm

Results: Building B Concentrations

Average daily(8:00 - 18:00)	380 ppm
Average nightly (18:00 - 07:59)	340 ppm

Discussion

In building A CO_2 levels were considerably lower than expected. As can be seen from the air flow measurements in section 7.2.8, the airflow varied considerably. This would affect the supply of fresh air into the building and hence lead to a higher CO_2 concentration. The average concentrations shown in Table 7.2 indicated levels more or less equal to ambient concentrations. In the U.S.A., CO_2 is used as an "indicator" of the quality of indoor air. The rationale for this methodology is that CO_2 is a normal product of human metabolism. Therefore the ACS should dilute any excess CO_2 and is indirectly an indicator gas for indoor environment.

An increased CO_2 level in an occupied space should indicate that the ventilation rate is insufficient to remove the metabolites from the air-conditioned space.

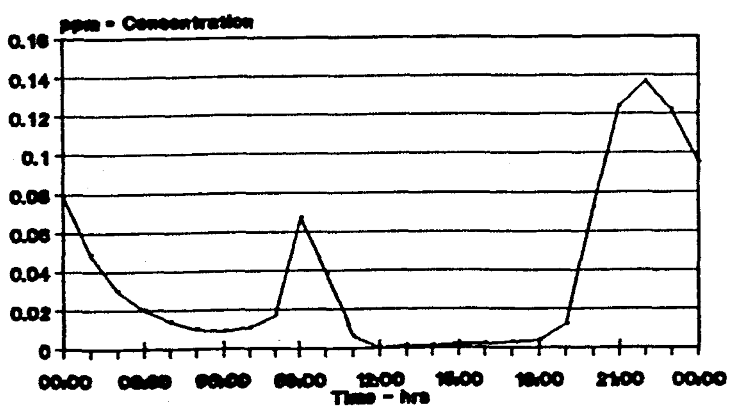
However, this theory was not supported during the OHS. Despite low readings of air velocity, the CO_2 levels remained very low. CO_2 levels increased in the mornings and maintained a concentration of between 400 and 450 ppm. At night these levels dropped to 200-250 ppm.

7.3.3 Nitrogen dioxide (NO_2)

Results: Building A

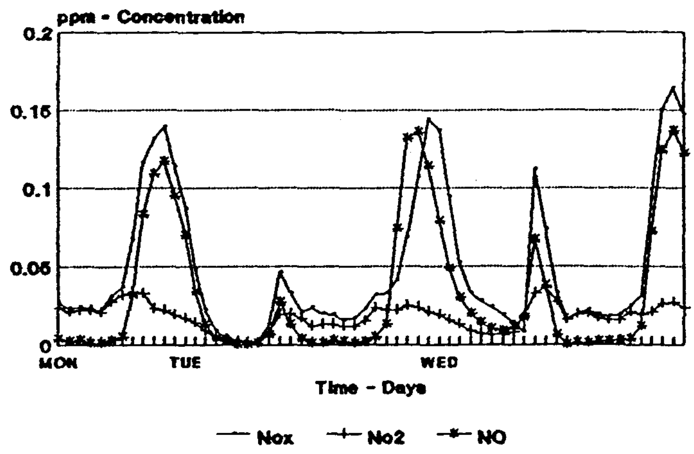
As with the Carbon Monoxides, these pollutants followed the same trends as with the CO. It increased in the mornings between 8:00 and 11:00 and again in the late afternoon between 18:00 and 22:00. They would also peak at approximately 22:00 and decreased during the early hours of the morning to follow the pattern of the CO as on the 28th floor. In comparison, the levels were higher in the evenings in building A due to ingress of the vehicle fumes from the parking basement. Whereas building B reflected the daily traffic peaks as it was naturally ventilated. This trend is shown below in figure 7.6.

Figure 7.6: Time profile of NO_2 in building A



The trends for NO_x in relation to Nitrous Oxide over three days is given in Figure 7.7. The NO_2 did not exceed any air pollution standards.

Figure 7.7: Time profile for NO_2 over three days

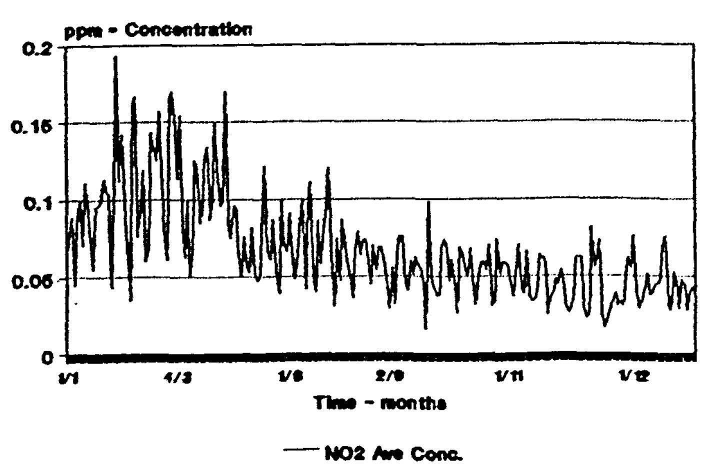


Results: Building B

In the presence of ultraviolet rays NO is converted to NO_2. This conversion process was also observed in building B. The concentrations were lower than those measured in building A.

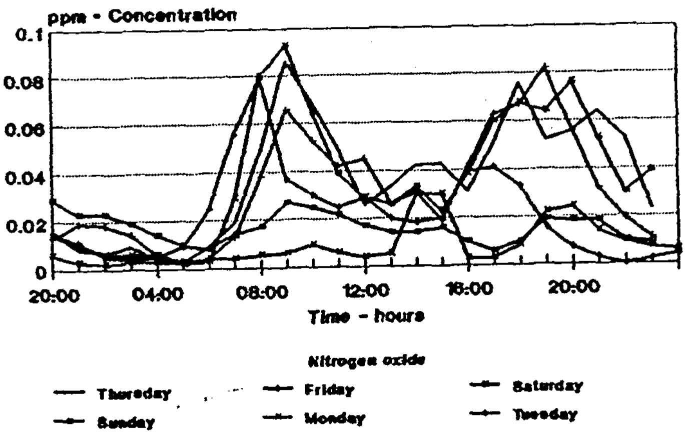
NO_2 displayed the typical increase and decrease due to the daily peak hour traffic patterns. As the windows of many of the offices are left open during the day, direct communication takes place between the offices and the outside air. In Figure 7.8, the daily maximum values of NO_2 measured at the City Hall by the Noise and Air Pollution Control Section are given as a reference point. The NO_2 did not exceed any air pollution standards.

Figure 7.8: Daily maximum values of NO_2 measured at the Johannesburg City Hall



The concentrations of NO_2 measured in building B are given in Figure 7.9. These values are similar to those measured at the City Hall.

Figure 7.9: NO_2 concentrations measured in building B



7.3.4 Formaldehyde (HCHO)

<u>Results: Building A Concentrations</u>
Sampler No. 1 <0.1 ppm
Sampler No. 2 <0.1 ppm

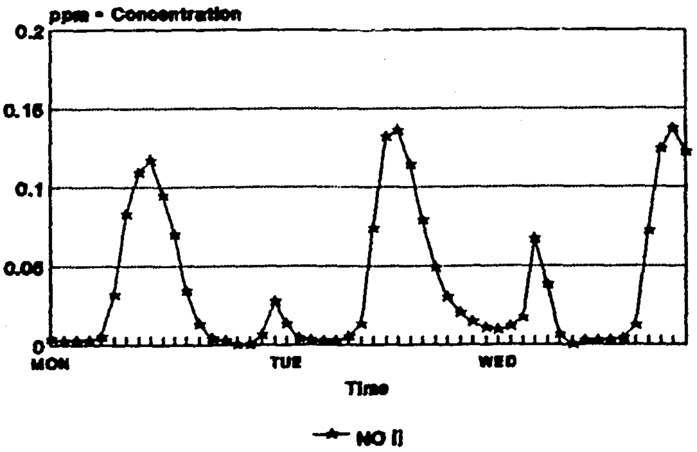
<u>Results: Building B Concentrations</u>
Sampler No. 1 <0.1 ppm
Sampler No. 2 <0.1 ppm

No formaldehyde was detected in either buildings and therefore did not exceed any air pollution standards.

7.3.5 Nitrous oxides (NO)

<u>Results: Building A</u>
The NO displayed similar pattern to that of the CO. The NO was oxidised during the day into NO_2 and then increased during the evenings to peak at night and gradually subside in the early morning (see Figure 7.10). In comparison, the levels were higher in the evenings in building A due to ingress of the vehicle fumes from the parking basement. Whereas building B reflected the daily traffic peaks as it was naturally ventilated.

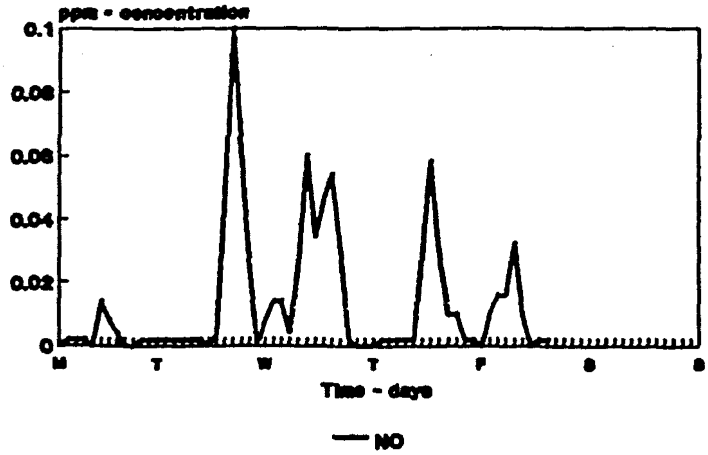
Figure 7.10: Time profile of NO in building A



Results: Building B

NO displayed the expected daily increases in concentration when traffic volumes were at there peak although these values were considerably lower than those seen in building A (Figure 7.11). The NO did not exceed any air pollution standards.

Figure 7.11: Time profile of NO in building B over one week

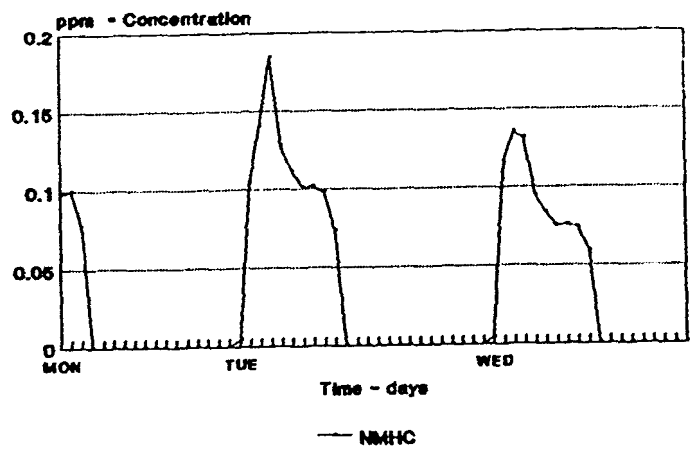


7.3.6 Non-Methane Hydrocarbons (NMHC)

Results: Building A

These were measured over an eight hour period during the day only due to limitations in the measuring instruments The concentrations of the NMHC were consistent when compared on a daily basis (see Figure 7.12). It was not possible to compare nightly variations.

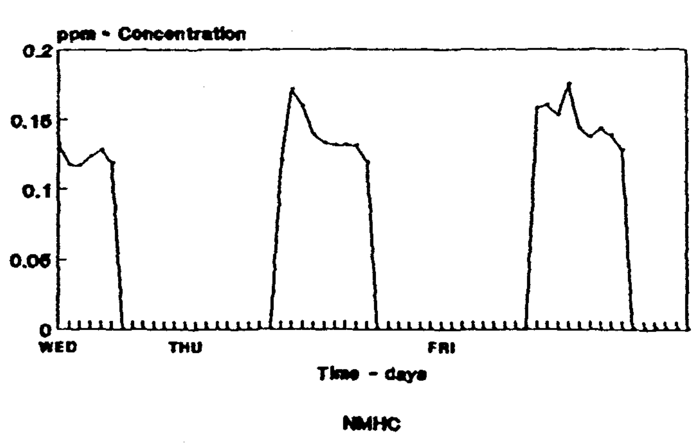
Figure 7.12: Non-Methane Hydrocarbons measured in building A over three days



Results: Building B

Fluctuations in the daily concentrations were observed on some mornings. However, these levels remained fairly constant with slight decreases on the weekends (Figure 7.13). In comparison, the levels were higher during the day in building A due to ingress of the vehicle fumes from the parking basement. Whereas building B reflected the daily traffic peaks as it was naturally ventilated.

Figure 7.13: Non-Methane Hydrocarbons measured in building B over three days



7.3.7 Asbestos

Results: Building A and B

Asbestos sampling indicated the presence of fibres but were below the recognised safety standard of 1 fibre per millilitre of air [MA83]. Although fibre insulation materials are used on the pipes inside the building , these were not disturbed.

Monitoring thus revealed no significant amounts of asbestos fibres in both buildings.

7.3.8 Particulates and other combustion products

Results: Building A and B

The measurements showed levels that were in excess of 43 $\mu g/m^3$ (24 hrs). Considerable staining or darkening of the filter paper occurred as these measurements were conducted in an office where a lot of photocopying was done at both monitoring sites.

These were measured using the same technique employed in building A. Respirable dusts were found to be acceptable and below any relevant standards.

7.3.9 Noise

Results: Building A and B

Levels were within the recognised health standard for noise.

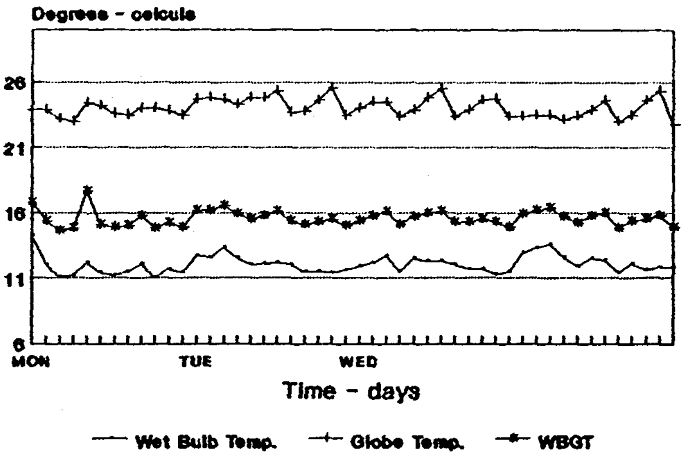
Noise levels at the monitoring site never exceeded 70 dB(A) but were always above 60 dB(A).

7.3.10 Thermal Parameters

Results: Building A

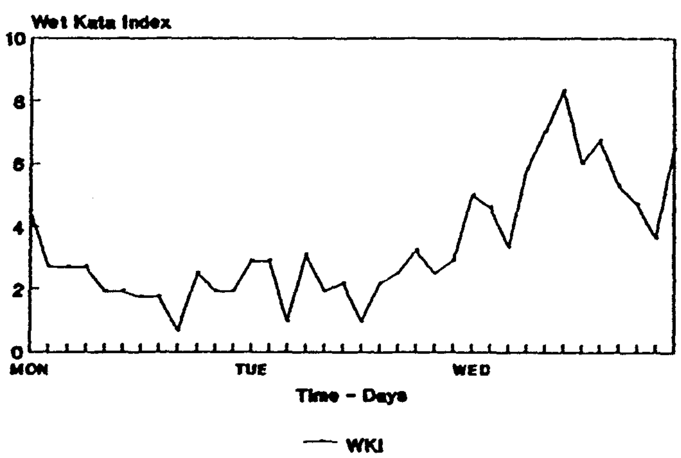
The Wet Bulb Globe temperature was maintained within reasonable limits of 23°C to 23,5°C (Figure 12). This was slightly higher than was experienced in other buildings which aim to keep the temperature at approximately 22^0 Celcius.

Figure 7.14: Temperature profile on 28th floor of building A



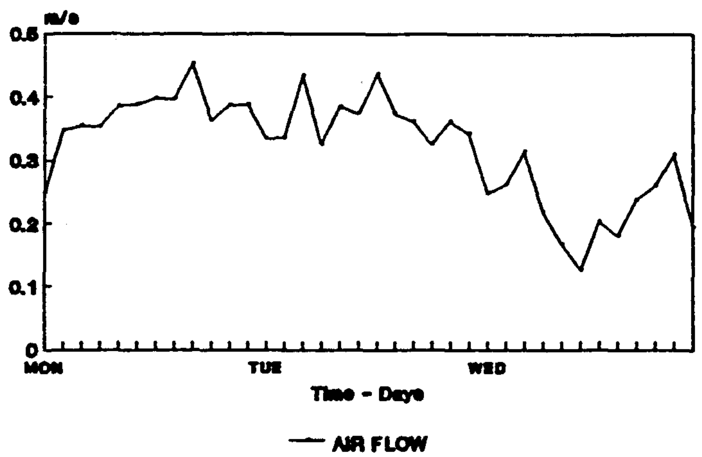
Air velocities calculated using the WKI revealed a continuous fluctuation of airflows (Figure 7.15).

Figure 7.15: Wet Kata Index on 28th floor of building A



In some instances airflow was fairly high and at other times non-existent. The airflow varied between 0 and 0.45 m/s, which reflects the type of variable airflow supplied by the design of the ACS (Figure 7.16).

Figure 7.16: Airflow measured on 28th floor of building A

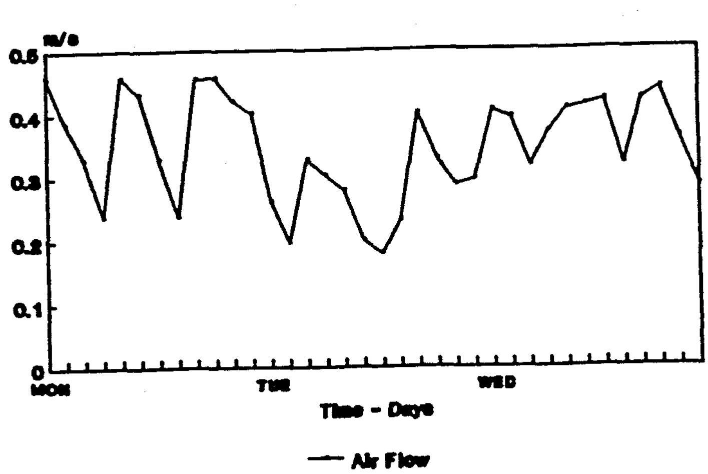


In the survey conducted in building A, the WKI was largely dependant on the cycle of the air inlet dampers. A figure of 16 is thought to represent ideal thermal conditions for indoor environments. In building A, the WKI readings varied greatly between 0 and above 10. The building temperature was controlled around 24°C, with a varying wet bulb temperature and WBGT index. The relative humidity at 35% is on the low side. The WKI did not show adequate cooling power in terms of the relevant legislation and the air velocity was at times below acceptable limits.

Results: Building B

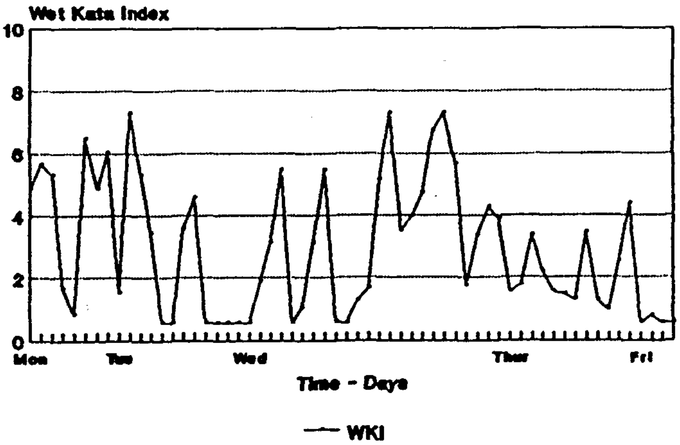
The trends of temperature and airflows are presented in the graph below. The direct effect of openable windows was observable in all the graphs in that the airflow fluctuated between 0 and 4.5 m/s. See Figure 7.17.

Figure 7.17: Temperature trends on the second floor of building B



Air velocities calculated using the WKI revealed a continuous fluctuation of airflows (Figure 7.18).

Figure 7.18: Wet Kata Index on 2nd floor of building B



7.4 DISCUSSION

The methodology used to analyse the indoor air of building A was aimed at gaining a representative indication of air quality for a large part of the building and was discussed in a previous chapter.

The daily fluctuations in the CO and NO_2 indicated that a pollutant source was causing these increases. These increases coincided with the daily peak hour traffic into the city and the building between 08h00 and 09h00. A lag phase of approximately one hour existed between the peak hour traffic and the measurement at the sampling site.

The intrusion of exhaust gases into building A is unacceptable from a health point of view. In building A, the contaminants measured did not exceed any TLV's or standards. The concentrations of CO were not life threatening but indicate how the incorrect management of one aspect of the building can inadvertently affect another.

Concentrations of CO, NO and NO_2 in the basement exceeded the EPA one hour and eight hour limit as well as the ACGIH TWA [AC90].

The airflow rates and WKI were far below the recommended level of 16. The thermal temperatures fluctuated throughout the day. The most pronounced problem was the lack of sufficient airflow due to the type of ventilation system which only provided air when the damper was opened by the temperature sensor. This system, namely the variable air volume system was commonly installed as the answer to the energy crisis when lower energy usage was required. In this study it can be seen that the airflow was stagnant and was unacceptable.

7.5 CONCLUSION

The OHS has confirmed two factors in the air-conditioned building known to contribute to SBS. These are:

1 Design features inherent in the ACS. The fluctuation of air volumes can be controlled within acceptable limits but the system has the potential to be inappropriately set, and
2 The transfer of vehicular exhaust pollution from the basement to the upper levels. This is caused by a desire to save on energy costs and also architectural design faults.

In the study we have objectively identified the physical causes of SBS based on accepted methods and measurements. These physical causes have not been identified in the routine maintenance programme. This emphasises the importance of holistic OHS being conducted in complex sealed buildings. Exposure to indoor pollutants are known to contribute to the total pollutant load to which individuals are exposed [TR90].

The contribution of the OHS has been significant in the building. The recognition, identification, evaluation and control of factors which may affect welfare and comfort of occupants were accomplished by this survey.

The study has quantified the pollution often studied in the field of indoor environments. It has measured the air to determine if there "are no known contaminants at harmful concentrations as determined by recognized authorities" (ASHRAE definition of acceptable indoor air quality). It has conducted a full occupational hygiene survey as set out in the objectives of the study.

No major differences were found in pollutants of both buildings. There was an aberration in the CO. In other studies there appear to be a continuim of sickness between naturally and artificially ventilated buildings and in this study the same could be the case [BU87].

A data base with the relevant information pertaining to buildings in the city will be useful in quantifying the extent of indoor air quality problems.

CHAPTER 8

CONCLUSION

8.1 INTRODUCTION

8.1.1 Summary of Questionnaire Survey

In order to fulfill the definition of ASHRAE Standard 62-1988 [AS89] of "acceptable indoor air quality", an objective validated and reliable measuring tool has been used to assess the satisfaction of the occupants in the study buildings.

The value of the ASHRAE method [AS89] was demonstrated in the high response rate to the questionnaire survey. Respondents in building A expressed dissatisfaction with temperature, humidity and odour in it. Respondents in building B expressed dissatisfaction with their indoor environments.

The questionnaire survey has compared the prevalence of SBS and related symptoms in the study buildings as defined in the objectives. It has also examined associations within the study population and the study buildings.

8.1.2 Summary of Occupational Hygiene Survey

The survey conducted in both the control and sample buildings revealed that pollutant levels were comparable in many respects.

Both buildings reflected the influx of vehicular pollutants although the sample building had higher levels. The study determined that the air in the sample building did not contain any air with harmful concentrations of pollutants as required by the ASHRAE's definition of acceptable IAQ [AS89].

This definition has been validated in the survey. It is a necessary facet of the survey.

The use of OHS techniques provides a multidisciplinary platform for building climate surveys. Ergonomic aspects were not examined, nor were psychosocial factors.

This survey provides a foundation for a data base of measurements in sealed buildings. The identification of vehicular exhaust gas intrusion into the building has revealed a regular occurrence in building environments which was not identified in the routine building maintenance programme.

This study has emphasised the value of monitoring the indoor environment of the building. It has indicated that a more holistic approach to building maintenance is required. Building managers are not qualified to deal with medical and health related issues. Furthermore, building managers do not measure the successful operation of the building on a symptom prevalence rate or the health complaints of its occupants.

Building related health complaints are a main issue of concern to employers who are tenants in buildings. Formalising complaint procedures and establishing a building environment complaint committee will go a long way to ease misunderstanding and reduce complaints. Greater sensitivity to building maintenance personnel, budgetary requirements and concerns would enable incorporation of sound building maintenance protocols at all levels of operation.

The use of the WKI in the measurement of indoor environments provides an easy, cheap and flexible tool which assesses heat and comfort requirements. The air-conditioning industry would do well to use this index as a standard method in building maintenance.

8.1.3 Shortcomings of the study

The study failed to investigate an association between SBS and worker absenteeism as set out in objective number 4, as it was not possible to gain access to detailed personnel records of the respondents within the study.

Only two buildings were used and this could have affected the outcome. It can thus be difficult to draw general conclusions from the study as it could not be taken as being representative for the city. In future studies, it is suggested that a greater number of buildings be incorporated.

The use of an interview based questionnaire can influence respondents' answers either way and in this type of study it is suggested that the self-administered questionnaire be used.

Other factors such as air-conditioning microbiological factors and volatile organic compounds should also be measured in future studies.

8.2 CONCLUSION

This small scale study has achieved the primary objectives. One of the main aims of the study was to measure the indoor environments of two representative buildings in Johannesburg as well as the perceptions and opinions of their occupants to them.

No association has been shown between any of the various environmental factors and the prevalence of SBS in the buildings studied.

The legislation pertaining to indoor environments has been investigated and reviewed. This legislation is not applied by those responsible for it, nor is it used proactively. Recommendations are proposed to remedy this problem. The further arrangement of the material in this way will provide a starting point for similar studies in this country. The project was designed and devised after rigorous consultation of the current literature and implemented along sound epidemiological and occupational hygiene principles.

The results of the questionnaire survey has yielded sound statistical results which have confirmed the findings of similar studies. No major differences were found in other buildings. In terms of the ASHRAE's definition [AS89] the sample building tended to be healthy. The study has confirmed the conclusions of Burge [BU87] that there is a continuous spectrum of buildings which cannot be easily separated into "sick" and "healthy" buildings. The result of Burge's studies [BU90a] indicates that the main difference between the sicker and healthier buildings was in the standard of maintenance, of record keeping and the availability of good manuals describing the system in each building.

In terms of SBS symptom prevalence, the control building indicated that it was the sicker of the two. This could be due to the fact that public sector buildings have more problems than private sector buildings [BU90b]. In the control building the population consisted mostly of public sector workers which confirms previous findings of other researchers. It was also the older of the two buildings although it required less maintenance. This is attributed to organisational factors or the buildings and maintenance themselves. Studies have shown that in general naturally ventilated buildings have less problems than air-conditioned buildings although there are some relatively good air-conditioned buildings and some sicker naturally ventilated buildings [BU90a]. The hypothesis is therefore not supported and the conclusion is that a greater number of buildings needs to be assessed to further confirm the hypothesis.

8.3 RECOMMENDATIONS

Arising from the experience of the small scale study there is a need for building management to understand that the key issue in satisfying occupants is not only the temperature and humidity of the air, but the total indoor environment perception of the tenant and occupant. Achieving this will involve major rethinking of current building maintenance programmes. In order to achieve this, greater understanding and awareness by those who can influence this field is necessary. The following recommendations are based on the review of the legislation and legislative in action and the findings of this study. Achieving this greater awareness can only be done by gaining the involvement of the various bodies and organisations who are able to influence the field significantly.

A serious commitment will be required from these bodies to remove the chance of SBS problems arising. Those directly involved with these issues are given in Table 8.1.

Table 8.1: Summary of proposed organisation involvement in IAQ issues

Organisation/Body	Action
First Level	
Central Government Departments - Health and Population Development - Manpower - Trade and Industry	1. Evaluate legislation with reference to new legislation in USA, UK & Sweden 2. Encourage self-regulation of ventilation. Industry with legislative incentives 3. Encourage local authority involvement through existing structures
Second Level	
Local Authorities - Building Survey - Health - Town Planning	1. Use existing law enforcement officers to extend assistance, advice in IAQ and related matters 2. Encourage various LA departments to "police" existing legislation more effectively 3. Create a central register of air-conditioned buildings giving details such as design, population and specifications of operation
Third Level	
Research and Educational Organisations: - CSIR - HSRC - MRC - Universiteits - Technikons	1. Gather information on the prevalence of SBS and related problems in SA 2. Participate in research similar to US EPA* and Harvard organisations to contribute to international knowledge on SBS and IAQ in general.
Fourth levels	
Associated organisations related to IAQ field - Air-Conditioning Associations - Architectural - Engineering - Energy - Health and related - Municipal	1. Participate in self-regulation of activities 2. Actively promote educators of programmes to increase public knowledge of IAQ

**EPA - Environmental Protection Agency*

8.4 IMPLEMENTING AN IAQ INVESTIGATION STRUCTURE

The first step in implementing the action proposed in Table 8.1 would require the mobilisation of the four levels of organisations who play a role in IAQ issues. Awareness programmes and additional educational courses should be made available to the relevant personnel. Initially, central and local authority levels could play the leading role by taking the action of making their sources available. This involvement would then broaden at a later stage. Table 8.2 proposes how this can be done.

Table 8.2: Implementing an IAQ assistance programme

Organisation	Resource/Body	Implemented by:
First Level		
Department of Manpower Department of Health and Population Development	Factories Inspectorate National Centre for Occupational Health	Factory Inspectors Occupational Hygienists, Epidemiologist
Second Level		
Local Authorities	Health Department Building Survey Department of Town Planning	Health Officers Building Inspectors Planning Officers

Most of the officers/professionals referred to in Table 8.2 have adequate experience and suitable training to provide the general public with a professional service. All of those involved would report to their local management in the course of their normal duties and functions. No extra financing would be required as existing legislation could be used to provide a legislative foundation if any legal matters require it. These officers/professionals could provide a first line of operations for IAQ complaints and refer complaints, needing more detailed measurements, to a body such as the National Centre for Occupational Health or Medical Research Council.

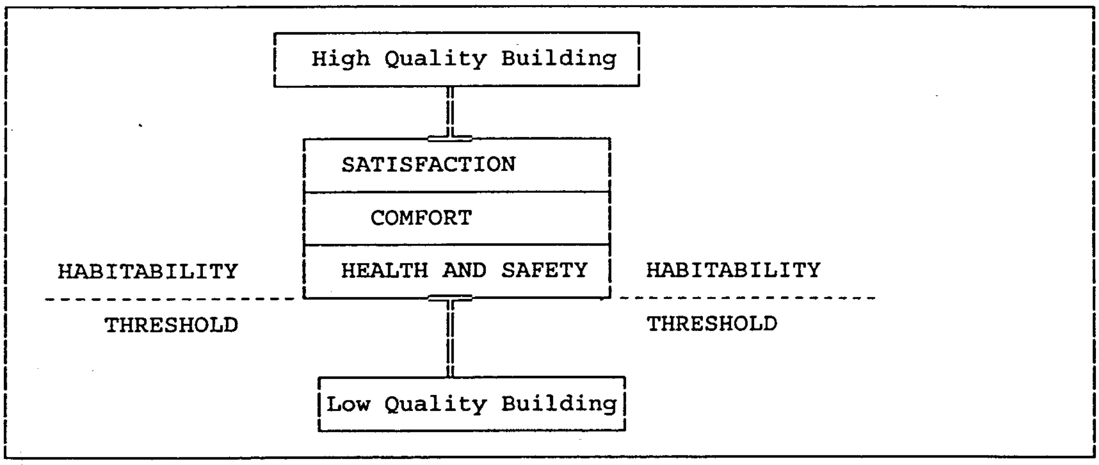
In order to assist these first and second level organisations, the third and fourth level bodies proposed in Table 8.1 would provide additional co-operative assistance as detailed in Table 8.1.

8.5 BUILDING SYSTEMS MANAGEMENT: THE KEY

The design of buildings and ventilation systems is the job of architects and engineers - professions whose students are given a high standard of training. The evidence of this training is easy to observe - many modern multi-storeyed buildings with different forms of ventilation systems. Usually sealed multi-storeyed buildings are maintained by a real estate company who employ an air-conditioning technician or subcontract to an outside company. The general management of the building is given to a "caretaker" or superintendent, normally an elderly person who lives in the building. This caretaker ensures that the tenants needs such as lighting, plumbing, electrical and space requirements, are provided for. The general management of these buildings is usually good. This practice however, has a large flaw - it manages the building, not the building and its occupants. The current approach is fragmented. Current practice is to employ a 'caretaker' to receive occupant complaints relating to health, ergonomic and engineering problems. Complaints received from one person on a regular basis can receive less sympathy and the complainant becomes 'hypochondriac'.

The concept of satisfying the office users' health needs is generally not considered to be a high priority to the industry in general. Rather, issues pertaining to building requirements are considered to satisfy these needs. A user satisfaction approach is proposed by Vischer [VI89] which reflects the beliefs that the best buildings are those with the most satisfied users, and that good environmental design should satisfy specific human needs. Determining the quality of a building can be done by considering Figure 8.1:

Figure 8.1: The Habitability Pyramid [VI89]



This diagram considers needs to be paramount. This model has limitations as pointed out by Vischer [VI89]. The building manager should remember that the model does not consider the interaction of users with the environment but rather that people seek comfort from their environment, which they can change or adapt to when required [VI89].

The important link in the model is the fact that health and safety issues should be considerd first. Most IAQ standards do not consider these needs at all, preferring the need for comfort as the primary issue. This is why health related complaints are not usually brought to the attention of a health professional. This leads to frustration amongst the tenants and a failure of the caretaker to understand the complex issues of indoor environmental management.

Generally when an IAQ complaint is received, the air-conditioning technician is informed by the caretaker or called directly by the complainants. The relative humidity and wet bulb temperature is usually measured by the technician.

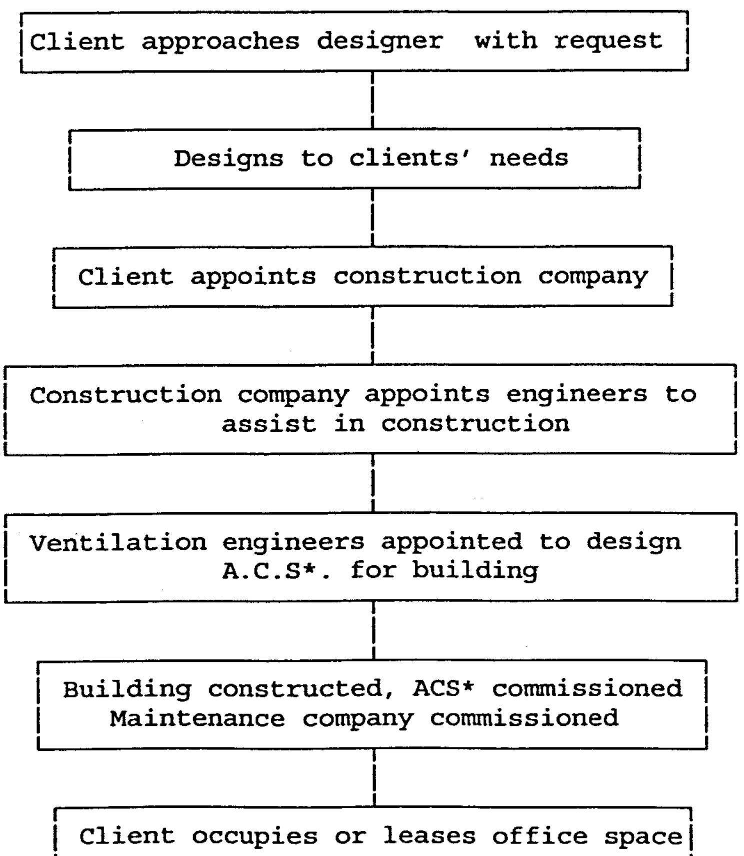
If these indices are not within the accepted range of the system, then the technician will attempt to rectify the matter. If after repeated complaints a remedy is not found, then various things can happen. The complaint is perhaps referred to an outside specialist consultant. Table 8.3 gives an indication of what steps could be taken to resolve complaints.

Table 8.3: Usual method of resolving IAQ complaints

STEP 1 -	Technician attempts to rectify with basic techniques
STEP 2 -	Technician remeasures and perhaps provides additional airvents/engineering solutions
STEP 3 -	Complaint can be referred to outside specialist
STEP 4 -	Complainant "labelled" when no corrective action can alleviate the complainant's discomfort

As has been discussed, each facet of the building design, construction and maintenance is undertaken in isolation of each other. This isolationism in the building industry can be described in the Figure 8.2:

Figure 8.2: Normal procedure for construction of a multi-storeyed building



**ACS - Air-Conditioning Systems*

A total approach to manage indoor environments is clearly needed. A total approach will use a multidisciplinary team from the inception of the building. This total approach should envisage the building as a more "human" concept for the occupant/s. Using this approach would enable the building to be designed as a unified concept.

8.6 LIVING BUILDINGS

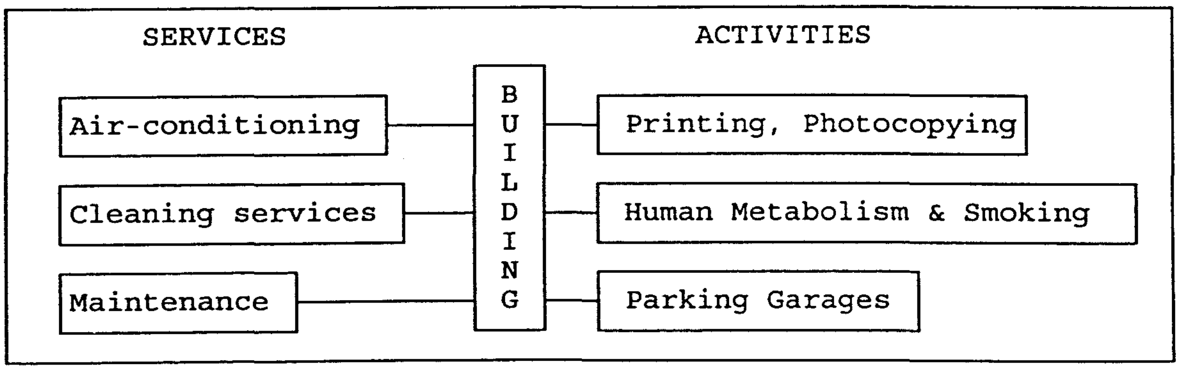
The principle of Living Buildings [TR92] is to treat the design, construction, maintenance and occupation of buildings as a living concept and create an awareness that every action and inaction has a definite and measurable reaction on the ecosystem of the building. This in turn can prevent any imbalance between the macro and micro environments in the building.

8.6.1 Balancing the system

As described in Figure 8.3, a variety of procedures takes place within a sealed building. The unco-ordinated execution of these activities from inception to commissioning of the building causes the building system to become unbalanced. This leads to the imbalance of the macro and micro environments and causes a mismatch between the occupant and the building.

This results in the occupant being exposed to factors/parameters which directly affect his wellbeing without any apparent reason. Sometimes, when complaints are registered with the building manager, the complainant is treated with disbelief. This is understandable as the unseen and unknown building factors (Figure 8.3) are interacting on the occupant.

Figure 8.3: Normal activities/processes in a building system



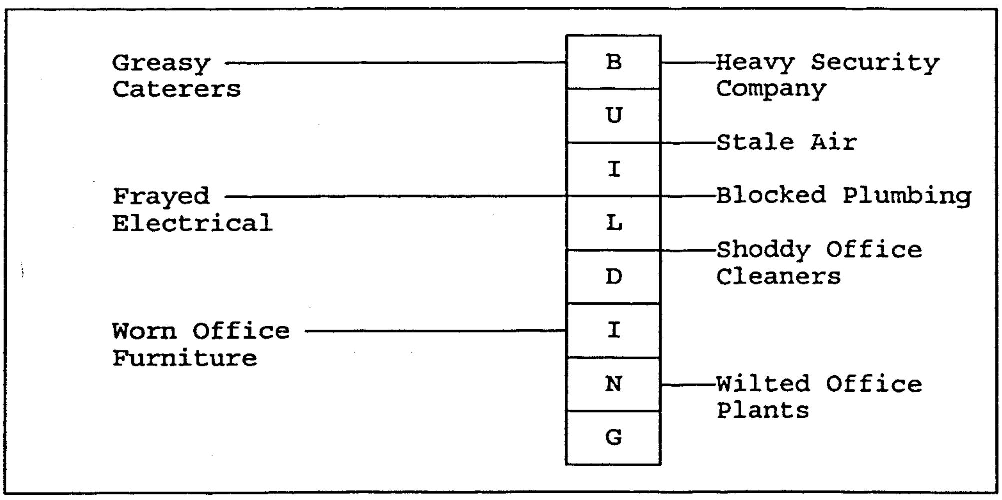
This view is substantiated by Fanger who states that most buildings comply with ventilation standards but complaints of SBS are still received and that chemical compounds measured are below health effect limits. He proposes that a method to quantify hidden pollution sources be used [FA87,FA88].

This proposal underscores the rationale for the living building approach. Various processes/activities which occur or operate, happen out of phase and affect the wellbeing of the occupant. A sealed multi-storeyed building is an ecosystem on its own. It is designed to protect and support the activities of its occupants. It enables the occupant to function in a particular manner so that it can conduct business activities. The building can be seen as a shell in which a host of different activities take place without due consideration for each other.

As in nature, a balance must exist between the various consumers and producers. This subtle balance can be equated to a building system. Figure 8.3 describes the various processes which make up part of this living building system.

In the past and at present, these factors have been treated as inanimate objects which have no effect on each other. However, this study has shown that in a sealed building pollutants cannot be localised by conventional means. Indoor pollutants do not respect boundaries or mechanisms to prevent the egress from the source. The natural physical laws describe this process (eg. brownian movement). Figure 8.4 overviews this concept of management.

Figure 8.4: "Typical" system of building management in South Africa



<u>Building profile:</u>
Age of Building: 17 years
Type: 41 floors, sealed multi-storyed, multitenants (72 lessees)
Owned by: Building Concern (Pty) Ltd
Managed by: Difficult Buildings Management
Caretaker: Mr N Otconcerned
Air-Conditioning Technician: Mr Sys Temisworking
Designed by: Mr Aes Theticallypleased

<u>Subcontractors and Contractors:</u>
It is proposed that the building be treated in á more animated form so as to assist the user and the manager. Figure 8.5 describes this concept.

Figure 8.5: Components of a living building

DERMIS : COVERING

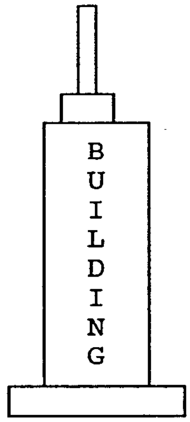
VASCULAR SYSTEM: ACS *

SKELETON: FRAME,STRUCTURE

FIRMAMENT: FOUNDATION

POPULATION: OCCUPANTS

ENERGY: POWER SUPPLY



**ACS = Air-Conditioning System*

8.7 DISCUSSION

This system is briefly explained as follows:

8.7.1 The building's dermis

The outer skin or covering of a building determines the thermal load and properties of a building. Another function is aesthetic appeal of the outer dermis.

8.7.2 The building's vascular system

As in humans, air supply to the tissues and organs is imperative. In a building a form of vascular air supply is required to ensure the wellbeing of the population.

This closed system depends on the efficiency of the plant room and its equipment. The thermal comfort of the individuals will be determined by the ability of the vascular system to perform.

8.7.3 The building's skeleton

The skeleton or frame can vary according to the type of material used. Thermal performance of the building can be determined by the dermis and the skeleton. This thermal performance in turn affects the design of the air-conditioning system which affects the wellbeing of the occupant.

8.7.4 The building's firmament

This relates to the base and basement of the building. The basement can play a significant role in both sink and source effects from motor vehicles and other sources such as radon daughters from the soil.

8.7.5 The building's population

As this implies, the occupants of all the buildings and offices are its population. This population contributes to the indoor air pollution load via metabolism (CO_2, CO) and work activities (Ozone, VOC's, tobacco smoke).

8.7.6 The building's energy

The energy supply to all services such as lighting, office machines, etc. is an expensive budgetary item. The energy used by the air-conditioning system constitutes a substantial amount of the building's monthly electricity account.

8.7.7 Building systems

The Environmental Protection Agency has proposed that while there is an acceptance of the need for a "building system" there is little information on their performance.

They state that building studies have demonstrated that many IAQ problems are mixture problems caused by pollutant mixtures and the interactions of these mixtures with the building system [EN87].

The living building system concept incorporates all the intrinsic and extrinsic factors which may influence the occupant and the building's ecosystem. It proposes a holistic or total approach to building management.

8.8 IMPLEMENTING THE LIVING BUILDING SYSTEM

While the proposed concept may seem workable on paper, getting it to work in industry will be difficult to achieve.

This system needs to be implemented in four stages of a buildings life.

Stage 1 Building's Conception
Stage 2 Building Design
Stage 3 Building's Construction
Stage 4 Building's Commissioning and Occupation

Stage 1: It would be difficult to assemble the whole Building Management Team (BMT) at this stage.

It is important that before a decision is made as to the building type etc. that the BMT play a specific role in advising the advantages and disadvantages of particular building types. An incorrect decision will cost more in the long rung - for instance glass skin buildings are more expensive due to increased thermal loads.

Stage 2: Usually the architect is solely responsible for the design of the building. However, the architect needs to design the building in consultation with a ventilation engineer, facilities manager and the client. This will ensure that the structure does not become only an architectural statement, but a user friendly structure which is also pleasing to the occupier.

<u>Stage 3:</u> At this stage the BMT is expanded to include the various managers involved with construction, the future building supervision and local authority representatives - eg. Health and Building Department.

The BMT should meet on a regular basis to monitor progress and to ensure that the Living Building concept is birthed.

<u>Stage 4:</u> The commissioning and occupation of the building signals the beginning of a building's life.

At this stage of process the building will be emitting a host of gases from the interior decorations such as carpeting, wall finishes, construction materials and furniture. Prior to tenant occupation, the BMT should consider a cycle of intense flushing of the system to reduce gas emissions.

Once occupation commenced, the BMT's role is converted to a monitoring function. To achieve this, a building management committee (BMC) is formed. It should consist of the following representatives:

- Ventilation engineer;
- Technician;
- Building owner/representative;
- Safety representative;
- Two or more elected representatives from staff in building;
- Building caretaker, and
- Health professional.

This BMC should meet on a regular basis to discuss the management of the building and its needs, etc. They will specifically deal with complaints pertaining to IAQ problems and have a set methodology for dealing with them.

8.9 DISCUSSION

A procedure for dealing with IAQ problems has been implemented in Canadian schools and is called the Total Building Approach [RO88]. In this case it has shown good results as it considers the cause of the occupants.

This Living Building approach is a new type of strategy designed to alleviate IAQ problems. It will only work if the building industry accepts it as a workable alternative. Thus it needs to be looked into, tested, tried and implemented in the industry.

8.10 CONCLUSION

As NIOSH [NI87] and the Canadian Board of Schools [RO88] have proposed, a totally integrated approach to managing indoor environments is imperative to achieve good IAQ. Poor IAQ is the result of poor building management and is only a symptom not a cause of the SBS. The key to its treatment lies in effective, open-minded building management. The path to implement this system can be undertaken by joint processes and mechanisms within the air- conditioning industry.

Support from the relevant local and state authorites will make it effective in dealing authoritatively, yet in a just manner, with building offenders.

REFERENCES

AB90 Abbritti G, Accottoli MP, Colangi C, Fabbri T, Muzi G, Fiordi T, Dell'Omom M, Gabrielli AR. Sick Building Syndrome: High prevalence in a new air conditioned building, Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 1, 513, 1990.

AC87 Air-Conditioning: South African Industrial Refrigeration and Air-Conditioning Contractors Association (SARACCA), Johannesburg, 1987.

AC90 ACGIH. Threshold Limit Values for Physical, Biological Substances, American Conference for Governmental Industrial Hygienists (ACGIH), Cincanatti, 1990.

AK84 Akiba S, Kato H, Blot WJ. Passive Smoking and Lung Cancer among Japanese Women, Cancer Research, 46, 4804-4807, 1984.

AL88 Alegheny County Health Department. Personal Communication, Joe Scropion, Pittsburg, October, 1988.

AN79 Annegarn HJ, Horne AR. Electrical Properties of the Indoor Atmosphere of the Carlton Centre, Int. Conf. Air Pollution, Pretoria, Vol 3, 6.1-6.6, 1979.

AS87 ASHRAE (American Society of Heating Refrigeration and Air-Conditioning Engineers, Inc.). Environmental Control Principles, Atlanta, 1987.

AS89 ASHRAE STD 62-1989. Ventilation for Acceptable Indoor Air Quality, Atlanta, 1989.

AS81 ASHRAE STD 55-1981. Thermal Environmental Conditions for Acceptable Indoor Air Quality, Atlanta, 1981.

AT83 Atmospheric Prevention Pollution Act No 45 of 1965, RSA, Pretoria.

BU87 Burge S, Hedge A, Wilson S, Bass JH, Robertson A. Sick Building Syndrome: A Study of 4373 Office Workers, Ann. Occup. Hygiene, 31, 493-504, 1987.

BU90a Burge PS, Jones P, Robertson AS. Sick Building Syndrome - Environmental Comparisons of Sick and Healthy Buildings, Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 1, 479, 1990.

BU90b Burge PS. Building Sickness - A Medical Approach to the causes. Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 5, 3, 1990.

CH73 Masterton WL, Slowinski EJ. Chemical Principles, W B, Saunders Company, Toronto, 1973.

EN87 Environmental Protection Agency, Preliminary Indoor Air Pollution Information Assessment, Appendix A,EPA - 600/8-87/014, Washington, June, 1987.

FA87 Fanger PO, Melikov AK. Draught and Turbulence, Proc. of Ind. Air '87, Vol. 1, Berlin, 1987.

FA88 Fanger PO, Melikor AK, Hanzaivi H, Ring J. Air Turbulence and Sensation of Draught, Energy and Buildings, 12, 67 - 74, 1988.

FI84 Finnegan M, Pickering C, Burge P. Sick Building Syndrome: Prevalence Studies. British Medical Journal, 289, 1573-5, 1984.

FI86 Finnegan M J, Pickering CAC. Building Related Illnesses; Clinical Allergy, 16, 389-405, 1986.

FI90 Fidler A T, Nilcox T G, Horning R N. Library of Congress Indoor Air Quality and work environment study: Health Symptoms and comfort concerns, Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 4, 604-605, 1990.

GO89 Godish T. Indoor Air Pollution Control, Lewis Publishers, Michigan, 1989.

HA77 Health Act No 63 of 1977, RSA. Pretoria, 1977.

HU86 Hughes B, O Brien L. Evaluation of Building Ventilation Systems, Am.Ind. Hyg. Assoc. J, 47, 207-213, 1986.

IN89 International Labour Organisation, Encyclopedia of Occupational Health and Safety, Vol. 1 and 2, International Labour Organisation Office, International Labour Office, 1989.

LE90 Leaderer B, Fidler A, Hurrel J, Clickner R, Teichman K. Protocol for a comprehensive investigation of building related complaints. Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 4, 609, 1990.

MA83 Machinery and Occupational Safety Act; No 6 of 1983, RSA, Pretoria.

ME90 Menzies RI, Tamblyn RM, Tamblym RT, Farant JP, Hanley J, Spitzer WO. Sick Building Syndrome: The Effect of Changes in ventilation rates on symptom prevalence: The evaluation of a double blind experimental approach, Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 1, 519, 1990.

MI72 Mine Ventilation Society of SA. Routine Mine Ventilation Measurements, 1972, RSA.

MO86 Molhave L. Indoor Air Pollution Due to Organic Gases and Vapours of Solvents in Building Materials, Env. Int. 8, 117-127, 1986.

MO87 Morris L. Sick Building Syndrome and the Office Equipment, Safety Practitioner, March 4-8, 1987.

NA86 National Research Council of the USA. Environmental Tobacco Smoke - Measuring and Assessing Health Effects, National Academy Press, USA, 1986.

NA87 National Research Council's Report on Policies and Procedures For the Control of Indoor Air Quality, Washington, USA, 1987.

NA88 National Building Regulations (NBR). (Amended by G 1726 on 26 August 1988), RSA, Pretoria.

NE90 Nelson L, Leaderer BP, Teichman K, Wallace L, Kollander M, Clickner B. Environmental Protection Agency indoor air quality and work environment study: Health symptoms and comfort concerns. Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 4, 616, 1990.

NI77 NIOSH(USA), Occupational Diseases - A guide to their Recognition and Control, Washington, June, 1977.

NI83 NIOSH Report. Industrial Hygiene Characterisation of Urea Formaldehyde and Polyurethane Foam Insulation, publ. no 83-108, 1983.

NI87 NIOSH. Guidance for Indoor Air Quality Investigations; National Institute of Occupational Safety and Health, Cincanatti, Jan., 1987

RE85 Reesner C, Levin I, Karon S. Atmospheric Pollution - A study of motor vehicle emissions as a component of this problem. University of Witwatersrand Community Medicine project, September, 1985.

RO86 Robertson A, Burge S. Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems, Br. Med. J., 20, 373-376, 1986.

RO88 Rozenwieg-Witherspoon J, Landras G. A Total Building Performance Approach to Indoor Environment Concerns in Schools, Proc. of the Ventilation 88 Conf., London; 535-542, 1988.

RU90 Ruotsalainen R, Jaakkola J. Symptoms and Environmental complaints in occupants of houses and apartments with different ventilation systems, Proc. 5th Int. Conf.on IAQ and Climate, Toronto, 1, 525, 1990.

SA83 South African Bureau of Standards, Code of Practice for the Measurement and Rating of Environmental Noise with respect to annoyance and Speed communication Code 0103, Pretoria, RSA, 1983.

SA87 SABS Code 0400-1987. Application of the National Building Regulations, RSA. Pretoria.

SA88 Samet JM, Marbury ML, Spengler JD. Health effects and Sources of Indoor Air Pollution part 1 and 2 Am. Rev. Dis., 137, 221-242, 1988.

SK90 Skov, P, Valborjn O. The Danish Town Hall Study: A one year follow up, Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 1, 787, 1990.

SP83 Spengler J, Sexton K. Indoor Air Pollution: A Public Health Perspective, Science, 221, No 4605, 9-16, 1983.

ST77 Sterling T D, Kobyashi D M. Exposure to pollutants in enclosed living spaces, Env. Research, 3, 1977.

ST90 Stenberg B, Hanson K, Sandstrom M, Lonnberg G, Wall S, Sundell J, Zingmark PA. The office illness project in Northern Sweden, Part 1: A prevalence study of Sick Building Syndrome (SBS) related to demographic data, work characteristics and building factors. Proc. 5th Int. Conf. on IAQ and Climate, Toronto, 4, 627, 1990.

SY89 Sykes JM. Sick Building Syndrome: A Review, Health and Safety Executive Report No. 10 UK, August 1989.

TP51 TPA, Transvaal Provincial Administrators Notice No. 148 of 21 February, 1951.

TR89 Truter R, Turner M, Ijsselmuiden C, Annegarn HJ, Schoeman JJ, Steinberg M, Padaychee GN , Hamman W, De Beer M, Hurwitz H. Sick Building Syndrome,Its Definition; Investigation and Solutions ; Proc. Int. Conf. Air-Conditioning and Refrigeration, Pretoria, April 1989.

TR90 Truter R, Schoeman JJ ,Steinberg M, Turner M, Annegarn HJ, Steyn S. A Preliminary study of Sick Building Syndrome in multi-storeyed office buildings in Johannesburg, Proc.of 5th Int. Conf. Indoor Air Quality and Climate, 1, 657, Toronto, 1990

TR91 Truter R, Annegarn HJ. Indoor Air - A regulatory. Imperative?, Proc of South African Conf. on Indoor Air Quality, Midrand, 1991

TR92 Truter R. Living Buildings:An Intergrated Approach for Resolving Sick Building Syndrome Problems in Sealed Buildings, Proc.of the Community Health Association of South Africa conf., Johannesburg, 6 Aug., 1992.

TS79 Tshongwe J, Annegarn HJA. Indoor/Outdoor relationships of particulates in Soweto, Int. Conf on Residential Air Pollution, Broederstroom, 4 November 1989.

TU83 Turiel I, Hollowell C. The effects reduced ventilation on indoor air quality in an office building. Atm. Env., 17, 51-64, 1983.

US86 United States Surgeon-Generals report on the Health Effects of Passive Smoking,EPA/600/6-90/006F, Office of Research and Developement, Washington, DC 20460, December, 1992.

VI89 Vischer J C. Environmental Quality in Offices, Van Nostrand Reinhold, USA, 1989.

WA87 Walsh PJ, Dudney CS, Copenhaver ED. Indoor Air Quality, CRC Press, Boca Raton, Florida, 1987.

WO89 Wolverton BC, Douglas WL, Bounds K. A Study of Interior Landscape Plants for Indoor Air Pollution Abatement - An Interim Report, Foliage for Clean Air Council, Washington, 1989.

APPENDIX I

APPENDIX

TERMS OF REFERENCE

1 **AIR-CONDITIONING**

- refers to having the air in a building that is sealed and mechanically ventilated, washed and brought to standard humidity, required temperature and circulating it in an office or building.

2 **ARTIFICIAL VENTILATION**

- has to do with air supplied to a sealed building, preferably high rise buildings in which outside or recirculated air is supplied to occupants after passing through various procedures intended to render the air usable for breathing purposes.

3 **PREVALENCE RATES**

- a rate obtained by using as the numerator, the number of persons sick or portraying a certain condition in a stated population at a particular time regardless of when the illness or condition began and, as the denominator, the number of persons in the population in which they occurred.

4 **SEALED BUILDING**

- high rise office building in which the windows are sealed for the purposes of mechanically supplied air.

5 **NATURAL VENTILATION**

- refers to a building in which no means of mechanical ventilation is present and fresh air is obtained via natural air movements through windows or ducting or any other natural means.

6 **OCCUPATIONAL HYGIENE**

- the science and art devoted to the recognition, identification, evaluation and control of those environmental factors which it is believed caused adverse effects, disease or death to man in the work place.

7 **THRESHOLD LIMIT VALUE Time Weighted Average (TLV-TWA)**

- the time weighted average concentration for a normal 8-hour work day or 40-hour work week, to which nearly all workers may be repeatedly exposed, day after day without adverse effect.

8 **TLV LIMIT VALUE short term exposure limit (TLV STEL)**

- the maximal concentration to which workers can be exposed for a period of up to 15 minutes continuously without suffering irritation, chronic tissue damage or narcosis of sufficient degree to accident proneness. No more than four 15 minute exposure periods per day are permitted with at least 60 minutes apart.

9 **NAAQS**

- National Ambient Air Quality Standards of the United States of America.

DEFINITIONS

The National Building Regulations defines the following concepts [NA88]:

10 **ARTIFICIAL VENTILATION SYSTEMS** - means a systems in which air is caused to circulate through a room by means of a mechanical apparatus which forces air into or extracts air from such room.

11 **NATURAL VENTILATION** - means the movement of air through a building due to natural causes.

12 **OUTSIDE AIR** - means air which is drawn into the building from the outside and which has not been circulated through the building.

The American Society for Heating and Refridgeration and Air-Conditioning engineers has defined the following concepts [AS89]:

13 **AIR-CONDITIONING** - process of treating air to meet the requirements of a conditioned space by controlling its temperature humidity, cleanliness and distribution.

14 **NATURAL VENTILATION** - the movement of air into and out of a space through intentionally provided openings, such as windows, doors, or through non-powered ventilators or by infiltration.

15 **OUTDOOR AIR** - air taken from external atmosphere, and therefore not previously circulated through the system.

16 **VENTILATION** - the process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned.

APPENDIX 2

Variable	Building A % (n)	Building B % (n)	p value
Type of Office			
Open Plan	37.71 (66)	58.5 (86)	
Closed Office	64.14 (107)	41.50 (61)	p=0
VDU User			
yes	69.71 (122)	53.76 (79)	p=0.005
Glare from V.D.U. screen			
Never	43.43 (76)	25.85 (38)	
Seldom	5.71 (10)	2.72 (4)	
Sometimes	10.29 (18)	18.37 (27)	
Often	8.57 (15)	4.76 (7)	
Very Often	1.71 (3)	2.72 (4)	p=0.002
Use of Anti-Glare screens			
Yes	17.14 (30)	8.16 (12)	p=0.002

Environment Conditions

Variable	Building A % (n)	Building B % (n)	p value
Comfort	71.43 (125)	71.43 (105)	
Acceptable	61.14 (107)	55.10 (81)	p=0.020
Temperature Acceptable	61.71 (108)	73.46 (108)	
Humidity Acceptable	61.14 (107)	70.75 (104)	
Odour Acceptable	64.00 (112)	65.98 (97)	
Noise Acceptable	74.29 (130)	70.74 (104)	
Overall_ Satisfaction Acceptable	71.43 (125)	82.31 (121)	
Environment Conditions Affect Ability to Work Yes	34.29 (60)	19.05 (28)	p=0.003

MEDICAL INFORMATION

Symptom	Building A	Building B
1. Aching Joints	18.86% (n=33)	19.05% (n=28) (ns)
2. Back Pain	37.14% (n=65)	33.33% (n=49) (ns)
3. Bladder Infection	6.86% (n=12)	6.80% (n=10) (ns)
4. Chest Congestion	17.14% (n=30)	22.45% (n=33) (ns)
5. Chest Pains	8.00% (n=14)	10.88% (n=16) (ns)
6. Contact Lens Problems	4.57% (n=8)	4.08% (n=6) (ns)
7. Disorientation	1.71% (n=3)	3.40% (n=5) (ns)
8. Dizziness	16.57% (n=29)	17.69% (n=26) (ns)
9. Dry and Burning eyes	33.71% (n=59)	31.97% (n=47) (ns)
10. Fatigue/Tiredness	50.86% (n=89)	55.78% (n=82) (ns)
11. Drowsiness/Lethargy	29.14% (n=14)	22.45% (n=33) (ns)
12. Headaches	48.57% (n=85)	52.38% (n=77) (ns)
13. Sinusitis	24.00% (n=42)	17.69% (n=26) (ns)
14. Nasal Congestion	26.86% (n=47)	25.17% (n=37) (ns)
15. Nausea	8.57% (n=15)	10.88% (n=16) (ns)
16. Nose Bleeds	7.43% (n=13)	16.33% (n=24) p=0.020
17. Palpitations	6.29% (n=11)	15.65% (n=23) p=0.011
18. Skin Irritations	12.57% (n=22)	23.81% (n=35) p=0.013
19. Hayfever	16.00% (n=28)	21.77% (n=32) (ns)
20. Sore Dry Throat	26.29% (n=46)	34.69% (n=51)
21. Insomnia	19.43% (n=34)	17.69% (n=26)
22. Unusual Taste	6.29% (n=11)	6.80% (n=10)
23. Digestive Problems	13.14% (n=23)	16.33% (n=24)
24. Abdominal Pain	11.43% (n=20)	24.49% (n=36) p=0.002
25. Ear Problems	8.00% (n=14)	12.24% (n=18) (ns)
26. Skin Problems	19.43% (n=34)	21.77% (n=32) (ns)
27. Flu Like Symptoms	45.71% (n=80)	48.30% (n=71) (ns)
28. Anxiety	17.71% (n=31)	27.21% (n=40) (ns)
29. Nervous Conditions	10.29% (n=18)	21.09% (n=31) p=0.11
30. Asthma	2.86% (n=5)	2.04% (n=3)
31. Difficulty in Breathing	8.00% (n=14)	7.48%(n=11)

Variable	Building A % (n)	Building B % (n)
House	78.29 (137)	72.79 (107)
Ground Floor Flat	2.29 (4)	4.08 (6)
Upper Ground Flat	9.71 (17)	16.33 (24)
Townhouse	8.00 (14)	4.76 (7)
Other	1.71 (3)	1.36 (2)

17.1 Job Description

Variable	Building A	Building B
1. Artisan	0.57% (n=1)	0%
2. Technical	5.14% (n=9)	13.61% (n=20)
3. Clerical	48.57% (n=85)	44.90% (n=66)
4. Supervisor	3.43% (n=6)	4.08% (n=6)
5. Managerial	20.57% (n=36)	9.52% (n=14)
6. Professional	15.43% (n=27)	20.41% (n=30)
7. Other	5.71% (n=10)	5.44% (n=8)
8. Don't Know	0.57% (n=1)	2.04% (n=3)
Total	54.35% n=175	45.65% n=322

(ns)

Proximity to Pollution Sources (2km)

Variable	Building A % (n)	Building B % (n)
Smoke stack or Chimney	15.43 (27)	22.45 (33)
Power station (2km)	89.71 (157)	92.52 (136)
Factory or Industry	81.71 (143)	85.71 (126)

Q19 Form of Travel to Work

Variable	Building A	Building B
Car	59.43% (n=104)	37.41% (n=55)
Train	21.14% (n=37)	25.17% (n=37)
Bus	14.29% (n=25)	27.89% (n=41)
Motorbike	0.57% (n=1)	0%
Bicycle	1.71% (n=3)	2.72% (n=4)
Walk	1.71% (n=3)	2.72% (n=4)
Other	2.86% (n=5)	6.80% (n=10)

Q23.1 User hours with V.D.U. by building

Variable	Building A	Building B
1-2 hours/day	30.29% (n=53)	45.58% (n=67)
2-5 hours/day	22.29% (n=39)	19.05% (n=28)
5-8 hours/day	21.71% (n=38)	18.37% (n=27)
>8 hours/day	2.86% (n=5)	1.36% (n=2)
Total	175	147

p=0.014

Q23.2 Colour of V.D.U. screen by building

Variable	Buiding A	Building B
Green	30.29% (n=53)	45.58% (n=67)
Amber	53.71% (n=94)	38.10% (n=56)
White	5.14% (n=9)	7.80% (n=10)
Blue	2.29% (n=4)	2.04% (n=3)
Don't Know	0.57% (n=1)	2.04% (n=3)
Total	175	147

APPENDIX 2: QUESTIONNAIRE

The English questionnaire is attached
The Afrikaans questionnaire is available on request

CONFIDENTIAL MEDICAL QUESTIONNAIRE

The purpose of this Questionnaire is to assess the health status of the office personnel in this building. This study is being conducted by Technikon Witwatersrand and the National Centre for Occupational Health.

Permission to carry out this study has been obtained from the relevant authorities.

Please answer the questions as honestly as you can and to the best of your ability.

Your answers will be kept in strictest confidence and only group results will be issued. These will be made available to youon request.

Due to factors beyond our control we are unable to present this questionnaire in Afrikaans

DO WE HAVE YOUR PERMISSION TO CONTINUE WITH THIS INTERVIEW ?

Interviewer________________________

Language of Interviewer______________________

What is your home language ?_______________________

OFFICE USE ONLY

A. PERSONAL INFORMATION

I am going to begin with some questions about yourself that may have a bearing on your health status

1. What is your :

   - age [ ][ ] years — 7

   sex ? male [1] female [2] — 8

   - approximate height ? [ ][ ][ ] cms — 11

   - approximate weight ? [ ][ ][ ] kg — 14

   - marital status

single 1	married 2	divorced 3	widowed 4

15

2. What is your HIGHEST educational qualification?

Nil - Std 1	1
Std 2 - Std 5	2
Std 6 - Std 9	3
Matric	4
Post Matric	5

16

3. Do you participate in sport at least once a week ?

   yes [1] no [2] — 17

4. Do you have any children? - yes [1] no [2] — 18

BACKGROUND HISTORY

OFFICE USE ONLY

The following questions refer to your smoking practices, past and present.

5. Have you ever smoked cigarettes ? (yes means more than 20 packs in your life or more than 1 cigarette a day for a year and include hand rolled cigarettes

yes [1] no [2] — 19

If no, please go to Question 9

If yes, to above

5.1 Do you smoke cigarettes now ? (as of one month ago)

yes [1] no [2] — 20

If yes to above

5.2 Please indicate approximately how many cigarettes you smoke a day ?

[ ][ ] — 22

6. Do you smoke cigars ? Yes [1] No [2] — 23

7. Do you smoke a pipe ? Yes [1] No [2] — 24

8. Do you smoke any of the above in your working environment ?

Yes [1] No [2] — 25

9. Does anyone in your immediate vicinity smoke ?

Yes [1] No [2] — 26

10. Is there a smoking policy in your office

Yes [1] No [2] Don't Know [3] — 27

if yes please elaborate: ____________________

____

____

____________________ — 28

C. RESIDENTIAL HISTORY

OFFICE USE ONLY

These questions refer to the place where you live

11. In which area do you stay at present?

______________________ 32

12. If you live in a different area to the above area while at work, please specify:

______________________ 36

13. Have you lived in your present area for more than one year?

Yes [1] No [2] 37

13.1 If yes please specify the duration

[ ] years [ ] months 40

13.2 If no;
please specify the area in which you last lived

______________________ 44

14. What type of residence do you live in ?

House	1
Flat :ground floor	2
Flat :upper floor	3
Townhouse	4
Other specify______	5

45

15.1 Is it rented or do you own it ? Rented [1] Own [2] 46

16. Do you live within two kilometres of any of the following:

OFFICE USE ONLY

smoke stack/chimney	Yes	1	No	2	don,t know	3	47
Power station	Yes	1	No	2	don't know	3	48
Factory/industry releasing smoke	Yes	1	No	2	don't know	3	49

D JOB AND OFFICE HISTORY

I am now going to ask you questions relating to your job

17.1 What is your present job title ? 52

____

*17.2

Artisan	
Technical	
Clerical	
Supervisor	
Managerial	
Professional	
Other	
Don't Know	

53

18. How long have you been employed in your present job?

☐☐ years ☐☐ months 55

19. What is your main form of travel to work?

OFFICE USE ONLY

Car	1
Train	2
Bus	3
Motor Bike	4
Bicycle	5
Walk	6
Other specify ______________	7

56

20. What is the average time you spend daily travelling to and from work ?

0 - 15 minutes	1
16 -30 minutes	2
31 - 60 minutes	3
61 - 120 minutes	4
more than 120 minutes.....	5

57

21. On what floor of the building is your office situated ?

☐☐ floor

59

22. In what type of office do you work ?

(READ)

open plan	1
closed office	2
don't know	3
other (please specify)	4

60

3. Do you work with a video display unit (VDU)? 61

If No, please go to question 24

yes [1] no [2] 62

23 .1 If yes,

How many hours a day do you work with a Video Display Unit?

1 - 2 hours	
2 - 5 hours	
5 - 8 hours	
If more than 8 please specify..	

63

23.2 What colour is the writing on the screen of your Video Display Unit?

green 1	amber 2	white 3	blue 4	Don't know 5

64

23.3 Do you experience glare from the VDU screen?

Never 1	Seldom 2	Sometimes 3	Often 4	Very Often 5

65

23.4 Do you use a anti - glare screen ?

Yes [1] no [2] don't know [3]

66

OFFICE USE ONLY

24. Approximately how many days a week do you work in your present office?

1 day a week	1
2 - 4 days a week	2
5 or more days a week	3

☐ 67

25. Are there windows that you can open in your office ?

Yes [1] No [2] Don't Know [3]

☐ 68

26. Is there a tea lounge or leisure area on your floor?

Yes [1] No [2] Don't Know [3]

☐ 69

If no, please go to Question 28

If yes to the above:-

25.1 Do you use it regularly?

yes [1] no [2]

☐ 70

26. How long, on average, do you use it per day ?

__________hours

☐ 1

OFFICE USE ONLY

29. Is there a photocopy machine in your building?

yes [1] No [2] Don't Know [3] — 3

If no or don't know please go to Question 30

if yes

29.1 Where is it kept ? — 4

in your office	1
kept somewhere on the floor	2
don't know	3

29.2 Where are the machines chemicals kept? — 5

next to machine	1
in a separate storeroom	2
don't know	3

29.3 How many photostat machines are there in your section? — 6

[ ][ ] machines

30. In the past three months has your office been -

refurbished/refitted	yes	1	no	2	7
repainted	yes	1	no	2	8
recarpeted	yes	1	no	2	9
relocated	yes	1	no	2	10
steam cleaned	yes	1	no	2	11

12

OFFICE USE ONLY

31. To what extent are you satisfied with your job ? (tick one)
(Note to Interviewer - Use cards provided)

Completely Satisfied	1
Very Satisfied	2
Satisfied	3
Dissatisfied	4
Not at all satisfied	5

☐ 13

32. What amount of control do you have over your workload?(tick one)
(Note to Interviewer - Use cards provided)

Complete control	1
More than average control	2
Average control	3
Less than average control	4
No control at all	5

☐ 14

33. In your opinion, how stressful is your job ? (tick one)
(Note to Interviewer - Use cards provided)

Very stressful	1
More than average stress	2
Average stress	3
Less than average stress	4
Not stressful at all	5

☐ 15

34. On average how would you describe the following environmental conditions in your office .
(Note to Interviewer - Use the scale provided

OFFICE USE ONLY

1	Completely Unacceptable
2	Unacceptable
3	Unsure
4	Acceptable
5	Completely Acceptable

How would you describe the following ?

34.1 Comfort	1	2	3	4	5	16
34.2 Temperature	1	2	3	4	5	17
34.3 Humidity	1	2	3	4	5	18
34.4 Air Freshness	1	2	3	4	5	19
34.5 Odour	1	2	3	4	5	20
34.6 Noise	1	2	3	4	5	21
34.7 Overall Satisfaction	1	2	3	4	5	22

35. What level of control do you have over the following factors in your office ?
(Note to Interviewer - Use cards provided)

1	Complete control
2	More than average control
3	Average control
4	Less than average control
5	No control at all

OFFICE USE ONLY

35.1	mechanical ventilation	1	2	3	4	5	23
35.2	natural ventilation	1	2	3	4	5	24
35.3	room temperature	1	2	3	4	5	25
35.4	lighting of room	1	2	3	4	5	26
35.5	work load	1	2	3	4	5	27
35.6	levels of stress	1	2	3	4	5	28

36. Does one or more of the above mentioned conditions affect your ability to work ?

Yes [1] No [2] Don't Know [3]

ONLY
29

If no ,please go to Question 37

36.1..If yes,please indicate which ones

mechanical ventilation	1	lighting of room	4	30
natural ventilation	2	work load	5	31
room temperature	3	levels of stress	6	32

V

OFFICE USE ONLY

37. Have you been on leave within the past 8 weeks ?

Yes [1] No [2] Don't Know [3] — 33

If no, please go to Question 38

37.1 If yes, please indicate the longest period you were on leave during this time

[ ][ ] Days — 34

. MEDICAL HISTORY

OFFICE USE ONLY

The following questions relate to your health status.

>38. Please indicate if you have had more than 2 episodes of any of the following in the past 3 months.If yesplease indicate when you experience these symptoms.

SYMPTOMS AND CONDITIONS	YES	NO	EVERY DAY	MOST WEEKS	MOST MONTHS	SELDOM	OFFICE USE ONLY
- aching joints/arthritis	1	2	3	4	5	6	35
- back pain	1	2	3	4	5	6	36
- bladder infections	1	2	3	4	5	6	37
- chest congestion	1	2	3	4	5	6	38
- chest pains	1	2	3	4	5	6	39
- contact lens problems	1	2	3	4	5	6	40
- disorientation	1	2	3	4	5	6	41
- dizziness	1	2	3	4	5	6	42
- dry and burning eyes	1	2	3	4	5	6	43
-fatigue/tiredness	1	2	3	4	5	6	44
- drowsiness/lethargy	1	2	3	4	5	6	45
- headaches	1	2	3	4	5	6	46
- sinusitis	1	2	3	4	5	6	47
- nasal congestion	1	2	3	4	5	6	48
- nausea	1	2	3	4	5	6	49
- nose bleeds	1	2	3	4	5	6	50
- palpitation	1	2	3	4	5	6	51
- skin irritations	1	2	3	4	5	6	52
- hayfever	1	2	3	4	5	6	53
- sore dry throat	1	2	3	4	5	6	54

38. Con't.

SYMPTOMS AND CONDITIONS	YES	NO	EVERY DAYS	MOST WEEKS	MOST MONTHS	SELDOM	OFFICE ONLY USE
- insomnia	1	2	3	4	5	6	55
- unusual taste	1	2	3	4	5	6	56
- digestive problems	1	2	3	4	5	6	57
- abdominal pain	1	2	3	4	5	6	58
- ear problems	1	2	3	4	5	6	59
- skin problems/dry skin	1	2	3	4	5	6	60
- flu like symptoms	1	2	3	4	5	6	61
- anxiety	1	2	3	4	5	6	62
nervous conditions	1	2	3	4	5	6	63
- asthma	1	2	3	4	5	6	64
- difficulty in breathing	1	2	3	4	5	6	65
- Other							66
:specify______________ ______________________							67

	OFFICE USE ONLY
39. Are you presently on any form of drug therapy ?	
If no, please go to Question 40	
Yes [1] No [2] Don't Know [3]	[ ] 68
If yes please specify reason for therapy:-	
40. Do you suffer from any allergies ?	
Yes [1] No [2] Don't Know [3]	[ ] 69
If no, please go to Question 41	
40.1.. if yes,please specify:	[ ] 70
41. In the past two months, has your health (tick one) :	

deteriorated	
improved	
remained the same	

[ ] 1

OFFICE USE

INTERVIEWER NOTE: This question for is women only !

2. Do you suffer from menstrual problems or irregularities

Yes [1] No [2] Don't Know [3] □ 2

. GENERAL

3. Is there anything else you would like to say about your work environment ?

____

____

____

____

______________________________ □ 3

4.Is there anything else you would like to mention ?

____

____

____

____

______________________________ □ 4

THANK YOU FOR YOUR PARTICIPATION AND CO OPERATION IN THIS PROJECT.

DEAR RESPONDENT

Thank you for participating in this study. Your participation has ensured it's success .

We are confident the results will benefit people interested in their health status.

If you have any queries, please contact me in this regard.

A summary of the results of this study will be made available to your employers for distribution to you.

Yours Faithfully

Richard Truter
Principal Researcher

APPENDIX 3

REPORT ON THE INDOOR ENVIRONMENT QUALITY

IN THE SABC NEWSROOM

R TRUTER
CITY HEALTH DEPARTMENT
JOHANNESBURG

27 JULY 1989

CONTENTS

1. SUMMARY

2. INTRODUCTION

3. CAUSES OF SBS

4. METHOD

5. RESULTS

6. CONCLUSION

7. RECOMMENDATIONS

8. BIBLIOGRAPHY

9. APPENDIX

REPORT ON THE INDOOR ENVIRONMENT QUALITY IN THE SABC NEWSROOM (PIET MEYER BUILDING)

ABSTRACT

1. SUMMARY

The SABC proposed an investigation into the air quality in the newsroom of their Piet Meyer Building. A control building was also investigated in order to assess the relevance of the results. The data obtained by interviewing 30 SABC personnel showed an overall dissatisfaction with their working environment, especially with regard to noise. There was a higher prevalence of lethargy, headaches and blocked noses among them, and they also reported fluctuations in the air temperature. Chemical measurements revealed a concentration of carbon monoxide, CO, which could momentarily exceed a recommended standard maximum. This was accounted for by the presence of smokers and a fault that was discovered in the ventilation system.

WHY

2. INTRODUCTION

The South African Broadcasting Corporation, in response to a report by staff members, offered that an investigation could be made into the conditions existing in the newsroom on the 1st floor of their Piet Meyer Building. This is a sealed multistory building in which the indoor air environment is controlled by an air-conditioning system. For some time office workers have been known to complain about this kind of work environment, and researchers overseas have called this phenomenon the "Sick Building Syndrome," or SBS. A range of symptoms that prevail in sealed buildings has been identified. These symptoms are:

- Rhinitis
- Dry Throat
- Eye irritation / Burning of the eyes
- Headaches
- Lethargy
- Dry Skin

The symptoms are non-specific, i.e. they may have more than one cause. The subject of indoor air quality is emotive and subjective; however, studies conducted in the USA (600) and in Britain (27) confirm that the symptoms listed above are characteristic of SBS.

A condition imposed by the SABC requires that the results of this investigation are not to be published without their prior approval.

THEORY

3. CAUSES OF SICK BUILDING SYNDROME

In the USA the National Institute for Occupational Health and Safety (NIOSH) has classified the causes of SBS into the following categories:

52 %	-	Inadequate Ventilation
17 %	-	Inside Contamination from sources within the building
11 %	-	Outside Contamination from sources outside the building
5 %	-	Microbiological
4 %	-	Building Fabric
11 %	-	Other Causes

In South Africa the sealed multistory buildings are not necessarily exact copies of their American counterparts. Nonetheless the above list provides a good base from which to depart on an investigation.

PRACTICAL

4. MATERIALS AND METHODS

The investigation was conducted on two fronts:

(a) Questionnaire Survey
(b) Industrial Hygiene Measurements

In order to assess the validity of the results obtained a control building with natural ventilation was selected and a similar survey was conducted there. A comparison of the results should show any differences between the sealed building and the control.

4.1 SELECTION OF THE CONTROL BUILDING

The control building chosen was the Civic Centre. This building, apart from its ready accessibility, was selected for the following reasons:

(a) The Civic Centre is naturally ventilated. The staff are able to control their air supply requirements individually.

(b) The staff are also employed by a semi-state institution, and a sample of persons closely matched in age, sex, education and job to those in the SABC newsroom could easily be found.

(c) The Civic Centre has an orientation which is similar to that of the SABC's Piet Meyer Building.

(d) The first floor office layout was similar in design and materials.

4.2 QUESTIONNAIRE SURVEY

30 Persons were randomly selected from the staff of the first floor of the building. Out of the SABC staff 30 persons were randomly selected. A questionnaire was designed and prepared for the purpose of ascertaining the prevalence of symptoms relevant to SBS. Trained interviewers used this questionnaire to evaluate the participants perceptions of the indoor environment and air quality in the newsroom. All the interviews were conducted in English.
A group of 28 people working in similar circumstances at the Civic Centre were selected for the control survey. They participated in the same questionnaire and interview process.

4.3 INDUSTRIAL HYGIENE SURVEY

Carbon monoxide, (CO), concentrations were measured over 8 hours of a working day using a CO meter and recorder. The meter was calibrated using a standard gas mixture. The CO measurements can be influenced by the amount of smoking taking place. Temperature variations were measured hourly over the same 8 hour period. The temperature analyser (Tempstress) was calibrated according to the prescribed calibration procedure. The air flow rate was measured using a digital anemometer which was calibrated prior to use by the supplier. Flow and thermal parameters indicate the operating efficiency of the air conditioning system.

A portable Miran infrared analyser was also used for measuring Carbon Dioxide, Nitrogen Dioxide, Total Hydrocarbons and Ozone. It was found, however, when recalibrating the instrument, that these measurements were not reliable and were therefore discarded. This is unfortunate, because the information would have been very useful.

FOUND

5. RESULTS

5.1 QUESTIONNAIRE RESULTS

For convenience a summary of the results has been recorded below. The full and detailed results may be found in the appendix. It must be mentioned that, statistically, data from such a small population has limited significance.

TABLE 1, PREVALENCE OF SYMPTOMS

Position	SABC Newsroom (Case Building)	Civic Centre (Control Building)
SBS symptoms	%	%
Lethargy, Drowsiness	36	14
Headache	36	32
Influenza symptoms	23	35
Dry skin	13	17
Dry throat	13	28
Blocked Nose	26	17
Control Symptoms		
Chest pain	13	14
Dizziness	10	14
Bladder Infection	3	3

TABLE 2, INTERNAL ENVIRONMENTAL CONDITIONS

Position	SABC Newsroom (Case Building)	Civic Centre (Control Building)
Dissatisfied	%	%
Comfort	23	42
Temperature	20	92
Humidity	36	50
Odour	36	17
Noise	76	78
Overall	60	78
Tobacco Smoke		
Smokers	47	21

TABLE 3, WORK-RELATED PARAMETERS

Position Parameter	SABC Newsroom (Case Building) %	Civic Centre (Control Building) %
Job satisfaction	93	92
Stressfulness	86	81
Use Video Display Units	80	21
On drug medication	20	21
Sub-M qualification	3	3
M-qualification	30	5
Post-M qualification	66	78
Control over workload	90	85

5.2 ANALYSIS RESULTS

TABLE 4 - MEASUREMENTS

Time, hours	0	1	2	3	4	5	6	7	8
Carbon Monoxide, ppm									
SABC Newsroom	3	3	7	7	4	4	6	7	7
Civic Centre	5	3.5	4	3	3	3	4	3	3
Temperature, °C									
SABC Newsroom	22.5	22.0	22.3	22.0	22.8	22.4	22.0	22.0	22.0
Civic Centre	19.4	18.7	18.7	18.8	20.2	20.5	21.6	21.3	21.5
Airflow speed, m/sec									
SABC Newsroom	0.1	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.2
Civic Centre	0.1	0.3	0.2	0.0	0.0	0.2	0.1	0.1	0.1

Airflow measurements were take n 2.3 metres above floor level.

NOTES: The Japanese and Swedish Indoor Air Threshold Limit Value (TLV) for carbon monoxide, CO, is 9 ppm. A CO recording shown in the appendix, which was made by a separate instrument, records the events where smokers were lighting up. On these occasions the TLV was exceeded.

The Airflow speed equates to 200 $l/m/sec^{-1}$. The NBR specifies 7,5l/sec of air person.

The tests were conducted on over the following dates 13,14 June 1989.

5.3 Ventilation System

The newsroom of the SABC Piet Meyer Building is ventilated by a "Dual Duct" system which, according to the maintenance staff, is regularly tested.

The investigation included an examination of the air supply to the newsdesk area. It was found by the maintenance staff that a fresh-air damper in the mixer box was not functioning. They addressed the problem immediately.

In the Civic Centre the windows may be opened and the office areas can be ventilated by this means.

6. CONCLUSIONS

6.1 Symptoms of Sick Building Syndrome

In the SABC newsroom there was a high prevalence of lethargy, blocked nose, and headaches.
The "control symptoms" showed a good correlation.

6.2 Carbon Monoxide and Carbon Dioxide

The influence of smokers on the CO concentration is demonstrated. In a sealed building a faulty damper can easily restrict the introduction of fresh air, which in turn causes a build-up of stale gases. Certain SBS symptoms would follow soon afterwards. It is interesting to notice the CO levels in both buildings dropped during the lunch break. In the Civic Centre the CO level also dropped after the first hour, when workers would naturally choose to open the windows.

6.3 Thermal Environment

In the SABC newsroom the thermal environment was acceptable. Workers did complain about varying temperatures in the work areas. The recordings do not illustrate this.
The temperature in the Civic Centre, as can be expected, received much more criticism.

6.4 Odours

In the SABC newsroom odours were noticed to a higher degree. In sealed buildings the presence of odorous substances has significance.

6.5 Noise

The level of noise was unacceptable in both buildings. In the Civic Centre the overall environment was considered unacceptable by a larger majority. It is interesting to note that temperature and noise must be the culprits. The SABC newsroom has only noise to account for the dissatisfaction of its occupants.

6.6 Work-related Parameters

The two populations, despite their environment and the stress, enjoy their work. The two groups are, in most respects, very similar. We find the following exceptions. The SABC group use video display units, which could have an effect on their well being. The Civic Centre group have more post-matric qualifications.

7. RECOMMENDATIONS

7.1 BUILDING MANAGEMENT

This is a subject which is becoming increasingly important. A new brand of engineer will develop whose specialization will be the management of a modern building.

Such an engineer will place reliable instruments in strategic parts of his building and take note of their warnings. Matters such as faults in the ventilation system, or micro-organisms in the humidifier water, will come to his attention and be dealt with promptly. A sealed building needs a building automation system. The SABC Piet Meyer Building is a sealed building.

7.2 Smokers

The National Building Regulations specify a higher rate of ventilation where smoking is permitted. This should not be overlooked.

7.3 Odours

The presence of Odours could be a warning of future SBS problems.

7.4 Comfort, Temperature and Noise

This survey has shown that temperature and noise are both major influences in the comfort of workers.

Future indoor environment and air quality surveys should include noise measurements.

/ 8. Bibliography

8. Bibliography

1. Guidance for Indoor Air Quality Investigation NIOSH booklet.

/ Appendix A .....

9. Appendix Results

TABLE A

Symptom Prevalence in both Buildings

SYMPTOMS	SABC (n = 30)	CIVIC CENTRE (n = 28)	P
Lethargy / Drowsiness	11 (36 %)	4 (14 %)	0.51
Headache	11 (36 %)	9 (32 %)	0.71
Flu like symptoms	7 (23 %)	10 (35 %)	0.30
Dry Skin	4 (13 %)	5 (17 %)	0.56
Dry Throat	7 (13 %)	8 (28 %)	0.65
Blocked Nose	8 (26 %)	5 (17 %)	0.42

TABLE B

Control Symptoms in both Buildings

SYMPTOMS	SABC (N = 30)	CIVIC CENTRE (N = 28)	P
CHEST PAIN	4 (13 %)	4 (14 %)	0.60
DIZZINESS	3 (10 %)	4 (14 %)	0.46
BLADDER INFECTION	1 (3.3 %)	1 (3.5 %)	0.50

/ TABLE C ...

TABLE C

Percentage workers satisfied with their jobs.

%	SABC (n = 30)	CIVIC CENTRE (n = 28)	P
Satisfied	28 (93 %)	26 (92 %)	0.7
Dissatisfied	2 (6 %)	2 (7 %)	0.7

TABLE D

Percentage workers who feel that their job is stressful

%	SABC (N = 30)	CIVIC CENTRE (N = 28)	P
Stressful	26 (86 %)	25 (81 %)	0.89
Not Stressful	4 (13 %)	3 (10 %)	0.89

TABLE E

Percentage of workers who work with video display units (VDU)

BUILDING	VDU USER (N = 30)	NON VDU USER (N = 28)	P
SABC	24 (80 %)	9 (30 %)	0.02
CIVIC CENTRE	6 (20 %)	19 (67 %)	0.02

/ TABLE F ......

TABLE F

Percentage of workers who are presently on some form of drug therapy

	SABC (N = 30)	CIVIC CENTRE (N = 28)	P
Drug Therapy	6 (20 %)	6 (21 %)	0.89
No Drug Therapy	24 (80 %)	22 (78 %)	0.89

TABLE G

Educational Stratification of workers in both buildings

LEVEL EDUCATION	SABC (N = 30)	CIVIC CENTRE (N = 28)	
STD 6 - STD 9	1 (3 %)	1 (3.5%)	
STD 10	9 (30 %)	5 (17 %)	
POST MATRIC QUALIFICATION	20 (66 %)	22 (78 %)	

TABLE H

Perception among workers of the amount of control of their workload.

WORKLOAD	SABC (N = 30)	CIVIC CENTRE (N = 28)	P
AVERAGE CONTROL	27 (90 %)	24 (85 %)	0.75
NO CONTROL	3 (10 %)	4 (15 %)	0.75

/ TABLE I ...

TABLE I

Percentage of workers who find the Office Environmental conditions acceptable - at the SABC building

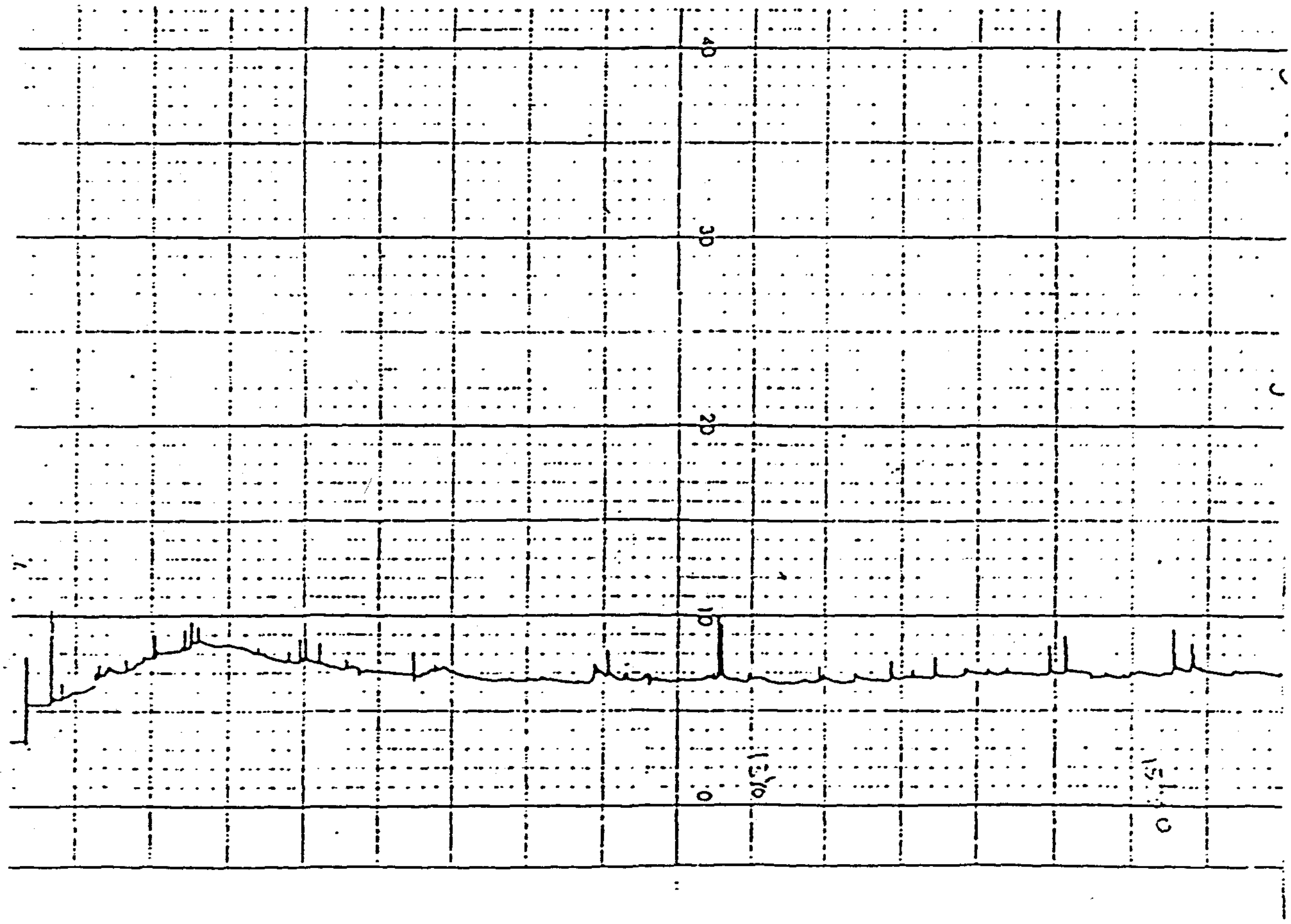
	ACCEPTABLE	UNACCEPTABLE	P
Comfort	23 (76 %)	7 (23 %)	0.11
Temperature	24 (70 %)	6 (20 %)	0.00
Humidity	19 (63 %)	11(36 %)	0.10
Odour	19 (63 %)	11(36 %)	0.30
Noise	7 (23 %)	23(76 %)	0.86
Overall Satisfaction	12 (40 %)	18(60 %)	0.12

TABLE J

Percentage of workers who find the Office Environmental conditions acceptable at the Civic Centre

	ACCEPTABLE	UNACCEPTABLE	P
Comfort	16 (53 %)	12 (42 %)	0.11
Temperature	2 (7 %)	28 (92 %)	0.00
Humidity	14 (50 %)	14 (50 %)	0.30
Odour	23 (82 %)	5 (17 %)	0.10
Noise	6 (21 %)	22 (78 %)	0.86
Overall Satisfaction	6 (21 %)	22 (78 %)	0.12

Average CO concentrations measured in the SABC Newsroom showing the lighting of cigarettes and pipes (16/6/1989)



Average CO concentrations measured in the Civic Centre (14/6/89)