AN INVESTIGATION OF INDOOR AIR QUALITY

ASSESSMENT IN OFFICE BUILDINGS

By

FRANÇOIS JANSE VAN RENSBURG

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fulfilment of the requirements for the degree

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Promoter : Ronelle Claassen

17 January 2000
 DECLARATION

“I François Janse van Rensburg hereby declare that:

- the work in this dissertation is my own original work;
- all sources used or referred to have been documented and recognized; and
- this dissertation has not been previously submitted in full or partial fulfilment of the requirements for an equivalent or higher qualification at any other recognized education institution.”

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ABSTRACT

Over the last several years studies have shown that the quality of indoor air may be worse than outdoor air. People spend as much as 90% of their time indoors, therefor, the associated health risk due to indoor air pollution may be greater than the risk due to outdoor air pollution. Building designs have altered dramatically over the last two decades resulted in "tighter" buildings that rely on sophisticated mechanical systems to provide for the quantity of air required throughout the building. These changes over the years could result in an increased number of complaints received regarding Sick Building Syndrome symptoms.

The World Health Organization (WHO) estimates that up to 30% of office buildings world-wide may have significant problems regarding poor indoor air quality (IAQ).

This study involves a literature study of the major indoor air pollutants regarding the source of the pollutant, the associated health effects, the measuring techniques available and the results of previous studies conducted on the specific pollutant. Measurements will be taken in two sealed buildings, one an old and the other a new building to identify the major pollutants. A questionnaire was compiled specifically for building occupants and completed by the occupants of both buildings. From the results obtained a step-by-step method for solving indoor air quality (IAQ) problems was proposed. The method was applied and evaluated in a case study of a problem building where indoor air quality related problems were experienced.

The results of the study revealed that the major indoor air pollutants are present in old as well
as new buildings. The study also revealed that some office workers might be more susceptible than others to the medical reactions cause to human beings by these pollutants. Some concentrations are higher in new buildings than in old buildings. The responses from the questionnaire was evaluated against the results obtained from the measurement study. The step-by-step method in the case study provided a more systematic approach at solving IAQ problems at buildings.

Solving indoor air quality problems is a very practical issue and does not necessarily require an investment of expensive high technology equipment, but might merely require a practical approach. Environmental Health Officers can play a major role in providing expert advice when scrutinizing building plans.

Environmental Health Officers should empower themselves with the knowledge to do inspections or investigations in office buildings by using the step-by-step method for investigating indoor air quality problems. By addressing indoor air quality problems in buildings, the workers in healthy buildings can increase their productivity with lasting effects on a company’s bottom line.
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AN INVESTIGATION OF INDOOR AIR QUALITY

ASSESSMENT IN OFFICE BUILDINGS

1. INTRODUCTION

It is a well-known fact that outdoor air pollution can damage human health. However, over the last several years, measurement studies have shown that the quality of indoor air may be even worse than that of outdoor air (U.S.EPA, 1991). In addition, it is estimated that people spend as much as 90% of their time indoors. The associated health risk due to indoor air pollution may, therefore, be greater than the risk due to exposure to outdoor air pollution.

With the advancement of modern technology, the number and types of contaminants released into indoor atmosphere have increased, while the amount of fresh outdoor air, that is being introduced into many structures, has generally decreased (U.S.EPA, 1991). This trend, of increased contaminant concentrations in indoor air, is due to the construction of well-sealed buildings, the use of synthetic and/or specialized building materials and fabrics, and/or the use of chemically-formulated personal care products, pesticides and household cleaners.

Office spaces have been dramatically altered in the last twenty years. Changes in building design and construction have resulted in “tighter” structures that must rely on sophisticated mechanical systems to provide for the quantity of air required throughout the building. The use of open plan offices that rely on partitions for individual privacy, may significantly impact on the distribution of air throughout the floor and particularly individual micro-environments. The use of desktop computers has dramatically changed
the way we utilize office spaces and perform daily activities. The introduction of various office products and machines into the office environment has also provided for many new potential contaminants to be added to the occupied areas of buildings. The result of the changing office environment is a change in office air quality. The degradation in indoor air quality can result in Sick Building Syndrome.

The Sick Building Syndrome (SBS) refers to a series of acute, non-specific health symptoms such as headache, eye, nose or throat irritation, dry cough, dry or itchy skin, dizziness and nausea, difficulty in concentrating, fatigue and sensitivity to odours. In a complaint building a large percentage (more than 15%) people will experience similar symptoms repeatedly over an extended time period. Those suffering from this "syndrome" tend to feel better upon leaving the building. Consequently, indoor air pollution is suspected (U.S. EPA, 1991).

The World Health Organization (WHO) estimates that up to 30% of office buildings world-wide may have significant problems, with 10 to 30% of the occupants of the building experiencing health effects that are, or are perceived to be, related to poor Indoor Air Quality (IAQ) (Van den Heever, 1997).

Several recent studies have revealed another compelling argument for green development. Improving office lighting, heating, ventilation and cooling, measures typically undertaken for energy savings and health, can make workers more comfortable and productive. According to a study by the Rocky Mountain Institute, productivity gains of six to sixteen percent, including decreased absenteeism and improved quality of work, have been reported from energy-efficient design (Rocky Mountain Institute, 1997). Since companies
spend an average of seventy times as much money on employee salaries as on energy, an increase of just one percent in productivity can result in savings that exceed the company’s entire energy bill. To a developer, these savings can mean higher lease rates and greater return on investment if the tenants understand the benefits. Most energy-efficient design practices are cost effective just for their energy savings, the resulting productivity gains make them indispensable.

Often the gains in productivity are an unexpected bonus. At the U.S. Post Office mail processing center in Reno, Nevada, a $300,000 retrofit was carried out to improve energy efficiency. Combined energy and maintenance savings came to about $50,000 a year, a calculated six-year payback. But it turned out that improvements in employee productivity dwarfed the energy savings (Rocky Mountain Institute, 1997).

2. INDOOR AIR POLLUTANT CATEGORIES

In order for a pollutant to have an effect on an individual, the person must first be exposed to that substance. The physiological mechanisms that occur, following the exposure, depend, not only on the individual, but also on the chemical and physical properties of the pollutant involved.

Indoor air pollutants may be chemical, physical or biological in nature. Chemical pollutants can be grouped into three broad categories based on their physical state: particles, gases and mixtures: (Examples are given under each heading)

- Chemical Pollutants
- **Particles**
  Asbestos, Lead, Radon

- **Gases**
  Carbon Monoxide, Formaldehyde, Nitrogen Dioxide, Organic Vapours, Radon Gas

- **Mixtures**
  Environmental Tobacco Smoke, Particulates, Pesticides, Biological Agents

- **Physical Pollutants**
  Noise, Vibration, Lighting

- **Biological Pollutants**
  Viruses, Bacteria, Fungi, Protozoa, Arthropods, Mammals and Birds

The source, health effects, measuring techniques of each of the major pollutants are outlined in Chapter 4.

Several studies by the United States Environmental Protection Agency (EPA) have identified indoor air pollution as one of the most important environmental risks to the nation’s health (U.S. EPA, 1991). The relatively high risk perceived from indoor exposure reflects the large number of people exposed indoors, as well as the large amount of time they spend indoors.

In addition to the health risks associated with indoor air quality, indoor air pollution has profound economic effects. The economic costs are generalized into three major types:

* Loss of productivity
The diverse indoor air quality related health problems or general discomfort experienced by those at work may result in lost economic productivity. Lost productive years due to major illness, lost time due to sick leave, and lost productivity while on the job reduce the produce of valuable goods and service.

* Direct medical costs

Indoor air quality related health problems may also result in financial costs for medical services, such as doctor or hospital care, surgery and medication. Millions of rands are annually lost due to major illnesses caused by indoor air pollution (U.S. EPA, 1991).

Immediate contact after either a single exposure or repeated exposures with pollutants, such as formaldehyde, cleaning agents, fibers or pesticides, may elicit acute effects, e.g. irritation of the eyes, nose and throat, headaches, dizziness and fatigue. On the other hand, everyday exposure to pollutants, such as environmental tobacco smoke, radon or asbestos, may elicit chronic effects, e.g. respiratory disease, heart disease and cancer. These chronic effects are usually not manifested until after several years of exposure. During the delay between exposure and effect, events are taking place in the body which eventually lead to observable disease(s) (U.S. EPA, 1991).

* Material and equipment damages
Finally, there are costs associated with indoor air pollution related damages to various equipment and materials.

3. PURPOSE OF THIS STUDY

3.1 Building Evaluation

Two sealed, mechanically ventilated buildings will be evaluated in this study. The buildings are used for office space only. The one, a three storey building, is newly build and the interior was completed three months prior to the study. The second, a seventeen storey building is 29 years old. Both buildings are dependant on cooling tower plants for ventilation.

The three storey building is situated at the eastern side of the Port Elizabeth Technikon, parallel to University Way. The third floor, housing the Bureau for Staff Development, was selected for this study. The three storey building, also referred to as the Technikon Building, consists of single and open plan offices, lecture rooms and boardrooms. The floor covering of the passage ways are tiled with a vinyl floor covering, but the offices, lecture rooms and boardroom are covered with carpet tiles. Lightweight ceiling panels are used throughout the building. The boardrooms and some lecture rooms are without any windows. The offices and other lecture rooms are, although mechanically ventilated, equipped with open-able windows. Offices are also equipped with vertical blinds. All walls were freshly painted with an acrylic paint. Most of the office furniture and desks in the lecture rooms are made from particle board with melamine veneer. The chairs
in the one boardroom are new high back fabric chairs. Each office is equipped with a computer printing to a central network laser printer in the media room. A photocopy machine, microwave oven and fridge are also housed in the media room. Directly to the western side of the building is a garden with scrubs and grass. Next to the garden is a circle road around the Technikon grounds for Technikon personnel. Next to that is a busy public road, University Way, carrying heavy, light vehicle traffic to and from the University of Port Elizabeth.

Brister House, a seventeen storey Municipal Building situated in the Central Business Area of Port Elizabeth was used as a second building for this study. It is flanked by a main street on the western side and a highway on the eastern side. The floor is divided into single offices and a boardroom. The entire floor is covered with carpet tiles. All ceilings were constructed with lightweight ceiling tiles. The walls were constructed with particle board. Most of the office furniture consist of particle board covered with veneer. Each office is equipped with a computer and most of the offices have laser printers. All windows are sealed. The entire floor was renovated two years ago by fitting new carpet and ceiling tiles, and redecorating with an interior PVA paint. All office furniture are old. A no smoking policy is enforced in the entire building. The building has a two level basement parking area. The fresh air inlet for the building is on the 17th floor and the outlet vent is on the third floor. The building is surrounded by busy city traffic and a busy highway on the eastern side, two storeys from ground level.

This study involves a literature study of the major indoor air pollutants regarding the source of the pollutant, the associated health effects, the measuring techniques
available and the results of previous studies conducted on the specific pollutant. The common symptoms of Sick Building Syndrome were specifically discussed.

The study further involves the measurement of specific pollutants in the two sealed buildings. A questionnaire is also completed by the occupants of the building to assess the conditions regarding indoor air problems. The responses from the questionnaire are evaluated against the results obtained from the measurement study.

From the results obtained from the investigation of indoor air pollutants in the two buildings a guideline or a step by step method in solving IAQ problems is proposed. This method is then applied and evaluated in a case study of a problem building.

The results of this study can be used as a guideline document by Environmental Health Officers (EHO’s) and building managers to perform investigations and to identify the reason for most of the occupant complaints.

4. INDOOR AIR POLLUTANTS

4.1 Respirable Particulate Matter (RPM)

Airborne particulate matter is ubiquitous and exists in a wide range of particle sizes and chemical compositions. Particulate matter is produced by many outdoor and indoor sources, such as, traffic, wind, construction work, walking, vacuuming, handling of paper, dusting, smoking and from the deposition of dust particles on
ceiling panels, curtains, vertical blinds, in carpets, etc.

Respirable Particular Matter is that fraction of ambient particulate matter capable of penetrating through the airways of the lower respiratory tract (tracheobronchial tree) of healthy adults and depositing in those portions of the lungs (alveoli) not protected by ciliary action.

4.1.1 Health Effects

The outdoor air quality standard for particulate matter is based on "inhalable particulate matter" with a size of approximately 10 µm (PM 10). This standard is intended to protect against exposure to particles capable of entering the trachea and lungs and contributing to health effects, such as, bronchitis and emphysema (DiNardi, 1997).

4.1.2 Sources

Coarse particles (generally > 10 µm in diameter) are produced by mechanical processes, such as, grinding and abrasion. Particles of this type are most commonly emitted from outdoor sources and consist largely of mineral components (silicon, calcium, iron and aluminum) and biological matter (pollen, insect parts and vegetation). Outdoor sources of coarse particles include mineral-based industries, mining operations, fugitive dust from roadways, and agricultural operations. These large particles can be found indoors, by means of tracked-in soil and as dust collected on
Inhalable particles (generally less than 10 µm) have both outdoor and indoor sources, and the smallest particles in this category (generally less than 3 µm), termed respirable particulate matter, are produced principally by vapour condensation and agglomeration of nuclei (Yocom and McCarthy, 1995). Outdoor sources of RPM include combustion processes, metallurgical operations producing metallic fume, and aerosols produced by photochemical smog. The single most important source of indoor RPM is tobacco smoking. The size of aerosol particles in environmental tobacco smoke (ETS) is on average 1 µm. Other indoor sources include unvented or improperly vented heating systems and cleaning operations, such as vacuuming. Indoor RPM consists of complex mixtures of organic compounds from cigarette smoke, sulfates, nitrates and ammonium salts produced both outdoors and indoors.

4.1.3 Measuring Techniques

Devices and methods for measuring RPM and other types of particulate matter are legion. Most are applicable in one form or another to indoor sampling and some are feasible personal samplers. One way to distinguish between these devices is to categorize them as samplers or monitors. Samplers collect a sample that must subsequently be analyzes (e.g., weighed) to produce a direct reading of particle concentration or a
surrogate for the concentration (e.g., light scattering).

Monitors are continually monitoring conditions and giving direct readings.

Examples of respirable particulate matter samplers are:

- Hi-Volume Samplers
- Filter Samplers
- Dust Gauges

Respirable particulate matter monitors are:

- Beta Gauge Samplers
- Central Electricity Research Laboratory (CERL)
- Triboelectric Probe
- Transmissometer
- Back Scatter monitor

4.1.4 Previous studies conducted

Studies by others concerning particulate matter have dealt primarily with the effect on indoor concentrations of RPM generated by indoor sources, such as smoking and wood stoves (Yocom and McCarthy, 1995). Most measurements reported were made with samplers using a cyclone with a cut size of 3.5 μm. Some measurements were made with dichotomous
sammers with a 2.5 µm cut size (Yocom and McCarthy, 1995).

The principal findings by the authors are as follows:

* Indoor concentrations of RPM tend to be higher than outdoor concentrations.
* There is some indication that indoor concentration of RPM are higher in the winter than in the summer.
* Smoking and operation of combustion devices indoors increase indoor RPM concentration.
* Some limited studies in which RPM samples were collected in several rooms of houses showed that there appeared to be good mixing of particles within the houses.
* No clear relationship was found between indoor RPM concentration and ventilation rates.
* One limited study showed that in homes with smokers the presence and use of an air conditioner tends to increase indoor RPM concentrations.

Environmental tobacco smoke (ETS) refers to side stream and mainstream tobacco smoke that nonsmokers are involuntarily exposed to due to their proximity to individuals smoking tobacco (Alevantis, 1989). The constituents of side stream and mainstream tobacco smoke include both gaseous and particulate materials. The contaminants produced by tobacco smoking are diverse and complex in nature.
Large scale epidemiological studies addressing the health effects of exposure to ETS have confirmed several health impacts on non-smokers. The most important of these is heightened lung cancer risk. Numerous studies have examined this relationship (Alevantis, 1989). Although there are some studies disputing the evidence of carcinogenic risk associated with ETS, most scientists studying this issue believe there is sufficient evidence that confirms the observed cancer risk associated with ETS (Koontz, 1989). A persuasive example of these studies was an examination of lung cancer mortality in non-smoking Japanese women whose husbands smoked (Washington D.C. National Research Council, 1981). This study examined a prospective cohort of more than 90,000 women. A statistically significant increase in lung cancer was observed in non-smoking women whose husbands smoked, with a demonstrated dose response relationship. The greater the number of cigarettes smoked by the husband, the greater the risk was for a non-smoking wife to develop lung cancer. In women, whose husbands smoked more than 1 pack of cigarettes a day, the lung cancer risk was twice than that observed for women with non-smoking husbands (Hirayama, 1981).

Acute respiratory illnesses (such as bronchitis and pneumonia) have also been observed to be more prevalent in non-smokers exposed to ETS. Several of the studies examining this phenomena have focused on infants whose mothers smoked. In these studies infants are directly exposed to ETS because of their frequent and close contact with their smoking
mothers. The relative risk of developing respiratory tract infections in infants exposed to ETS ranges from 1.4 to 2.7 (whereas unexposed infants have a relative risk of 1.0) (Higgins, 1985).

The most common complaints offered by nonsmokers exposed to ETS in building are offensive odours and eye irritation. The more debilitating chronic health effects cited above present, of course, much more serious concerns than do the irritation and comfort complains. These health concerns have helped to stimulate smoking restrictions inside buildings to prevent ETS exposures and the resultant adverse health effects.

The impact of ETS in the work environment will undoubtedly continue to increase. As a part of a long-term research effort, the EPA has determined that ETS increases the risk of lung cancer in healthy nonsmokers, and has classified ETS as a Group A human carcinogen ("Respiratory Health Effects of Passive Smoking : Lung Cancer and Other Disorders") (U.S. EPA, 1992). The Group A human carcinogen designation is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to an agent and cancer (U.S. EPA, 1986). According to the EPA’s recent report, a nonsmoker exposed to ETS during everyday activities faces an increased lifetime risk of lung cancer of roughly 1 in 500 to 1 in 1000 ((U.S. EPA, 1992). The report further indicates that exposure to environmental tobacco smoke can increase the risks of fluid in the middle ear, asthmatic attacks, respiratory tract irritation, and reduced lung function. Furthermore, children up to 18
months of age are at twice the risk of bronchitis and pneumonia if their parents smoke (U.S. EPA, 1992). Concerns over the health effects of ETS are reflected in the increasing numbers of workplaces prohibiting smoking.

The New York Times of 14 March 1992 reported that, according to the Office of Smoking and Health at the Central District Council, 59% of all workplaces with 50 or more employees banned or restricted smoking (compared to 27% in 1985) (Musleah, 1993, Section 13).

A study on a small number of nonsmoking Greek women indicated that the wives of heavy smokers have a higher risk of lung cancer than those of nonsmoking husbands. (Wadden and Scheff, 1983). An analysis of 177 000 nonsmoking American women did not reveal statistically significant differences in lung cancer rates between those married to smokers and nonsmokers (Wadden and Scheff, 1983). Cultural conditions may provide significant explanations for differences between these studies.

In one study a full cleaning regime for dust, which included high efficiency vacuuming of tiles, was observed to significantly reduce symptom prevalence rates when compared to a prior-cleaning period (Raw, 1993a). Based on the results of the above-mentioned studies, it was proposed that indoor surface pollution by particle dusts be considered a major risk factor for SBS symptoms (Raw, 1993b). Such dust could cause symptoms as a result of toxic effects, irritation or immunological mechanisms. The potential toxic or irritative effects may furthermore be increased as a result of the adsorption of gases and vapours.
A casual relationship between indoor surface dust and SBS symptoms is further supported by the fact that personal exposures of office workers to dust have been shown to be three to five times greater than dust levels measured from area sampling (Raw, 1991). Individuals create their own “dust cloud” as settled dust is stirred up during work activities.

Evidence of a potential relationship between surface dust and SBS symptoms is further suggested from USEPA headquarters building studies. Significant associations were reported for perceived dustiness and the following symptoms: headache, nasal, chest, eye and throat symptoms, fatigue, chills and fever, difficulty concentrating, dizziness, dry skin and for comfort concerns (Wallace, 1991).

4.2 Carbon Monoxide (CO)

Carbon Monoxide is an odourless, tasteless, colourless gas. CO is an unreactive gas and readily penetrates from outdoors without undergoing significant depletion by physical and chemical processes other than by dilution through air exchange. Once it is present in the indoor air, whether from outdoor or indoor sources, it can be removed only by exchange with fresh, CO-free air. Its stability often makes it useful as an indoor tracer for air exchange determinations.

4.2.1 Health Effects
Carbon Monoxide is an asphyxiant that converts hemoglobin to carboxyhemoglobin, thus decreasing the amount of oxygen transported to tissues and resulting in tissue hypoxia. Exposure results in fatigue, shortness of breath, headache, nausea and at high levels, death. Carboxyhemoglobin levels above 4 -5% can exacerbate symptoms of cardiovascular disease. Extreme altitudes may exacerbate the detrimental effects of CO on persons with this disease. Health effects of low-level CO exposure resulting in less than 3% bound hemoglobin are not well established, but probably include effects on the heart and brain. In general, when CO exposure levels do not exceed 25 ppm, the carboxyhemoglobin levels in the non-smoking population are in the range of 0.3 - 0.7 %, while for smokers this is 2 - 3% (DiNardi, 1997).

Carbon Monoxide can, among other health effects, cause, irreversible brain damage, coma and even death (at high concentrations). This gas can elicit symptoms that range from mild (headaches, nausea, breathlessness) to severe (visual disturbances, cyanosis, angina).

4.2.2 Sources

Carbon Monoxide exposure usually occurs in a combination of combustion products, many of which have distinctive odours. The most common sources for CO in non-industrial environments include automobile exhaust fumes from indoor garages, inappropriately placed air intakes, and smoking. Improperly vented gas or oil furnaces, fireplaces, wood stoves
and environmental tobacco smoke are some of the indoor sources of this gas.

4.2.3 Measurement Technique

The most commonly used method for measuring CO at fixed points, indoors and outdoors, is by means of a non-dispersive infrared (NDIR) analyzer. Infrared energy from a source is passed through a cell containing the gas to be analyzed into his case CO, and the quantitative absorption of energy by the CO in the sample cell is then measured by a suitable detector. The photometer is sensitized to CO by employing CO gas in either the detector or in a filter cell in the optical path, thereby limiting the measured absorption to one or more of the characteristic wavelengths at which CO strongly absorbs (Yocom and McCarthy, 1995).

The US EPA has recognized the gas filter correlation (GFC) method as equivalent to NDIR for measurement of CO. GFC is also a method based on infrared radiation, but in this case the radiation passes through a spinning filter wheel that contains CO and nitrogen reference cells. The infrared radiation then passes through a detector cell containing the air being sampled. The differences in signal between the nitrogen cell and the CO cell are proportional to the CO concentrations in the sample (Yocom and McCarthy, 1995). These devices could be hand-held, belt mounted or carried over the shoulder like a camera or purse.
Several passive CO detectors are also available. These monitoring devices make it possible to conduct human exposure studies for CO. The most successful operating principles for these devices are electrochemical or catalytic oxidation of CO.

The US EPA added a microprocessor date logger to an existing electrochemical CO monitor. This instrument is based on the oxidation of CO to CO$_2$ in a proprietary solid polymer electrolyte. The electric signal produced is proportional to the concentration of CO in the sample air. CO concentration is read directly from the liquid crystal display. A chemical filter removes interferences, such as NO$_2$ (Yocom and McCarthy, 1995).

4.2.4 Previous studies conducted

Many studies have been carried out to measure CO in several types of indoor environments using a variety of monitoring techniques. CO has been measured in homes, office and public buildings, and automobiles. Monitoring techniques have included fixed point monitors and small portable samplers, used at fixed points or as personal exposure monitors (PEM’s). The data based on CO studies is fairly extensive, and continues to grow.

* The greatest number of studies have focused on the most ubiquitous source of CO, i.e. motor vehicle exhaust. The studies inside vehicles most frequently used personal exposure monitors
based on electrochemical principles. Concentrations within the vehicles were dependent on both the density and speed of surrounding traffic and, to a lesser extent, on the type of vehicle being studied. Reported concentrations were generally in the 10 to 30 ppm range, with some peaks as high as 45 to 44 ppm (Yocom and McCarthy, 1995).

CO concentrations in buildings have been measured with both fixed monitors (e.g. NDIR) and PEMs. It has been found that both changes proximity to traffic and seasonal influence the indoor CO levels. Indoor concentrations are less than outdoor concentrations, with variations attributed to source and ventilation variables. Measured levels in commercial office buildings range from 1 to 10 ppm. Parking garages and other “indoor” vehicle areas can be two to three times higher (Yocom and McCarthy, 1995).

The third type of study focused on CO levels related to unvented indoor combustion appliances. Studies have been conducted in field settings, as well as in controlled laboratory test chambers. In homes, concentrations are highest in the room with the combustion appliance. Depending on the type of home and appliance, concentrations in the range of 6 to 10 ppm are common (Yocom and McCarthy, 1995).

Research on space heating appliances has shown that emission rate
is dependent on the various design (e.g., type of burner head in kerosene stoves) and operational procedures (e.g., wood burn rate in stoves) (Yocom and McCarthy, 1995).

The trend in indoor research on CO is to focus on monitoring exposures of sensitive subpopulations and relating these exposures to possible health effects (Yocom and McCarthy, 1995).

4.3 Carbon Dioxide (CO₂)

Carbon Dioxide is an odourless, colourless gas that is formed whenever carbon-containing substances are burned. CO₂ is also produced by human metabolism and exhaled through the lungs. The amount of CO₂ produced is a function of food composition and the activity level of an individual. CO₂ is a normal constituent of the earth’s atmosphere. In the center of large cities, where large amounts of fuel are burned for power generation, heating and vehicular propulsion, outdoor ambient CO₂ concentrations under stable atmospheric conditions can easily reach levels twice those found in remote locations. Although somewhat soluble in water, CO₂ is quite unreactive and readily penetrates the indoor environment from outdoors. Thus, in the absence of indoor sources, concentrations indoors follow outdoor concentrations.

Measurements of CO₂ indoors are commonly made in SBS studies or other building ventilation studies. Since CO₂ is not normally of concern as an important pollutant, but rather as an indicator of inadequate ventilation, extensive databases
on indoor CO₂ levels similar to databases on indoor pollutants, are not readily available.

4.3.1 Health Effects

Carbon Dioxide is an asphyxiant in that it replaces oxygen, and at high concentrations (30 000 ppm) it may cause headaches, loss of judgement, dizziness, drowsiness and rapid breathing. At levels above 800 ppm, quality complaints are beginning to increase (Yocom and McCarthy, 1995).

It should be remembered that in these cases it is not always the CO₂ causing the complaints, but other pollutants also accumulating in the environment, probably due to inadequate ventilation. The presence of high measured ventilation rates may be indicative of inadequate mixing in the occupied space.

4.3.2 Sources

In non-industrial occupational settings the primary sources are human respiration and tobacco smoke. The amount of CO₂ normally exhaled by an adult with an activity level representative of an office worker is about 200 ml/min (0.0073 cfm) (Woods, 1980).

4.3.3 Measurement Techniques

Extremely high CO₂ concentrations can be measured by the Orsal Method
commonly used in stack sampling, in which CO$_2$ is absorbed in KOH solution and estimated by volume reference. A analytical method is presented which is based on bag sampling and subsequent Gas Chromatography analysis using a thermal conductivity detector (Manual of Analytical Methods, National Institute of Occupational Safety and Health (NIOSH). The working range of this method is between 500-1500 ppm (Yocom and McCarthy, 1995).

Since CO$_2$ absorbs strongly in the infrared region, non-dispersive infrared (NDIR) spectrophotometry is an excellent method for its accurate measurement. Fixed recording NDIR instruments are useful for measuring CO$_2$ in buildings during daytime. Small portable instruments are especially useful in surveying CO$_2$ levels in buildings to provide an initial indication of ventilation rates and ventilation effectiveness.

4.3.4 Previous studies conducted

In a major study of the effects of reduced ventilation in a large office building, the indoor air quality in terms of several pollutants during two different ventilation conditions: i.e. 100% outside air and 15% outside air, was measured (Yocom and McCarthy, 1995). CO$_2$ measurements were made semi-continuously at four locations in the building using a single NDIR instrument which sampled the four areas sequentially for 10-minute intervals. Indoor CO$_2$ concentrations varied directly with occupancy and reached maximum values of approximately 800 ppm with 100% outside air
and approximately 1600 ppm with reduced ventilation. Some of the contaminants measured (“fine” particulate matter, hydrocarbons and formaldehyde) showed increased indoor concentrations with reduced ventilation of the same order as CO₂, but odours judged by building occupants and odour panelists were essentially the same under both conditions.

Studies were also carried out on comfort and acceptability of indoor air quality based on body odours in both a climatic chamber and a lecture hall by Fecker (Fecker, et.al., 1987). The parameters measured were CO₂ concentrations and temperature. It was found that the upper limit for CO₂ is 1500 ppm since at this concentration 15% of the occupants complained of unpleasant odour. However, 30 to 40% of people who entered the chamber or lecture hall found odours unacceptable at this CO₂ concentration. The authors concluded that CO₂ fails as an indicator of acceptable indoor air quality if there are sources of indoor pollutants and odours other than human occupants.

CO₂, formaldehyde and temperature were measured in a large number of homes by Konopinski (Konopinski, 1989). Detector tubes were used for CO₂. The indoor CO₂ samples yielded a mean concentration of 734 ppm and a maximum of 3000 ppm. In view of some of the high indoor values measured, a further study was made in a single residence using a continuously recording portable BDIR CO₂ monitor. Indoor CO₂ concentrations were monitored in several rooms of the house and in relation to several activity patterns. Peak CO₂ in the kitchen-family room
was of the order of 2500 ppm during occupied periods. Peaks of the same order were found in the bedroom during sleeping periods. The author inferred from these data that during the night and depending upon the sleeping position, human exposures to CO$_2$ could be much higher than depicted by sampling of general room air.

Exposure of healthy individuals for prolonged periods to 1.5% CO$_2$ apparently causes mild metabolic stress, while exposure to 7-10% will produce unconsciousness within a few minutes (Wadden and Scheff, 1983). Exposure of nuclear submarine crews to 0.7 to 1.0% CO$_2$ demonstrated a consistent increase in respiratory minute volume and cyclic changes in the acid-base balance in blood. The CO$_2$ uptake and release in bone may be related to biochemical changes. This effect may cause reduction in bone density due to release of calcium (Wadden and Scheff, 1983).

A number of investigators have attempted to evaluate ventilation conditions in buildings and SBS symptom prevalence rates or satisfaction/dissatisfaction with air quality. Because of the widespread use of CO$_2$ levels as a guideline for ventilation adequacy, attempts have been made to determine whether there is any significant relationship between CO$_2$ levels and symptom prevalence. Carbon dioxide levels could, in theory, serve as an indicator of building ventilation conditions.

No significant relationship between CO$_2$ levels and the prevalence of SBS
symptoms has been observed in the Danish Town Hall Study and in 6 sick schools and 11 office buildings in Sweden (Scov and Valbjorn, 1987) (Norback, 1990). In studies performed by Burge in the UK, symptom prevalence was observed to be higher in mechanically ventilated air-conditioned buildings than in naturally ventilated buildings, despite the fact that the latter had higher CO₂ levels (Burge, 1990). A study in three Canadian office buildings was unable to observe any correlation between building-related discomfort and CO₂ levels (Broder, 1990). In a study conducted in 15 office spaces and 5 assembly halls in 18 non-complaint buildings in the greater Copenhagen area no correlation between CO₂ levels and panel-assessed dissatisfaction were observed (Fanger, 1998). In a study of 10 school buildings a relationship was, however, observed between perceived air quality and indoor CO₂ levels, with perceived air quality decreasing with increased CO₂ levels (Thorstensen, 1990). Results of these studies indicate that there is little or no relationship between CO₂ levels and SBS symptoms or occupant satisfaction/dissatisfaction with air quality.

The absence of an apparent association between CO₂ levels and SBS symptoms/occupant dissatisfaction with air quality is not altogether surprising. CO₂ is a good indicator of bio-effluent levels, but at best, is only a relatively crude indicator of building ventilation conditions. Consequently, other ventilation assessment methods have been used to evaluate the effects of ventilation conditions on SBS symptom prevalence rates and/or occupant satisfaction/dissatisfaction with air quality. These
included measuring volumetric flow rates through outdoor air intakes and
determining actual air exchange rates by using tracer gases. The latter is
clearly superior because the former does not account for infiltration-related
air exchange.

In a study of multiple floors of a problem office building, it was observed
that symptom prevalence rates were paradoxically highest on the floor with
the highest outdoor volumetric flow rate (39 l/sec/person) and lowest on
the one with the lowest flow rate (8.5 l/sec/person) (Salisbury, 1984). There
appear to be a trend in the seven floors investigated toward
increasing symptom prevalence rates with increasing outdoor air flow.

On the other hand, in a study of an office building in Alaska, it was
observed that symptom prevalence decreased with increasing outdoor air
flow rates (Hodgson, 1990). In a 41 office building study both high and
low symptom prevalence rates were observed to be independent of
outdoor ventilation rates (Burge, 1987).

4.4 Formaldehyde (HCHO)

Formaldehyde is colourless, and in a high enough concentration, can give off a
sharp, pungent odour. Indoor measurements of HCHO exceed outdoor levels in
all studies conducted (Yocom and McCarthy, 1995). Formaldehyde emissions,
and thus indoor concentrations, show significant temporal fluctuations. Studies
have shown that emissions are not only dependent on the age of the product, but
also on temperature and on relative humidity. The highest concentrations are associated with higher temperatures. (Wanner and Kuhn, 1984, p 31)

4.4.1 Health Effects

Formaldehyde exposure has been associated with mucous membrane irritation, allergies and possible cancer. Exposure to this gas, even at concentrations below 1 ppm can elicit symptoms such as eye, nose and throat irritation, upper respiratory tract irritation, fatigue, headache, dizziness, nausea, sneezing, metallic taste, sleeping disturbances and skin rash (Hansen, 1991).

4.4.2 Sources

Formaldehyde is a common component in synthetic resins. Indoors it is emitted from a variety of sources, including particle-board, glues and resins in furniture, carpets and paneling, urea-formaldehyde foam insulation, various treated fabrics and environmental tobacco smoke.

4.4.3 Measurement Techniques

There are three commonly employed measurement techniques used for HCHO, i.e., impinger sample collection with colourmetric analysis, automated wet chemistry and passive dosimeters (Yocom and McCarthy,
The impinger method may use two different trapping solutions, viz./i.e. distilled water or 1% sodium bisulfite. Both solutions should be cooled to approximately 5 °C for sample collection and storage. The analytical methods are different for each collection media (Berge and Mellegaard, 1979).

An automated wet chemical device is also available which uses sodium tetrachloromercurate with sodium sulfate as the trapping solution, and pararosaniline is added to produce a calorimetric reaction. It has a lower detection limit of 0.002 ppm and an adjustable range up to 10 ppm (Yocom and McCarthy, 1995).

There are three commercially available passive dosimeters for formaldehyde. The principle of operation is molecular diffusion and sorption and rely on spectrophotometric quantification of formaldehyde. The badges are used for integrated samples ranging from 15 min to 1 week. These badges are sensitive to concentrations ranging from 10 µg/m³ (8 ppb) to 10 mg/m³ (8 ppm). The trapping solution and the resulting blue cationic dye is measured colorimetrically (Yocom and McCarthy, 1995).

In addition to the passive badges, there are two active sampling techniques which use solid sorbents coated with 2,4-dinitrophenylhydrazine. This technique can be used as a personal monitor or as a fixed sampler. Both methods utilize high performance liquid chromatography for analysis, thus
laboratory costs are high.

K & M Environmental® has developed a Chromair® badge for measuring formaldehyde. The device is constructed from six cells attached on one side to a flat indicator layer and on the other side to a series of different diffusive resistance and reacts with the indicator layer, producing colour change from yellowish-brown to brown. The colour produced on the indicator layer is a direct measure of the exposure dose. Visual colour is achieved by observing the formation of the brown threshold colour on the individual cell and reading the corresponding exposure dose. The badge changes colour from yellowish-brown to brown in the presence of formaldehyde. The exposure range is between 0.3 - 12 ppm per hour and the minimum and maximum sampling time varies between 15 minutes and two days at a relative humidity range between 30 - 80% and temperature between 16° - 35°C with no effect in the presence of light or UV sunlight. The badge must be used with the Chromair formaldehyde colour comparator (K & M Environmental®, 1997).

The benefits of these badges are that it is an accurate measurement device designed to react selectively with formaldehyde with minimum interference from other substances. These badges may be used for personnel screening and for area monitoring or area mapping. It is a direct read device that gives immediate, on-site results, at a relatively low cost.

4.4.4 Previous studies conducted
Particle board and urea-formaldehyde foam insulation have been identified as formaldehyde emission sources (Wadden and Scheff, 1983). Formaldehyde concentrations of 60-1673 ppb (O°C, 1 atm), with an average of 463 ppb, were measured in 25 rooms in 23 Danish dwellings where chip board was used in walls, floors and ceiling (Wadden and Scheff, 1983). An empirical mathematical model was developed by them for room air concentration:

\[
C = \frac{(RT - N)(aH + b)}{1 + nf/\alpha} 
\]

(4.1)

where \(C\) is air concentration in mg HCHO/m\(^3\);

\(H\) is humidity

\(T\) is temperature °C

\(n\) is air change rate per hour

\(g\) is H\(_2\)O/kg dry air

\(\alpha\) is area of board surface per volume of room, m\(^{-1}\)

Constants for program are as follows:

\[R = 0.064\]

\[a = 0.143\]

\[b = 0.048\]

\[f = 0.0304\]
\[ N = 0.764 \]

The equation was found to be applicable for the following ranges: 17-32 \(^0\)C, 5-13 g H\(_2\)O/kg air, and 0.4-3 air changes/hr. Since the concentration data supporting the above Equation (4.1.) were all taken after equilibrium had been reached between emissions and removal by ventilatory flow, formaldehyde released from particle board can alternatively be represented by an emission factor \( S' \), where

\[
S' = \frac{nC_{iss}}{\alpha} = \frac{(kn/\alpha)(RT - N)(aH + b)}{1 + n/\alpha} \tag{4.2}
\]

where \( C_{iss} \) is the steady-state indoor concentration;

\( k \) is a term to describe the efficiency of mixing.

For the factors defined as above, \( S' \) will have the units of mg HCHO/hr. m\(^2\) of board surface.

Using average parameter values of \( n/\alpha = 0.67 \) m/hr; \( T = 22.8^0\)C and \( H = 7.1 \) g/kg (Wadden and Scheff, 1983) and assuming perfect mixing \( (k = 1) \) results in a value of \( S' = 0.41 \) mg/m\(^2\).hr. This value is somewhat larger than those derived form the studies of Berge and Melgaard (1979) in a closed system where \( S' \) approximately 0.035 mg/m\(^2\).hr at 22-25\(^0\)C at an undetermined relative humidity. In addition, more realistic values of \( k \), ranging between 0.1 and 0.3, would bring the two values closer together.
Also of interest, is the observation that formaldehyde emissions from particle board aged for 13 months were still about 70% of originally measured values (Wadden and Scheff, 1983).

A survey of 334 mobile homes (608 samples) in the state of Washington revealed formaldehyde concentrations from 40 μg/m³ (30 ppb) to 2370 μg/m³ (1770 ppb). 66% of the results were between 130 and 660 μg/m³ (100-490 ppb) and 21% were higher than 670 μg/m³ (500 ppb). A total of 523 persons experienced one or more symptoms which could reasonably be related to formaldehyde exposure. Particle board and plywood were identified as the major formaldehyde sources (Wadden and Scheff, 1983).

There is some evidence, based on laboratory and home measurements, that emissions from particle board decrease exponentially with time. The relationship between indoor formaldehyde concentration and time since installation, \( t \), can be expressed as

\[ C = G_1 e^{G_2 t} \quad (4.3.) \]

where \( G_1 \) and \( G_2 \) are empirical constants. The equation does not take into account amount of particle board, temperature, humidity or ventilation. The half-life based on the previous equation has been variously reported as 2 years (Scandinavian home construction particle board), 5.8 months (Danish homes), 69 month (randomly selected Wisconsin mobile homes) and 28 months (complained about Wisconsin mobile homes). When these
data are combined, the half-life is 53 months, although the variation from this value for individual homes may be considerable (Wadden and Scheff, 1983). An analysis of ½-hr samples taken from mobile homes in Minnesota demonstrated the same general trend (Wadden and Scheff, 1983). Whether reduction in formaldehyde concentration with time was due to reduced off-gassing or because of a change in the binding agent formulation over time could not be determined.

In spite of the large database, most studies tend to be directed at specific problems such as mobile homes or homes with urea-formaldehyde foam insulation (UFFI) and therefore do not provide the basis for an accurate assessment of total population exposure to indoor formaldehyde. The principal findings from these studies are summarized as follows:

* Indoor concentrations of formaldehyde vary widely, from below the detection limit to a high of several ppm, depending on the type and age of structure, indoor sources, sampling method and its sensitivity, ventilation rate and sampling duration.

* Concentrations of formaldehyde in mobile homes, with their extensive use of panelling containing urea-formaldehyde resins and adhesives, are higher than concentrations found in other types of housing.

* In homes (including mobile homes), where formaldehyde measurements were carried out over time, concentrations decreased with time.
* Smoking and use of indoor combustion appliances appear to have little influence on indoor formaldehyde concentrations.

* Although one would expect indoor formaldehyde concentrations to increase with indoor temperature, currently available studies indicate that over the range of normal indoor temperature fluctuations, there is little, if any, influence of indoor temperatures on indoor formaldehyde concentrations.

* The few studies in mechanically ventilated buildings indicate that formaldehyde concentrations in such settings are quite low.

* Most of the studies use the impinger sampling method and absorption by chromotropic acid solution. Several studies used passive samplers and one study reported using colorimetric detector tubes (Yocom and McCarthy, 1995).

4.5 Volatile Organic Compounds (VOC’s)

Volatile organic compounds represent a large class of compounds with numerous sources both indoors and outdoors. Exposure to VOC’s occurs in many micro-environments associated with human activity (Yocom and McCarthy, 1995). These carbon-based substances possess sufficient vapour pressure so that they may exist as vapours at typical indoor temperatures.

Most of the major classes of organic substances have been detected in buildings (Hansen, 1991). These include:
* Aliphatics - methane, ethane, propane, butane, etc.

* Olefins - propene, isobutene, isopentene, etc.

* Aromatics - toluene, xylenes, benzene ethyl benzene, 4-phenyclohexene, etc.

* Halogenated hydrocarbons - trichloroethylene, perchloroethylene, 1,1,1-trichloroethane, etc.

* Miscellaneous - acetone, methanol, isopropanol, methyl ethyl ketone, methyl isobutyl ketone, etc.

### 4.5.1 Health Effects

While some of the VOC's have been suggested as possible carcinogens the actual health implications of most compounds found in indoor air are not presently well defined. Evidence is increasing that accumulation of mixtures of VOC's may play a major role in SBS. Exposure of volunteers in a chamber to mixtures of VOC's has replicated symptoms of SBS (DiNardi, 1997). Most VOC's are lipid soluble, readily cross the blood-brain barrier, and are easily absorbed through the lungs. Most are neurotoxic and, in levels in access of occupational acceptable limits, may cause central nervous system depression, vertigo, visual disorders and, occasionally, tremor, fatigue, anorexia and weakness. Potential genotoxic effects are still under investigation. Effects of low level exposure to VOC mixtures over long periods of time are unknown.

### 4.5.2 Sources
Indoor sources include household products, building materials, gas, dry cleaners and occupant activities, such as hobbies or tobacco smoke.

4.5.3 Measurement Techniques

VOC levels in buildings are usually reported either as total VOC’s, derived from summing all the individual peaks on a chromatogram, or as the sum of all the identified peaks (DiNardi, 1997). Instrumentation and methods for monitoring VOC's must meet several criteria. These include high sensitivity, easy portability in the field and ability to provide accurate and reproducible results. There are a variety of methods which meet these criteria, but the ones involving sample collection in the field with subsequent analysis in the laboratory are the most appropriate. Alternative approaches include portable gas chromatographs with various types of detectors, including mass spectrophotometer. These sophisticated instruments are very expensive and require highly skilled field personnel to operate (Yocom and McCarthy, 1995).

Two different collection techniques are used i.e., solid sorbents and treated stainless steel canisters. Two different types of solid sorbents are commonly used, i.e., polymeric resin or activated carbon. There are three basic steps involved in the use of solid sorbents; adsorption of the vapour phase compounds, desorption of the sorbed material and analysis of the desorbed material. The stainless steel canisters only require two steps; collection of air in the vessel and direct analysis of the sample (Yocom and
McCarthy, 1995). Active and passive sampling methods exist for two of the solid sorbents.

4.5.3.1 Active Sampling Techniques

All of the solid sorbent techniques are limited by breakthrough volume. Functionally, this is the saturation capacity of the sorbent allowing elution to occur during sampling. It is defined as the volume of air sampled at which more than 50% of the compound entering the sample cartridge is stripped off and is lost in the exit stream. Breakthrough volumes are chemical and sorbent specific, and usually are determined experimentally. Once the critical chemical is identified, sample volumes and size of sorbent trap can be modified to provide optimum sensitivity. Most sampling cartridges contain a front and backup section of sorbent. The two sections are separated by a plug which can be either glass, wool or urethane foam. By analyzing these sections separately, it can be determined analytically if breakthrough occurred (Yocom and McCarthy, 1995).

4.5.3.2 Polymeric resin

With this method air is drawn through a sampling tube packed with Tenax GC™. The tube may be either glass or
stainless steel. The sampling flow rates are determined by the compounds of interest and the desired sampling time; and can vary from 0.01 l/min to 1 l/min. Volatile compounds are thermally desorbed with helium and condensed in a liquid nitrogen cold trap. The sample is then introduced into a gas chromatograph/mass spectrometer for compound identification and quantification.

A second technique is to use Soxhlet extraction and vacuum drying at 100°C. To provide optimum sample integrity, storage and packing of sampling cartridges should be done under clean room conditions, and all samples should be stored in cleaned, sealed containers.

Detection limits for this method are dependent on several factors, including the compound, sample volume, background contamination and instrument detection limits (Sheldon, et al., 1984).

### 4.5.3.3 Activated carbon

The activated carbon technique has been traditionally used to monitor the industrial environment. Activated carbon is non-polar. The process by which volatile compounds are
collected on the carbon is referred to as chemisorption. This process efficiently collects low molecular weight compounds and other compounds with boiling points less than 300°C. The sample cartridge for the activated charcoal is a glass tube, approximately 6 mm by 70 mm. These tubes hold approximately 150 mg activated carbon. Larger tubes are also commercially available. A small personal sampling pump is used to draw air through the cartridge. The analysis method involves solvent desorption and subsequent analysis by gas chromatography with either an electron capture or flame ionization detector, depending on the compound of interest (Yocom and McCarthy, 1995).

**4.5.3.4 Stainless steel canisters**

This method collects whole air samples in passivated stainless steel canisters. The interior of the canister is specially treated by the SUMMA™ passivation process, which leaves a surface of pure chrome-nickel oxide. Samples may be collected under pressurized and sub-atmospheric pressures. Analysis is performed by GC/MS. Many compounds can be analyzed by this method at concentrations of ppb by volume. The sampling procedure involves drawing air into an
evacuated SUMMA\textsuperscript{TM} canister through a sampling train, which includes a particle filter, mass flow controller, electronic timer and Magnelatch valve. Both the sub-atmospheric pressure and pressurized techniques use an evacuated canister. The difference is in the sampling train, where the latter technique includes an additional pump to provide positive pressure.

After the sample is collected, it is taken to the laboratory for analysis. The canister is attached directly to the GC/MS system. Water vapour is removed with a special dryer. The VOC’s are cooled in a cryogenic trap and volatilized prior to injection into the GC-MS.

The advantage of this method is its sensitivity to a wide array of VOC’s. The sampling package can be programmed to collect discrete air volumes over an extended time period (e.g. 24 hours) to provide a long term integrated sample. The disadvantage is that the sampling apparatus is large and sophisticated, relative to the solid sorbent techniques. Special care must be taken in the handling and cleaning of the sampling apparatus to avoid contamination of the canister (Yocom and McCarthy, 1995).
4.5.3.5 Passive sampling techniques

Passive samplers for VOC’s use solid sorbents and operate on the principle of molecular diffusion. Both activated charcoal and Tenax GC™ have been used in passive sampler badges. In general, exposure times are fairly long, e.g., 30 days.

The activated charcoal badge has been used more frequently than the recently developed Tenax GC™ badge. The passive badge technique has been used in monitoring organic compounds in office environments. The Tenax GC™ has a lower sensitivity and using thermal desorption tubes with ease (Yocom and McCarthy, 1995).

4.5.3.6 Portable Gas Chromatographs

Portable gas chromatographs provide real-time data collection in the field. They can serve as screening device to guide the collection of further samples by other techniques, or when equipped with accessories, such as sample loops and data loggers, effectively collect continuous data. The prime disadvantage of this method is generally high detection limits, because there is no preconcentration of the sample as occurs when solid
sorbents are used. Given the advantage of real-time monitoring, portable GC's may be modified to be of use in indoor, non-industrial environments (Yocom and McCarthy, 1995).

4.5.4 Previous Studies Conducted

The largest study designed to estimate total exposure to VOC’s is EPA’s Total Exposure Assessment Methodology (TEAM) study (Wallace, 1987). The method of sampling was with personal samplers using Tenax GC™, followed by GC/MS analysis. The initial phase was designed to examine sampling and analytical procedures for four classes of toxic chemicals. These were VOC’s, such as benzene and trichloroethylene; organochlorine pesticides and PCB; metals, such as lead, arsenic and cadmium and polycyclic aromatic hydrocarbons, such as benzo(a)pyrene. Several pilot studies were conducted during this first phase using air samplers worn by test subjects to measure exposures over discrete time intervals in occupational and residential settings. Biological samples, such as blood, breath, urine and hair, were also collected and analyzed to determine if exposure measurements could be correlated with biological measurements. The primary goals were two-fold: firstly, to develop methods to measure individual total exposure to VOC in air, water and food and to calculate the associated body burdens, and secondly, to use these analytical methods on various representative subjects drawn from several different cities (Yocom and McCarthy, 1995).
The second phase of the TEAM study entailed a comprehensive exposure study of 22 selected VOC’s from air and water samples in two towns in New Jersey. Air samples were collected by passing air through a solid sorbent trap with analysis by gas chromatography/mass spectroscopy. The air samples were collected in the subject’s breathing zone for twelve hour time periods sequentially over a 72-hour study period. Outdoor air samples were also collected.

The next phase of the TEAM study examined personal and outdoor concentrations of VOC’s at several locations throughout the U.S. One of the objectives of this study was to compare heavily populated and industrialized areas with rural non-industrial areas.

The principal findings from the studies are as follows:

* A common finding across all the studies in the U.S. is that indoor VOC concentrations are higher and consist of more complex mixtures of compounds than are found outdoors.

* VOC’s commonly found indoors in concentrations higher than those outdoors are aliphatic, aromatic and chlorinate hydrocarbons. Indoor concentrations, although higher than those outdoors, seldom exceed a fraction of a ppm. For example, a typical value for toluene would be in the range of 20 to 100 µg/m³ (5.2 to 26 ppb).
* Concentrations of VOC’s inside newer houses are higher than those inside older homes.

* Occupancy levels, indoor activities and indoor furnishings tend to produce elevated indoor VOC concentrations. Smoking tends to be associated with increased indoor concentrations of aliphatic and aromatic VOC’s. (Yocom and McCarthy, 1995).

* Indoor sources are the caused of elevated indoor levels and appear to be due to off-gassing from building materials, consumer products and hobbies, e.g. particle board, fabric paintings and glue from model building.

* Indoor exposures outweighed the impact of traditional major point and area sources on personal exposure.

Emission were determined from 42 commonly used building materials, including two types of felt carpet and two other types of textile floor covering (Molhave, 1982). A total of respectively, 24 and 28, different VOC’s were identified for the two felt carpet emissions and respectively, 28 and 61 VOC’s from the two textile floor covering. Emissions of VOC’s varied in the range of 1.95 - 3.15 mg/m³ for three of the samples and was relatively high for the fourth (39.6 mg/m³). Specific compounds were not reported.

In another study extensive environmental chamber testing of carpeting and other textile products were conducted to identify and quantify VOC’s emitted (Bayer and Papanicolooulos, 1990).
Those most frequently detected compounds are as follows:

Benzene  Ethylmethylbenzenes
4 - Phenylcyclohexene  Trimethylbenzenes
Ethanol  Chlorobenzene
Carbon disulfide  Chloroform
Acetone  Benzaldehyde
Ethyl acetate  Styrene
Ethylbenzene  Undecanes
Methylene chloride  Xylenes
Tetrachloroethene  Trichloroethene
Toluene  Phenol
1,1,1 - Trichloroethane  Dimethylheptanes
1,2 Dichloroethane  Butyl benzyl phthalate
Hexanes  1,4 - Dioxane
Octanal  Pentanal
Acetaldehyde  Methylcyclopentane
Methylcyclopentanol  Hexene

Other detected compounds included heterocyclic compounds, such as furans and pyridines, sulfur-containing compounds, such as dimethyldisulfide, and nitrogen-containing compounds, such as ethanamines. Concentrations ranged from 10 ppt to 50 ppm, depending on the individual carpet tested. Measurements were made under dynamic laboratory chamber conditions of 75°F (24°C), 50% RH and an air
exchange rate of 0.5 air changes.

VOC emissions decrease rapidly after installation of carpeting (Singhvi, 1990) (Molhave, 1982). As a consequence, health complaints associated with carpet TVOC exposures are not expected to persist for more than a week (Kerr, 1991). In building studies in Sweden, carpeting had been in place for eight to ten years (Norback and Torgen, 1989). In these and other studies on the associations between carpeting and symptoms, it’s unlikely that emissions of VOC’s initially reported for carpeting are the major contributing cause. In the Danish Town Hall Study the significance of the relationship between the prevalence of SBS and fleecy surfaces (such as carpets) was suggested to be due to fleecy surfaces serving as a reservoir for the adsorption and release of VOC’s (Nielson, 1987). Fleecy surfaces such as carpeting have a large specific surface area (total surface weight or volume) and, as such, have a large capacity for adsorbing different volatile substances.

Carpet-sink studies have been conducted by several investigators who reported that a carpet was a much stronger sink for tetrachloroethylene than
other materials tested (e.g., wallboard, ceiling tile and pillow) (Tichenor, 1990).

Borazzo observed that VOC’s adsorption on carpet fibers depended on volatility of the VOC; the less volatile the species, the more strongly it was adsorbed (Borazzo,
A number of human studies were conducted to determine potential effects of exposures to VOC mixtures. These studies demonstrated that a mixture of VOC’s in the concentration range reported for new or renovated buildings can cause changes in perceived air quality, mucous membrane irritation and neuro-behaviour. These results have been for the most part confirmed in other exposures studies conducted by the Danish researcher and in exposures studies conducted by USEPA (Molhave, 1990)(Otto, 1990). In the USEPA study subjects were exposed to 25 mg/m³ VOC’s for 2.75 hours. The people found the odour of VOC’s unpleasantly strong and reported increased headache and general discomfort, as well as decreased perception of air quality. The USEPA group was, however, not able to show any effects of TVOC exposures on performance as measured by neuro-behavioural tests (Otto, 1990)(Otto, 1992).

4.6 Relative Humidity (RH)

Low relative humidity has been blamed for some of the symptoms of SBS, for an increased susceptibility to infectious disease and for exacerbation of asthma. Eye irritation, throat irritation and cough are often also blamed on low RH. It is, however, becoming clear that most people are comfortable at RH levels that routinely occur, even in cold winter climates, if adequate ventilation is provided to control odours and other air pollutants.
Some evidence indicates that host susceptibility to airborne infectious agents is not affected by RH as was once thought (Jennings and Faoagali, 1980). Usually the increased incidence of colds and influenza in winter has been used as evidence for the role of RH in susceptibility to infections. The dry air is considered either to damage mucous membranes or to damage the infectious agents themselves. Damage to mucous membranes at other than extremely low RH (5%) has not been documented. RH is one of the environmental factors controlling the viability of both airborne and surface microorganisms, but the relation is extremely complex. Some viruses survive well at low and high RH, but not at intermediate levels. Bacteria often have a narrow range of RH in which they survive as an aerosol. “Legionella”, for example, was shown in one study to survive best at 65% RH and least at 55% RH (Hambleton, et al., 1983) (Katz and Hammel, 1987). Growth of microorganisms on surfaces and the survival of the house dust mite, a source of potent asthma-inducing allergens, are facilitated by high RH (60%) (Arlian, 1977). Even at lower RH, cool surfaces may lead to condensation or locally much higher RH that can support fungal and/or dust mite amplification.

It should be noted that monitoring RH is also important to control microbial growth in ducts, carpets and other building materials. It is recommended that RH be maintained in the range of 40 - 60% to contain microbial growth (Hansen, 1991).

4.6.1 Previous Studies Conducted
Humidity may have a variety of relationships relative to health, comfort and perceived satisfaction/dissatisfaction with air quality. As previously indicated, humidity significantly affects thermal comfort (Godish, 1995). Low humidity has also been reported to have direct effects on mucous membranes and human skin. Humidity may also affect human perception of air quality and levels of some contaminants (Godish, 1995).

Association between humidity and SBS symptoms have been observed in several epidemiological studies. A significant association between SBS symptoms and dissatisfaction with building humidity was reported (Hawkins and Wang, 1991). In the Canadian winter-time study low relative humidity was observed to be the most important risk factor for air quality complaints (Tamblyn, 1993). Experimental studies in Finland reported lower prevalence rates of dry skin, nose and throat and obstruction of the nose in humidified (30 - 40%) as compared to non-humidified (20 - 30%) rooms (Reinikainen, 1991). Humidification appeared to have a positive effect in reducing SBS-type complaints. In further studies humidities in the range of 30 - 40% were observed to be associated with significantly lower prevalence rates of skin and eye symptoms, but not symptoms of the nose and throat, than humidities in the range of 20 - 30% (Reinikainen, 1992). Allergy-type symptoms were less prevalent under humidified conditions. Increased airway irritation has also been reported to be associated with elevated humidity levels in a sick library building (Lundin, 1993).
It was, furthermore, reported that the sensation of “stuffiness” was more commonly reported in humidified rooms (Reinikainen, 1992). In another study of the building by the same researcher it was observed that both the perception of “stuffiness” and unpleasant building odour increased when room air was humidified (Reinikainen, 1993). From this perspective, humidified air (30 - 40% RH) was less acceptable than non-humidified air (20 - 30% RH). Increased “stuffiness” associated with increasing humidity has also been reported by other researchers (Berlund and Cain, 1989).

4.7 Temperature

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) defines thermal comfort as "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE, 1992, Standard 55-1992). The perception of thermal comfort is related to metabolic heat production, its transfer to the environment and resulting body temperature. Personal activity, clothing and the environmental factors of air temperature, air movement and RH all interactively influence body temperature and, therefore, thermal comfort. For sedentary workers, air temperature, air movement and clothing are the most important factors, while RH has little effect on thermal comfort. In fact, it has been shown that sedentary people are unable to perceive changes in RH over a relatively wide range (Wadden and Scheff, 1983, p 135-138). Lowering RH in the presence of active workers has a cooling effect. In environments where both active and sedentary workers coexist, a slightly warm air temperature at low RH might provide comfort for most, although it is rarely possible to satisfy everyone.
Increasing air movement decreases body temperature and causes the temperature to feel lower. However, minimal air movement can lead to complaints of stuffiness and poor air quality.

4.7.1 Previous Studies Conducted

A number of epidemiological studies have attempted to evaluate potential associations between workspace temperatures and SBS symptom prevalence rates. A significant initial association between temperatures and prevalence of general and mucous membrane symptoms was observed in the Danish Town Hall Study (Skov and Valbjorn, 1987). When multivariate statistical models were applied to the data, temperature was observed to vary in a co-linear fashion with other factors, which investigators concluded, were more directly related to SBS complaints (Skov, 1990). However, in a follow-up study of a portion of the buildings studied, a strong relationship between office temperatures and prevalence of general symptoms were observed (Skov, 1990). The relative risk of general symptoms increased by a factor of three for every 3°C rise in temperature.

In an epidemiological study of a modern eight-storey office building in Helsinki, Finland, it was observed that air temperature appeared to be the most important indoor parameter affecting SBS symptoms and the sensation of “dryness” (Jaakkola, 1989) (Jaakkola, 1991). A linear relationship was observed between SBS symptom prevalence and
temperatures above 22ºC. An excess of SBS symptoms was also observed when occupants considered the temperature to be too warm or too cold. It was suggested that SBS symptoms may reflect general satisfaction with building temperatures (Jaakkola, 1989) (Jaakkola, 1991). A significant linear relationship over the temperature range of 21 - 25ºC was observed for SBS symptoms, allergic symptoms and dryness symptoms in a follow-up longitudinal study conducted on the same building (Reinikainen and Jaakkola, 1993). Positive associations were also observed between temperature and the sensation of dryness and warmth.

Another study was conducted of 10 Canadian office buildings to determine whether environmental conditions were different in offices of those individuals who complained of poor air quality and those that did not (Tamblyn, 1993). A variation in the relationship between perceptions of air quality and environmental parameters was observed. Mean workspace temperatures were less than the deviations from optimal temperature conditions relative to the perceptions of poor air quality.

In a study of 15 office buildings in the U.K. a significant association between SBS symptoms and dissatisfaction with workspace temperatures and other thermal comfort parameters was observed (Hawkins and Wang, 1991). In the Dutch Office Building Study, the absence of personal control of temperature in the workspace was related to nearly all health and indoor climate complaints (Zweers, 1992). However, in Swedish school study of Norback there was no association between SBS symptoms and
temperature (Norback, 1990a).

4.8 Biological Contaminants (Pollen, Spores and Moulds)

Bioaerosols are defined as airborne particles, large molecules, or volatile compounds that are living or were released from a living organism. Bioaerosols represent a heterogeneous category of indoor pollutants, comprised of bacteria, endotoxins, fungi, protozoa and antigens. Bioaerosols also vary in size, ranging from less than 0.1 µm to 100 µm. It must be understood that three conditions are necessary for bioaerosols to become airborne. Firstly, the presence of a reservoir, such as living hosts is required. Secondly, the organism must be able to amplify; increase in number or concentration. This requires that the conditions of the reservoir be conducive to growth. Thirdly, a mechanism for dissemination or aerosolization, e.g., an Heat Ventilation and Air Conditioning system (HVAC), which includes a humidification component, is required (Yocom and McCarthy, 1995).

Observations of the number of bacteria-carrying particles in air may be required in premises where safe working depends on the bacteria content of air being kept at a very low level, e.g., surgical theaters and premises where certain foods or pharmaceutical materials are prepared. In hospital wards, in which there is an outbreak of cross-infection, it may be required to examine the air for its content of a particular pathogen. The number of bacteria in the air at any time is dependent on a variety of factors, the most important of which are the number of persons present, the amount of their body movements and the amount of disturbance of
their clothing. When a drought-free room is vacated and left undisturbed, the bacterial content of the air falls to a low level in the course of about 30 min (Mackie and McCartney, 1996).

### 4.8.1 Health Effects

The presence of microorganisms indoors has been associated with infectious disease and allergic reactions. The presence of moisture from water damage, standing water or elevated humidity is commonly associated with the proliferation of these organisms indoors (National Academy of Sciences, 1981).

Viruses are simple organisms composed primarily of a strand of either DNA (deoxyribonucleic acid) or RNA (ribonucleic acid) surrounded by a protein coat. Viruses have no internal mechanism for reproduction. Instead, the virus inserts viral genetic material into the host cell, which sends a message to the cell to make new viral particles. Thus, viruses are always obligate intracellular parasites; they can never grow freely in the environment, although they can survive brief periods in environmental reservoirs, including in air (Knight, 1973).

Bacteria are relatively simple cellular organisms that lack an organized nucleus and hence are called prokaryotic. The bacterial cell is surrounded by a cell wall, the nature of which allows classification of bacteria into broad groupings: gram-negative bacteria (those readily decolorized during
the Gram staining procedure) with a lipopolysaccharide wall; gram-positive bacteria with a peptidoglycan cell wall; and the acid-fast bacteria with a wall rich in mycolic acids. Some bacteria form pseudo-filaments and are called “actinomycetes”.

Within this group there are thermophilic organisms (heat-loving) that grow at high temperatures (56°C) and produce very resistant dry spores. Most bacteria are free-living, although a few pathogenic forms have not been recovered from the environment and may have lost the ability to reproduce outside of a living host. Bacteria are generally small (<1 µm), and can become airborne as intact cells, as smaller fragments, or within water droplets.

Legionnaires’ disease, caused by the bacteria *Legionella pneumophila*, was first identified after an extensive investigation of illness and deaths among attendees of an American Legion convention in a hotel in Philadelphia, Pennsylvania, in 1976 (Imperato, 1981). The disease syndrome is characterized by high fever, headache and malaise and may also include cough and gastrointestinal problems. If untreated, it may progress to lung consolidation, respiratory failure and death. Approximately 15% of 21 infected individuals at the Philadelphia American Legion convention died of the disease. Though the mortality rate was high, the attack rate was relatively low. The incubation period was 2 to 10 days. A variety of factors appeared to predispose individuals to the disease. These included middle age, cigarette smoking, excessive alcohol use, existing respiratory
disease, malignancy and immunosuppressive drugs (Ager and Tickner, 1983).

Since its initial identification as the cause of the epidemic outbreak of acute febrile illness in Philadelphia, cases of Legionnaires’ disease have been widely reported. It has been found to be a relatively common cause of human pneumonia (Muraca, 1988). A number of cases have been reportedly occurred in hotels and hospitals and sporadic cases have been observed in the general population (Rosmini, 1984) (Fisher-Hoch, 1981). Studies of sporadic community-acquired Legionnaires’ disease implicate tobacco smoking, alcohol consumption, residing near excavation sites and travel prior to disease onset as risk factors (Storch, 1979).

Legionnaires’ disease is caused by *Legionella pneumophila*, a bacterium widely distributed in streams and lakes. Because *L. pneumophila* is somewhat chlorine tolerant, it is commonly found in potable water systems. As a consequence, it may not be removed in normal water treatment processes. It may grow in water environments which provide a favourable temperature, physical protection and sufficient nutrients. Such environments include hot water storage tanks, recirculation lines, hydraulic heat rejection systems, such as cooling towers, evaporative condensors, and closed-loop recirculating cooling systems (Muraca, 1988).

In the first identified case of Legionnaires’ disease in Philadelphia, exposures appeared to have resulted from contaminated aerosols from a
cooling tower. Since that time a number of outbreaks have been associated with aerosol drift from cooling towers and evaporative condensor (Klaucke, 1984) (Dondero, 1980). The warm water in such systems provides excellent growing conditions for the causal organism.

Fungi are complex multicellular organisms with an organized nucleus and a complex cell wall composed primarily of acetyl-glucosamine polymers and β(1-3)d-glucans. The fungi are usually filamentous, and produce one to many resistant spore stages during each life cycle. It is these spores that become airborne and result in respiratory exposure and disease. Virtually all fungi are free-living and become airborne from environmental reservoirs. Most fungal spores common in indoor air are dry and hydrophobic (lacking affinity for water); a few are produced in droplets of polysaccharide-rich mucous and are hydrophilic (having a strong affinity for water). Fungal spores range in size from about 2 to >100 µm. In addition, fungal fragments and metanolites can become airborne on much smaller particles (DiNardi, 1997).

Hypersensitivity reactions, such as pneumonitis and asthma, have been caused by fungi and dust mites that are known to concentrate in some homes and offices.

Protozoa are unicellular animals that are common in soil and water. Many are obligate parasites, but none of these cause disease via the airborne route. The protozoa are relatively large, and the intact animals cannot be
considered to form true aerosols; rather, living organisms are carried briefly through the air in large droplets. Protozoa also shed soluble material into water that can become airborne on small particles (DiNardi, 1997).

Arthropods are jointed animals with exoskeletons. Cockroaches and dust mites are the arthropods that are considered important from an air quality point of view. Cockroaches are insects and are among the most successful creatures on earth. They are abundant throughout the world, are able to colonize human habitats, and reproduce at an astonishing rate. They colonize environments with available water and a food source. Cockroaches shed proteins as body parts and fecal material that become airborne, although particle sizes remain unknown.

Dust mites are tiny insects that consume shed human skin. Their feces are identified as a predominate cause of bronchial asthma (Patts-Mills and Chapman, 1987). Dust mites are acarids, and are related to spiders. Dust mites are abundant in most parts of the world, although they are probably least common in desert environments. They colonize dust in houses when humidity is consistently above 60%. They are small, <100 µm, but live in dust reservoirs from which they rarely become airborne as intact animals. Dust mites shed protein-containing fecal particles that are 10-15 µm in diameter (DiNardi, 1997).

Birds and mammals are familiar to all. These vertebrate organisms shed
proteins in the form of dander (skin scales), urine, saliva, and blood components into the environment as small particles that can form aerosols. Rarely, they also may shed infectious agents that, if they become airborne in high concentrations, may cause human disease. This problem is very rare in occupied buildings, but has been reported in derelict buildings (DiNardi, 1997).

Plants are complex multicellular organisms that synthesize carbohydrates from CO\textsubscript{2} and water (mediated by chlorophyll) and have cellulosic cell walls. Plants produce many allergens, the best known of which are borne on pollen grains.

Individual pollen grains range from 10-80 µm, with most being in the 15-25 µm range. Although none are abundantly produced indoors, they penetrate interiors and are resistant, residing in dust for long periods. Latex (the sap of the rubber plant), used for many consumer products, also contains important allergens (DiNardi, 1997).

4.8.2 Sources

Some of the contamination sources applicable to indoor environments are viruses, bacteria, fungi, protozoa, arthropods and mammals and birds.

Molds is a term used commonly to describe a number of biologically similar organisms, known as fungi. The largest percentage of fungal species extant on the earth’s surface today are organisms of decay,
particularly of materials of plant origin. These decay organisms are
described as being saprophytic. Other fungi may be obligate or
opportunistic pathogens of plants, animals or humans. The reproductive
propagules (spores) and, to a lesser extent, vegetative fragments of fungi
(hyphal), are a common component of aerosol fractions of both ambient
and indoor air. As such, they represent a major form of air contamination
and potential human inhalation exposure.

Atopic individuals may develop an immunological sensitization as a result
of exposure to one or more fungal allergens. Once sensitized to allergens
of a particular fungal species, an individual may develop typical allergy-
type symptoms whenever re-exposures are of sufficient magnitude.
Symptoms can only develop from exposure to allergens to which an
individual has been sensitized. It is not, however, uncommon for atopic
individuals to have become sensitized to allergens from several or more
fungal species, as well as other allergens.

4.8.3 Measurement Techniques

There are three general categories of sampling methods: Gravity samplers,
inertial impactors, and filtration devices. Gravitational collectors consist of
a collection plate which contains a growth medium. Collection occurs via
both gravity and inertial impaction, as the air over the plate is rarely still.
This method is not a recommended technique, because it is subject to both
qualitative and quantitative errors.
Inertial impactors and filtration devices are the preferred types of collection devices.

Inertial impactors operate by either pulling air across a culture plate or by rotating the plate through the air at a constant speed. The types of devices included in this category are slit impactors, sieve impactors, and liquid impingers. Slit impactors operate by rotating a plate containing a culture medium. They are useful in collecting time discriminated samples, e.g., when sampling before and after the potential source is disturbed. They can collect particles down to 10 µm, which includes pollens, various fungi spores and allergen carriers. However, human pathogens are not collected efficiently.

Sieve impactors are also called cascade impactors. The operational principle is that air is drawn through a wide orifice, accelerating as it passes through the plates of smaller and smaller caliber. Culture plates are placed under each sieve plate and the microorganisms are impacted on them. Larger particles are collected in the upper plates and smaller organisms are collected in the lower plates. This method can be used to collect both bacteria and fungi.

Liquid impingers are another type of impaction device. They draw air through a liquid, trapping the particles. This technique is used for the collection of soluble materials (e.g., mycotoxins, antigens, endotoxins) and
for bacteria and fungi that require gentle handling. Impingers are also useful in areas where very high concentrations are expected (e.g., agricultural environments), because the collecting liquid can be diluted for culture.

Another type of device in this category is the centrifugal impactor. It is easily portable and allows sampling with minimal disruption of the occupants. A potential drawback, noted by Macher and First (1983), is that the instrument is calibrated by the manufacturer and this calibration may be inaccurate.

The final type of device, a high-volume electrostatic sampler, is very sophisticated. It is designed to collect particulate matter continuously from a large volume of air and deposit it into a small amount of liquid. The sample uses an electrostatic field, a corona, to separate microorganisms from the air stream. The sample is used for collecting bioaerosols that cause health effects at very low concentrations, e.g., viruses or protozoa.

The method used for analyzing for *Legionella pneumophila* is called the Most Probable Number (MPN) method. Bacteria are recovered from an appropriate volume of water (100 ml or more) by membrane filtration (0.45 µm pore size Millipore type HA). The membrane is then submerged upside down in 10 ml sterile tap water and sonicated for 10 minutes to release bacteria from the membrane (Tobin, et al., 1986). Volumes of 0.1 ml of this concentrate, and appropriate tenfold serial dilutions of the
concentrate, are spread on buffered charcoal yeast extract agar (BCYE) plates in triplicate (Feeley, et al., 1979). In contrast to previously used methods, the concentrate is not heat or acid treated and no antibiotics are incorporated into the growth medium. After incubation at 35°C for three days, representative smears of growth on each plate are stained by the direct fluorescent antibody (DFA) technique (using polyvalent conjugate for Legionella pneumophila serogroups 1-6 and Legionella micdadei) and analyzed microscopically (Cherry, et al., 1978). Plates are recorded as positive when they contain morphologically typical Legionella colonies which yield a positive DFA test. Only brightly fluorescent and morphologically typical rods are considered positive in DFA tests. The count of Legionella bacteria in the original sample is calculated from the number of positive plates in an appropriate series of tenfold serial dilutions using MPN statistical tables (Woodward, 1957).

Apart from recovering more Legionella bacteria and yielded higher counts, the new MPN method is quantitative and has the important advantage of being less expensive, cumbersome and time saving, yielding results in three days instead of 14 days. In view of these features the method is ideally suited for research on the incidence and behavior of Legionella bacteria in water environments and water treatment processes.

4.8.4 Previous Studies Conducted
An investigation was conducted of work-related illness symptoms including throat irritation, eye irritation, headache and lethargy among museum personnel (Ahlen and Skange, 1993). Most of the affected individuals tested positive to the antigens of *Phoma spp.*, one of the mold taxa isolated from museum air. None of the spouses of affected individuals tested positive to Phoma, indicating that the exposure was work-related.

Cross-sectional studies that have implicated fully air-conditioned buildings as a risk factor for SBS symptoms provide indirect evidence of a potential association between SBS symptoms and biological agents, which may include mold and its antigens (Burge, 1987)(Zweers, 1992). Such systems produce condensate waters that provide a favourable growth environment on organic dust deposited in condensate drip pans, HVAC system filters and porous acoustical/thermal system insulation (Morey and Williams, 1990).

5. **MEASURING INDOOR AIR QUALITY**

The measuring of the abovementioned indoor air pollutants were conducted in both the Port Elizabeth Technikon and Port Elizabeth Municipality buildings described in Chapter 3. An explanation of the chosen measuring techniques, the results obtained and a comparison to the legal and comfort limits for each specific pollutant will be covered in this section.
5.1 Respirable Particulate Matter

The reason for sampling for total dust was to determine what levels of dust is present and to compare the levels between the new and old building. An Air Con2 High Volume Air Sampler was used. The following procedures were followed:

1. Air flow calibration was done by using a soap bubble burette.
2. Three readings were taken and the pump was set to pump at a flow rate of 1 l/min.
3. Cellulose acetate filters with a 25mm diameter with 0,8 μm pore size were used.
4. The filters were acclimatized beforehand by standing in a petri-dish overnight in a desiccator containing silica gel.
5. The filters (including blank filters) were weighed to an accuracy level of 0,01 mg on a chemical balance.
6. The weighed filters were placed directly into the filter container and sealed. The blank filters were placed in a petri-dish and left in the desiccator and the control sealed in a filter holder.
7. In order to prevent damaging the filter a pincette with flat ends was used to place the filters in the filter container. The filter container was sealed with a special sealing band and numbered clearly.
8. The sampling line was then completed by linking the filter to the portable Gilian sampling pump.
9. The filter container was mounted in such a way that the open face points forward and slightly downward.
10. The pump was switched on and the time was recorded.
11. A five day sampling period was selected.
12. At the end of the sampling period the exact time was recorded.
13. After exposure the filter was carefully removed from the filter container
    and placed in a petri-dish and, once again, placed in the desiccator to
    acclimatize, together with the blank filters that have not been exposed.
14. Both the exposed and the blank filters were weighed.
15. The following calculations were made:

Technikon Office (New Building)

\[
Volume\ of\ air\ (m^3) = \frac{flow\ rate\ (litres/min) \times time\ (min)}{1\ 000}
\]

\[
= \frac{1 \times 7\ 200}{1\ 000}
\]

\[
= 7.2\ m^3
\]

\[
Concentration\ of\ dust\ (mg/m^3) = \frac{mass\ of\ dust\ (corrected)(mg)}{volume\ of\ air\ sampled\ (m^3)}
\]

\[
= \frac{0.03893}{7.2}
\]

\[
= 0.00540\ mg/m^3
\]

Municipal Building (Old Building) :-

\[
Volume\ of\ air\ (m^3) = \frac{flow\ rate\ (litres/min) \times time\ (min)}{1\ 000}
\]

\[
= \frac{1 \times 7\ 200}{1\ 000}
\]

225
Concentration of dust \( \text{mg/m}^3 \) = \( \frac{\text{mass of dust (corrected) (mg)}}{\text{volume of air sampled (m}^3)} \) (5.2.)

\[
= \frac{0.05039}{7.2} \\
= 0.00699 \text{ mg/m}^3
\]

16. Note that the mass of the dust collected on the filter is corrected by adding the mass difference of the blank filter disk to the known mass of the dust if the blanks indicate a decrease, and by subtracting it from the calculated mass of dust collected on the filter if the blanks indicate a mass increase (Schoeman and Schröder, 1994).

Results obtained (concentration of dust)

<table>
<thead>
<tr>
<th>Sample Building</th>
<th>Flow Rate</th>
<th>Time</th>
<th>Mass</th>
<th>Total Dust Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technikon Building</td>
<td>7 200 l/min</td>
<td>72 hours</td>
<td>0.03893</td>
<td>0.00540 mg/m³</td>
</tr>
<tr>
<td>Municipal Building</td>
<td>7 200 l/min</td>
<td>72 hours</td>
<td>0.05039</td>
<td>0.00699 mg/m³</td>
</tr>
</tbody>
</table>

The American Society of Heating, Refrigerating and Air Conditioning Engineers’ standard (ASHRAE, 1989) recommends a maximum of 0.15 mg/m³ for a 24-hour average and 0.05 mg/m³ for an annual average.

The Respirable Particulate results obtained in both buildings are below the ASHRAE limits. If the results for dust concentrations at the offices of both
buildings are considered, is it important to note that the carpets in the municipal building was vacuumed the second sampling day and that the carpets of the Technikon building was not vacuumed at all. Respirable dust will in general settle out outside office hours. It will be in suspension during office hours, because of the numerous activities taking place in an office which create dust, including movement on carpets by walking. Dust concentrations in older buildings tend to be higher due to a dust build up on ceiling tiles, window frames, air conditioning ducting over time, and due to bad housekeeping. In new buildings it might just be a matter of time before dust starts to build up. The dust concentration was lower in the Technikon building, a new building.

5.2 **Carbon Monoxide, Carbon Dioxide, Temperature and Relative Humidity**

Carbon monoxide was measured to determine variation in the concentrations present in the office buildings. The following limits are important: Exposure to concentrations exceeding 10 ppm can lead to fatigue, 25 ppm to vision impairment and 50 ppm to headache and irregular heartbeat.

Carbon dioxide was measured to establish differences in concentrations between new and old buildings. CO\(_2\) itself is not a contaminant, but measurement of the indoor CO\(_2\) concentration can be used as a surrogate to determine if building ventilation is adequate.

Temperature and relative humidity were measured to determine the comfort of office areas, and relative humidity is further important to control microbial growth.
in ducts, carpets and other building materials (TSI, 1996).

A TSI\textsuperscript{R} Q-Trak\textsuperscript{R} direct reading Indoor Air Quality (IAQ) Monitor was used in both buildings for a continuous sampling period of five days. The TSI\textsuperscript{R}'s Q-TRAK\textsuperscript{R} IAQ monitor simultaneously measure CO\textsubscript{2}, temperature, Relative Humidity and CO using a single instrument with a single probe (TSI\textsuperscript{R}, 1996). It is furthermore portable and is equipped with a data logger for data storage.

Table 1 is a summary of the Technikon results.

A graphic presentation of the results is shown in Figure 1.

The results for the Municipal building are summarized in Table 2 and the graphs are shown in Figure 2.
### TABLE 1: TECHNIKON BUILDING (NEW BUILDING)

<table>
<thead>
<tr>
<th>Test ID</th>
<th>Model: Q-Trak with CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Abbreviation</td>
<td>Serial Number: -15301</td>
</tr>
<tr>
<td>Test Start</td>
<td>08:24:29 on 08/07/98</td>
</tr>
<tr>
<td>Test Stop</td>
<td>08:28:29 on 08/14/98</td>
</tr>
<tr>
<td>Test Length</td>
<td>7 days, 0 hours, 4 minutes, 0 seconds</td>
</tr>
<tr>
<td>Logging interval (mm:ss)</td>
<td>01:00</td>
</tr>
<tr>
<td>Time constant (seconds)</td>
<td>10</td>
</tr>
</tbody>
</table>

#### Channel 1: Carbon Dioxide (ppm)
- Average = 411 ppm
- Minimum = 366 ppm at 04:57:34 on 08/10/98
- Maximum = 697 ppm at 11:47:28 on 08/11/98

#### Channel 2: Temperature (°C)
- Average = 21 °C
- Minimum = 18.7 °C at 06:27:38 on 08/09/98
- Maximum = 23.3 °C at 11:58:07 on 08/11/98

#### Channel 3: Relative Humidity (%)
- Average = 50.7%
- Minimum = 0% at 07:18:19 on 08/14/98
- Maximum = 62.6% at 11:58:11 on 08/11/98

#### Channel 4: Carbon Monoxide (ppm)
- Average = 0 ppm
- Minimum = 0 ppm at 08:24:38 on 08/07/98
- Maximum = 5 ppm at 08:27:48 on 08/14/98

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FIGURE 1: VARIATION IN CO₂, TEMPERATURE, RELATIVE HUMIDITY AND CO AT THE TECHNIKON BUILDING
**TABLE 2 : MUNICIPAL BUILDING (OLD BUILDING)**

**TEST STATISTICS**

Test ID : 1

Model : Q-Trak with CO

Test Abbreviation :

Serial Number : -15301

Test Start : 07:57:54 on 01/04/99

Test Stop : 07:58:54 on 01/11/99

Test Length = 7 days, 0 hours, 1 minutes, 0 seconds

Logging interval (mm:ss) = 01:00

Time constant (seconds) = 10

Channel 1 : Carbon Dioxide (ppm)

Average = 474 ppm

Minimum = 428 ppm at 05:17:22 on 01/08/99

Maximum = 687 ppm at 08:51:10 on 01/04/99

Channel 2 : Temperature (°C)

Average = 24.6 °C

Minimum = 22.3 °C at 07:36:45 on 01/08/99

Maximum = 26.9 °C at 13:58:45 on 01/10/99

Channel 3 : Relative Humidity (%)

Average = 57.9%

Minimum = 52% at 17:24:59 on 01/07/99

Maximum = 64.4% at 05:33:22 on 01/06/99

Channel 4 : Carbon Monoxide (ppm)

Average = 0 ppm

Minimum = 0 ppm at 07:58:03 on 01/04/99

Maximum = 1 ppm at 11:34:34 on 01/10/99
FIGURE 2: VARIATION IN CO₂, TEMPERATURE, RELATIVE HUMIDITY AND CO AT THE MUNICIPALITY BUILDING
Regulations and guidelines pertaining to IAQ for CO₂, CO, Temperature, Relative Humidity are as follows:


It requires regular monitoring of CO₂ and levels less than 800 ppm indoors is acceptable. The relative humidity level should be below 60%.


Acceptable indoor air quality is defined 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”. It recommends 20 cfm (0.56m³/min) per person as a minimum outdoor air requirement for office spaces based, on maximum occupancy of seven people per 1 000 ft² (92.90m²). It limits CO₂ to a maximum of a 1 000 ppm. It, furthermore, restricts CO to a maximum level of 35 ppm for 1 hour exposure (not to be exceeded more than once per year) and 9 ppm for 8 hour exposure (not to be exceeded more than once per year) by referencing EPA Ambient Air Quality Standards.


The recommended typical temperature range is from 20°C to 26°C and relative humidity level
between 30 and 60%. These ranges are based on thermal conditions acceptable to 80% of the building occupants.

Discussion of results

The results obtained from temperature, carbon monoxide, cardon dioxide and relative humidity monitoring in the 2 buildings were all within the comfort or legal limits. Furthermore, the results obtained from the two buildings did not show a significant difference in CO₂ levels.

Cyclic variations in temperature between day and night could be observed in the Technikon Building. Maximum day temperatures vary from 21°C to over 23 °C. The CO₂ peaks correspond to the higher temperatures. The low CO₂ levels are due to the number of people in the office during the long weekend of 8 to 10 August 1998. A low relative humidity change could be observed over the measurement period. One occurrence of high CO levels could be observed on the 14th of August 1998.

Cyclic variations could be observed in Municipality Building. Maximum day temperatures vary from over 25°C to nearly 28°C. Cyclic CO₂ variations could be
observed for the first 5 days, the last 2 days corresponding to the presence of personnel at the office over the weekend. No cyclic changes in relative humidity, unlike the Technikon Building, could be observed. One large CO peak at the end of the period could be observed.

Although the average carbon monoxide results were zero ppm, the maximum level obtained during the sampling period at the Technikon Building was 5 ppm, compared to 1 ppm at the Municipal Building. The fresh air inlet of the Technikon Building is approximately 60 meters away from a busy road. It may be possible that CO from the busy road, next to the Technikon Building, is filtered into the building through the ventilation system. The fresh air inlet of the Municipal Building is approximately four storeys from street level. CO from the busy road next to the municipal building could be filtered into the building through the basement and through the lift shafts with a negative draft. At the mechanical ventilation inlet on the fourth floor the CO concentration will be so diluted that it would not have any effect at all.

Temperature and relative humidity were higher in Municipal building than in the Technikon building. This can be due to the position of the Technikon close to the sea with cool sea breezes and prevailing winds. The Municipal building is situated in a trough with little wind movement.

5.3 Volatile Organic Compounds

Traceair® organic vapour monitoring badges were used for monitoring VOC’s. They are simple and economical passive diffusion devices. These badges are very
reliable and exceed NIOSH and OSHA accuracy requirements. The badges were removed from the tube, the covers on both ends were removed and set up in the room at the breathing zone level for 48 hours. After sampling the covers were replaced and badges were returned to the package. They were sent to the laboratory for GC-MS analysis, according to the NIOSH manual for VOC’s. The results are shown in Table 3.

**TABLE 3 : VOC RESULTS**

<table>
<thead>
<tr>
<th>Building</th>
<th>Sample No</th>
<th>VOC</th>
<th>Concentration µg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal Building</td>
<td>1</td>
<td>N.d.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>N.d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>N.d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>N.d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>N.d</td>
<td></td>
</tr>
<tr>
<td>Technikon Building</td>
<td>1</td>
<td>toluene, ethyl benzene, xylene</td>
<td>120.64, 1.78, 4.26</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>N.d.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>N.d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>toluene, ethyl benzene, xylene</td>
<td>311.00, 4.60, 11.25</td>
</tr>
</tbody>
</table>
The following qualitative VOC’s were also detected at the Technikon but cannot be quantified:

Alpha pinene
Camphene
Ethyl methyl benzene

**Discussion of results**

Due to the Municipal Building been old and no-smoke offices, VOC’s were not detected. Several VOC’s of which the highest concentration of toluene was detected in the Technikon Building. The presence of the VOC’s in the new building could be detected in the paint, glue and fabrics.

**5.4 Biological Agents in Air**

The settle plate method was used by which larger particles are settling by gravity from the air onto a petri-dish containing an blood agar medium of known surface area of 65 cm². The petri-dish is left open for 15 minutes. Blood agar is suitable for an overall count of the pathogenic, commensal and saprophytic bacteria in the
air. Large bacteria-carrying dust particles can settle onto the medium. The plates are incubated aerobically for 24 hours at 37°C. The colonies were counted with the use of a plate microscope to detect even the smallest ones. The results are expressed as the number of bacteria-carrying particles settled on a given area in a given period of time. One petri dish sample was obtained for the office area for each of the five sampling days.

Discussion of results

The higher the spore counts the greater the chances of occupants experience sinus problems. However, people react differently to different numbers of spores and may be more sensitive to a lesser number than others. The results obtained for the concentration of biological agents given in Table 4.

TABLE 4 : BIOLOGICAL COUNTS AS PER PETRI-DISH METHOD

<table>
<thead>
<tr>
<th>Sample</th>
<th>Technikon Building (New Building)</th>
<th>Municipal Building (Old Building)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5 spores/m³</td>
<td>7 spores/m³</td>
</tr>
<tr>
<td>2</td>
<td>1 spore/m³</td>
<td>11 spores/m³</td>
</tr>
<tr>
<td>3</td>
<td>9 spores/m³</td>
<td>6 spores/m³</td>
</tr>
<tr>
<td>4</td>
<td>2 spores/m³</td>
<td>3 spores/m³</td>
</tr>
<tr>
<td>5</td>
<td>3 spores/m³</td>
<td>11 spores/m³</td>
</tr>
<tr>
<td>Average</td>
<td>4 spores/m³</td>
<td>8 spores/m³</td>
</tr>
</tbody>
</table>
Considering results obtained from spore counting it is evident that the old Municipal building has levels on average higher than the Technikon building. Every day, except day 3, the Municipal building exceeded the Technikon levels. This can possible be due to the age of the building, the build up of dust over time, a lack of regular maintenance to the HVAC system, etc.

5.5 Biological Agents in Water

*Legionella pneumophila* analysis

A one liter water sample was taken from the outlet (bottom section) of the cooling tower of each of the two buildings and sent to a laboratory for analysis according to the MPN method.

The results obtained were as follows:

Technikon Building (New Building)

*Legionella pneumophila* - negative

Municipal Building (Old Building)

*Legionella pneumophila* - negative

The negative results indicate that the cooling towers are maintained on a regular basis and that the water was sterilized with a biocide on a daily basis. As part of maintenance to cooling towers, the regular cleaning of ducting, at least twice a year before summer and winter, and the cleaning of filters should be conducted.
Maintenance to the HVAC system at the Technikon building was done on a more regular basis than at the Municipal building (Personal Communication, 1998).

5.6 Formaldehyde

Two K & M Environmental® HCHO passive badges were used for monitoring formaldehyde in both buildings. Formaldehyde concentrations were measured for a period of 48 hours. The colour change on the badges were converted to concentrations by comparison with the K & M Environmental® comparator. The results are as follows:

<table>
<thead>
<tr>
<th>Badge no.</th>
<th>Technikon Building (New Building)</th>
<th>Municipal Building (Old Building)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.5 ppm/h</td>
<td>3.5 ppm/h</td>
</tr>
<tr>
<td>2</td>
<td>8.5 ppm/h</td>
<td>3.5 ppm/h</td>
</tr>
</tbody>
</table>

Discussion of results

The reasons for the higher formaldehyde levels in the Technikon building could be due to the new office furniture, especially the desks, which were made of melamine and particle board (“chip board”). The glue used to lay the carpets could also be a contributory factor. Formaldehyde was also used as thermal insulation in ceiling panels in this two months old building. Formaldehyde emissions, and thus indoor concentrations, show significant temporal fluctuations. Researchers found that
emissions are dependent not only on age, but also on temperature and relative humidity (Wanner and Kuhn, 1984).

Although the municipal building is 29 years old, it was redecorated and revamped three years ago with new particle partition board walls, paint and carpets, new ceiling panels and with new furniture. Due to the age of these products the formaldehyde levels are much lower. It is stated in literature that formaldehyde concentrations dropped to half the original concentration between two and five years (Hanrahan, 1985).

Burning of the eyes and general irritation of the upper respiratory passages are the first signs experienced at formaldehyde concentrations in the 0.1 - 5 ppm range. Formaldehyde is generally sensed at 1 ppm, but some individuals can detect it at 0.05 ppm (National Academy of Sciences, 1981, b). Concentrations of 10 - 20 ppm may produce coughing, tightening in the chest, a sense of pressure in the head and palpitation of the heart. Bronchial asthma and acute asthmatic attacks may be experienced at exposures between 0.25 - 5 ppm. Exposures above 50 - 100 ppm can cause serious injury such as collection of fluid in the lungs and inflammation of the lungs or death (NIOSH, 1980).

The U.S. Department of Housing and Urban Development (HUD) has established maximum indoor formaldehyde concentrations for manufactured homes and office, based on source strengths, at 0.4 ppm (U.S. Department of Housing and Urban Developing, 1984). This has prompted manufacturers of pressed wood products to develop low formaldehyde emission products.
These products use formaldehyde-containing adhesives that react more completely with other constituents, resulting in lower amounts of free formaldehyde as compared to the older formulations. This results in overall lower formaldehyde emissions. This action has had the effect of reducing formaldehyde concentrations inside many building structures.

In the US therefore, new office buildings or businesses may prevent potential building related complaints by specifying for low formaldehyde emission materials and/or office equipment in their tender documents.

5.7 Summary of results

A summary of the monitoring results for both buildings is shown in Table 5.

**TABLE 5 : SUMMARY OF SAMPLE RESULTS FOR MUNICIPAL AND TECHNIKON BUILDINGS**

<table>
<thead>
<tr>
<th>POLLUTANT</th>
<th>MUNICIPAL BUILDING</th>
<th>TECHNIKON BUILDING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PARTICULATE MATTER</strong></td>
<td>0.00699 mg/m³</td>
<td>0.00540 mg/m³</td>
</tr>
<tr>
<td><strong>CARBON MONOXIDE</strong></td>
<td>Average 0 ppm</td>
<td>Average 0 ppm</td>
</tr>
<tr>
<td></td>
<td>Minimum 0 ppm</td>
<td>Minimum 0 ppm</td>
</tr>
<tr>
<td></td>
<td>Maximum 1 ppm</td>
<td>Maximum 5 ppm</td>
</tr>
<tr>
<td><strong>CARBON DIOXIDE</strong></td>
<td>Average 474 ppm</td>
<td>Average 411 ppm</td>
</tr>
<tr>
<td></td>
<td>Minimum 428 ppm</td>
<td>Minimum 366 ppm</td>
</tr>
<tr>
<td></td>
<td>Maximum 687 ppm</td>
<td>Maximum 697 ppm</td>
</tr>
<tr>
<td><strong>TEMPERATURE</strong></td>
<td>Average 24.6 °C</td>
<td>Average 21 °C</td>
</tr>
<tr>
<td></td>
<td>Minimum 22.3 °C</td>
<td>Minimum 18.7 °C</td>
</tr>
<tr>
<td></td>
<td>Maximum 26.9 °C</td>
<td>Maximum 23.3 °C</td>
</tr>
<tr>
<td><strong>RELATIVE HUMIDITY</strong></td>
<td>Average 57.9%</td>
<td>Average 50.7%</td>
</tr>
<tr>
<td></td>
<td>Minimum 52%</td>
<td>Minimum 38.8%</td>
</tr>
<tr>
<td></td>
<td>Maximum 64.4%</td>
<td>Maximum 62.6%</td>
</tr>
<tr>
<td>VOLATILE ORGANIC COMPOUNDS</td>
<td>Not detected</td>
<td>Average for 3 samples</td>
</tr>
<tr>
<td>----------------------------</td>
<td>-------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>toluene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ethyl benzene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>xylene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trimethyl benzene</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BIOLOGICAL AGENTS</th>
<th>Average 8 spores/m³</th>
<th>Average 4 spores/m³</th>
<th>Minimum 3 spores/m³</th>
<th>Minimum 1 spores/m³</th>
<th>Maximum 11 spores/m³</th>
<th>Maximum 9 spores/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LEGIONELLA PNEUMOPHILA</th>
<th>Negative</th>
<th>Negative</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>FORMALDEHYDE</th>
<th>Average 3.5 ppm/h</th>
<th>Average 8.5 ppm/h</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

In comparing the IAQ in the buildings the following can be deduced:

* The Municipal Building contained the highest amount of Particulate Matter and Spores. However, both these pollutants are present well below Health and Safety exposure limits.

* Carbon Monoxide was present in extremely low amount in both buildings.

* The Municipal Building had the highest CO₂ concentration average, however the range of CO₂ variations was the highest in the Technikon Building.

* The temperature and relative humidity of the Indoor Air in the Municipal Building were, on average 3.6°C and 7% respectively higher than that of the Technikon Building. This most probably is due to seasonal variations.

* No VOC’s were detected in the Municipal Building, while toluene, ethyl benzene, xylene and trimethyl benzene were present in the Technikon Building.
* Formaldehyde levels were significantly higher in the Technikon Building than the Municipal Building due to the age of the furniture and carpets.

* No *Legionella pneumophila* was detected in water from cooling towers from both buildings.

6. QUESTIONNAIRE

6.1 Compilation Of Questionnaire

A questionnaire was formulated to assess whether IAQ problems were perceived by the majority of respondents (Annexure A). The first three questions deal with personal information e.g. sex, age and race. The next section of the questionnaire assess the working related conditions such as sharing of offices, working on computers, perceived stress in work, satisfaction with occupation, etc. This section also addresses the condition in the offices regarding ventilation, lighting and humidity. The last section of the questionnaire addresses the medical history and aims to identify any sick building syndrome symptoms experienced by respondents. Exposure to smoking is also been evaluated.

6.2 Completion of Questionnaire

The questionnaire was completed by all office workers in both buildings. The municipal building consists of 24 single offices and a boardroom on the 13th floor. Only one person occupies an office. The third floor at the E-block, the latest edition to the Technikon building, consists of single offices with one or two
persons sharing and a working area where four to five people are working.

The monitoring in the municipal office took place in one office on the 13th floor. A total of 17 respondents completed the questionnaire in the Bureau of Staff Department. At the Technikon nine personnel at reception were requested to complete the questionnaire. The combined results of the questionnaires are shown in Annexure B.

6.3 Discussion of Questionnaire

Most of the respondents at the Municipal Building, 93% are Europene males, with an age variation from 26 to 60. A more or less even distribution of sexes occurred at the Technikon, while 66% of the respondents were European. None of the respondents shared offices at the Municipal Building, while only 2 people were sharing at the Technikon Building. Since the Technikon Building a new building, all the respondents were working in the building less than 2 years. Correspondently the majority of respondents from the Municipal Building work there for 11 - 15 years (47%).

All of the respondents at the Municipal Building perform work on a computer, however for short durations during the day. Most of the respondents at Technikon Building work on computers for varying periods during the day.

In general the individuals at both buildings were performing low-stress work. 100% of the individuals at the Technikon Building were satisfied, but in contrast,
41% at the Municipal Building were dissatisfied with their work.

Adequate natural lighting was supplied in both buildings. However, uncomfortable artificial lighting to 30% of the Technikon Building respondents. The humidity in the offices was comfortable to nearly all, but 1, respondent.

Ventilation and temperature, on the other hand, were uncomfortable for 29% at the Municipal Building, while only 22% experience it at the Technikon Building.

From the medical information section some individuals in both buildings indicated that they experienced allergies. Very few sick building syndrome symptoms were experiences by most of the respondents. The only significant symptom occurring at the Municipal Building was headaches for 29% of the individuals. “Burning eyes” was the only significant symptom experienced by the Technikon respondents. Since both buildings had a policy regarding smoking in offices, few respondents were exposed to smoke.

6.4 Summary of questionnaire results

The results of the questionnaire show that in general few sick building syndrome symptoms were significant. Headaches were experienced by 30% of respondents in the Municipal Building.

Furthermore, in the same building uncomfortable ventilation/temperature conditions were experienced by 30% respondents.
A third of the respondents of the Technikon Building indicated that burning eyes were experienced by them in the two weeks prior to completion of the questionnaire. 30% of the Technikon Building individuals indicated that artificial lighting was uncomfortable.

7. EVALUATIONS OF RESULTS

The results from the questionnaire were evaluated against the results obtained from the monitoring at the two buildings. The following can be deduced:

* In general, the Indoor Air in both buildings was of a high quality. This correlates well with the relative low amount of symptoms experienced by the respondents.

* Uncomfortable conditions were experienced regarding ventilation/temperature by the respondents of the Municipal Building. This is confirmed by the relatively high average temperature and relative humidity measured in the Municipal Building. In addition headaches was also experienced by a third of the respondents. This can be due to the high temperature and relative humidity.

* Burning eyes were encountered by the Technikon respondents. This symptom can be related to the VOC’s detected in the air, and the formaldehyde concentration with were significantly higher in the Technikon Building compared to Municipal Building, where no such symptoms were recorded.

8. DISCUSSION
The above investigation into IAQ in two buildings indicated that results obtained from measurements can be approximately correlated to symptoms encountered by the building occupants.

However, to propose methods to solve the IAQ problems more information is required, other than measured results. The exact cause of symptoms or conditions need to identify. For such investigation a systematic approach is required where all aspects relating to IAQ are assessed. This includes ventilation, building design, interior make-up, occupant behaviour, equipment, seasonal trends, etc. This shows that a comprehensive step-by-step method is required in solving IAQ problems. The following section propose a guideline for solving such problems.

9. A STEP-BY-STEP METHOD IN SOLVING IAQ PROBLEMS

Although most of the above results obtained in this study do not exceed recommended exposure levels, occupants in these office buildings react differently to each pollutant. Some people may be more sensitive to a specific pollutant than others. In general IAQ complaints, and the associated sick building syndrome, seem to be a problem of place, not process. The term “Sick Building” implies that the problem lies with the building, not its occupants. The most effective approach to resolving IAQ problems is to optimize as many environmental factors as possible in order to enhance the working environment of the building occupants.

Both the Environmental Protection Agency (EPA) and National Institute for Occupational Safety and Health (NIOSH), who have investigated hundreds of sick buildings, agree that
most problems are related to heating, ventilation and air conditioning (HVAC) systems
(EPA, 1991). Most IAQ problems are the result of how the ventilation system has been
designed and operated, especially in energy-efficient systems. Lack of proper HVAC
maintenance also plays a role. A major purpose of an indoor air quality evaluation is to
determine whether or not adequate amounts of relative clean outside air are being
delivered to the building occupants. The fact that so many IAQ problems are ventilation-
related means that a well-informed building or maintenance engineer can be pivotal with
respect to IAQ problems, either to prevent air quality problems, or to correct them when
they occur.

To solve indoor air quality problems in office buildings, a systemic and self-discipline
approach must be followed. Where the reason for an air quality complaint is not self-
evident, a systematic approach to information gathering, to formulate a hypothesis, and to
implement solutions must be followed. Figure 3 shows a “decision tree” for indoor air
quality investigations that outlines the systematic approach recommended. While it might
not be necessary to include every step, failing to do all the “homework” can lead to
frustrating, sometimes embarrassing and possibly dangerous consequences.

9.1 Planning

Planning is a vital aspect before starting with the survey. There usually are very
specific concerns that must be addressed during the pre-survey information
gathering phase that might otherwise not be anticipated. Advanced planning also
serves to increase efficiency on-site.

FIGURE 3 : FLOW DIAGRAM INDICATING STEPS REQUIRED TO SOLVE A IAQ
As much information as possible should be collected in advance of the survey, including the complainant’s perception of the problem, the general physical environment of the office or work area, and potential perceived causes of the
problem (e.g., formaldehyde, copy machines or diesel exhaust). When arranging the survey, ask that other information sources that might be needed be available, such as mechanical drawings and floor plans, a ventilation engineer, maintenance personnel, key complainants, and their managers.

9.3 Outside walkabout

Before entering the building to do the survey, walk around the outside. Take note of the environment that surrounds the building. Questions, such as the following can be of assistance;

* are there nearby emission sources, such as exhaust stacks;
* are cooling towers, chemical-using processes or loading docks near ventilation equipment?
* can these emission filter into the building’s ventilation system?
* is the building new, old, or recently refurbished (indicating that off-gassing of construction materials or furnishing might be a factor)?
* is there equipment located outside for which more details are required, such as ventilation fans, boiler stacks or heat exchanges?

9.4 Determining problem (formulate problem)

Indoor air quality complaints rarely arrive on the investigator’s desk with all the information needed to allow quick resolution. The investigator should be somewhat skeptical of the facts of the case put forward prior to getting involved.
For example, building occupants’ perception of the problem may be coloured by an active “rumour mill”.

The investigator, from the information gathered, should determine what the problem is and how widespread it actually is. Complaints limited to one or two people in a large office population, such as an allergy or an unusual individual reaction to an environmental factor, can indicate a problem that might be beyond the reach of procedures presented here. On the other hand, a high incidence rate of illness and discomfort often means that there are factors in the work environment that can be manipulated to bring relief.

The investigator needs to know who the affected people are, where they are located and when the symptoms occur. This can be assessed in several ways.

* One can accept only the complainant’s or management’s word for it. At the least, this might be misleading because either of these information sources are rarely unbiased, however, well-meaning, and they commonly have incomplete information. For example, this method invariably identifies the loudest complainers (but might miss the silent sufferers). It will also alienate the non-involved parties.

* Spend time talking to enough people, both management and employees, to feel confident that you understand the scope of the problem. Be aware that this might require a lot of on-site time, depending upon the number of persons to be interviewed and can be disruptive to the workplace.
Circulate a questionnaire to assess symptoms and locate illness cases. This is often the best method, since control of the information collected is being exercise and the building occupants will feel that confidential attention is being paid to their concerns. Unfortunately, someone will have to analyze all the survey data. An additional problem is that individuals without concern commonly do not respond to questionnaires, this makes the situation appear worse than it actually is.

In most cases a mixture of methods will be required. A reasonable approach might be to verbally interview a representative number of occupants until enough information has been collected. Regardless of the method(s) chosen, there are simple questions which occupants should be asked regarding their symptoms. It may also be useful to define which people are affected (the cases), which are not affected (non-cases) and map where each of the cases and non-cases are located. The resulting graphic can demonstrate where efforts are most needed and can help isolate the cause by pinpointing the most affected area.

The assessment should serve to identify the answers to several questions (or at least, to help focus subsequent survey efforts). The items which should be focused on as a result of the assessment include the following: determination of the history of the problem, localization of the problem, discovery of any hidden agendas, and an estimation of the anxiety levels of the participants. Each of these items is further explained below.

Determine the history of the problem. For example, how and when it
started, who else has been involved as an investigator before you (and what
they did or concluded) and the office’s recent history.

* Localize the problem to the extent possible, both in time and place. In
other words, when and where does the problem occur (and to whom). The
more precisely this step is accomplished, the easier it will be to find the
source of and thus the solution to the problem.

* Discover any hidden agendas. These are the mine fields of IAQ
investigations, especially if the problem has gone unresolved for some time
and battle lines have been drawn. Labour relations problems and
unsatisfying working conditions are notoriously common adjuncts to IAQ
episodes. The polarizing of the workforce over unrelated issues can
precede the development of IAQ complaints.

* Estimate the anxiety level of the occupants. Fear, frustration and anxiety,
usually present to some extent in IAQ situations, cannot be ignored. For
reasons not entirely clear, if the occupants are already convinced you will
not help them, you often will not, regardless of what corrective actions you
take.

9.5 Visual investigation

Most of the evaluation for IAQ problems will be conducted with the eyes rather
than with sophisticated measuring equipment. The tools required for a visual
inspection are simple. Useful questions asked about the building may help to
direct the investigation. With this information (and equipment) in hand, the
following issues must also be addressed during the visual inspection:
* Are there any obvious sources of air contamination inside the office? These might include cleaning and janitorial supplies, copy machines, new construction or furnishing and food.

* Are there sources outside the space, either in other parts of the building or outside? For example, are there re-entrained exhaust gases from other buildings or processes, or chemicals reticulated from other areas in the building through shared ventilation systems?

* Is water damage either evident to the occupants or in hidden areas, such as above suspended ceiling? Look for mold in carpets and ceiling tiles. Is there a history of water leaks or floods?

* How clean is the air? Is there dirt buildup on ventilators or horizontal surfaces? Dirt in ventilation ducts? Unexplained smells?

The single most important element of any investigation is usually the ventilation system, either as a carrier of contaminants or as a source of contaminants or both. Understand how the HVAC system works. The ventilation engineer or maintenance person responsible for the system is the best source of information. Modern office building ventilation systems can be remarkably complex. Be aware that how the engineer believes the system is operating may be different from how it is actually operating (depending on how much hands-on involvement this individual has). Because of this discrepancy, building engineers, maintenance people, etc. should be handled tactfully to avoid a defensive reaction if reality does not meet expectation. For example, a facilities engineer may boldly describe the virtues of his periodic maintenance program, which, upon visual inspection, is
disproven by a sea of mold in the drip pans. To continue this example, further questioning may reveal that the engineer has never examined the equipment (or the maintenance contract might not include drip pans). Because this person can be influential during the investigation (either an enemy or an ally), as well as during the resolution of the problem, be particularly careful not to alienate him or her.

The two most common types of systems utilize either constant air velocity or variable air volume (VAV). In constant air volume systems the amount of total air (outside + recirculated air) delivered to spaces stays approximately the same regardless of temperature. The amount of outside air in the air stream is determined by louvers usually located near the fan. Energy-efficient fans typically use VAV controls. In this case, the occupied space is divided into zones. The air supply to each zone is controlled locally by louvers in a mixing box, usually located in an above-ceiling space. With a VAV system, the amount of air reaching a space can be very difficult to quantify, because the volume changes with temperature. In all types of systems there are usually dampers serving individual ducts that must be accounted for.

Once you understand the HVAC system, observe as much of the hardware as possible, both inside and out, to determine its condition and mode of operation. Note the general state of cleanliness and repair. Look for slime in drip pans and chiller coils, dust buildup and lack of maintenance. Ask questions, such as the following:

* What is the duty cycle (that is, when does the fan turn on and off; does the
fan operate only when heating or cooling is called for)?

* Where is the air supply intake?

* Is there potential for contamination from other sources, such as boiler or paint-spray booth stacks, idling cars and trucks, or birds nesting in the louvers?

In general, a clean, well-maintained system with a knowledgeable engineer in charge is the desirable situation. Use smoke tubes or tissue paper to check that each of the supply and exhaust grills in the areas is operating and that air flow between areas of the building appropriately isolated potential air contaminants.

Whether or not an HVAC system is operating as intended can be determined by measuring how much outside air is reaching the occupied spaces. This can be done two ways as indicated in Annexure C.

In some cases, adequate supply air might not be adequately mixed within an office space. This can happen when supply and return grilles are located such that supply air is simply exhausted as soon as it enters the space. Another common cause of incomplete air mixing is high partition walls commonly found in modular offices. Partitions may prevent air from getting down into office cubicles even though adequate quantities are reaching the space.

Increasing the amount of outside air delivered to occupants is the classic “cure” for sick building syndrome. In severe cases, the system should be set to deliver the maximum possible proportion of fresh air, relative to recirculated air. If the IAQ
symptoms abate, recirculation can be gradually increased to find the optimum setting. Generally, offices should be maintained at a minimum of 20 cfm outside air per person.

9.6 Contaminant Monitoring

Building occupants may want to measure and quantify all sorts of potential contaminants. In the early days of IAQ investigations, many air samples were collected, at great cost, but to little effect. In the case of unknown reasons for IAQ complaints, air sampling can often be of little value. In fact, using sensitive analytical methods almost always shows the presence of large numbers of low-level organic chemicals, especially in new or remodeled buildings. “Low level” in this context usually means orders of magnitude less than the Personal Exposure Limits (PEL’s) or Threshold Limit Values (TLV’s). However, once these data are in hand, they must be explained to the building occupants. Since the list of common contaminants includes carcinogens (for example, benzene) and central nervous system depressants (chlorinated solvents and petroleum-based chemicals), even at the very low levels measured, the acknowledged presence of these common air contaminants can be frightening to the occupants (even though it is often not very relevant). The health effects of exposure to these contaminants at such low levels are not known. Because the exposure cannot adequately explain the symptoms observed (since it is usually much lower than the TLV or the PEL, for example) and since these traces of the chemicals themselves cannot be fully eliminated, this sort of “shot-gun” analytical sampling may actually raise the anxiety level of the occupants and make the investigator’s job more difficult. The rule of thumb is to
only sample for what you have reason to sample for. Some well-placed air
sampling often does yield useful information and can reassure building occupants.
Common contaminants to sample for include formaldehyde, carbon monoxide,
carbon dioxide; and also measurements of temperature and relative humidity.

In the case where a questionnaire is used to assess the IAQ problem and 30% of
the respondents indicated a certain symptom has been experience, for example,
burning eyes, headache etc., the problem must be noted and possible causes must
be investigated. It should be determined if the old carpets were replaced with new
ones, if the walls were redecorated, if the office area was fumigated, if new office
equipment were bought or if any solvent spillage occurred.

10. CASE STUDY EMPLOYING METHOD OF INVESTIGATION

A case study was performed where the proposed method, section 9, was tested. A thirty
one year old six storey office building was used in this case study. For the purpose of this
study emphasis was put on the sixth floor. The reason for identifying this particular
building was that a lot of complaints were received from personnel working on this floor.

10.1. Outside walkabout

An outside walkabout was conducted which revealed that the building was
surrounded by four busy central business area roads. The air conditioning inlet and
outlets were on the eastern and western sides of the building, directly above the
entrance and exit to the basement parking area. The grills of the air conditioning
inlet and outlets were fairly clean, but the streets surrounding the building were, although tarred, very dusty.

10.2. Survey

On the sixth floor are thirty six people doing clerical and laboratory work. Two laboratories were identified, one a ballistic laboratory that was 95% computerised and a new forensic/chemical laboratory. In the ballistic laboratory is a huge International Ballistic Information System computer scanning bullets. This computer generates a lot of heat. In the new forensic laboratory are a lot of new melamine shelving and cupboards. The interior wall surfaces were painted with an acrylic paint about two weeks prior to the investigation. New vinyl floor tiles were also laid two weeks prior to the study. The laboratory has not been stocked with chemicals at the time of the investigation. The administration office is joint on both sides by the two laboratories. In the administration office are two laser printers, four computers, a fax machine and a photostating machine. The administration office accommodates four people. Four other offices are shared by two people. The rest of the staff are working in single offices. Of the thirty six employees, fifteen are working in the two laboratories. All thirty six employees have their own computer.

10.3. Complaints

The people are complaining about discomfort, as far as the temperature and relative humidity are concerned and symptoms such as runny noses, headaches and
burning eyes. They are also complaining that these conditions are worse during the afternoons and disappear after about two hours after they have left the office.

An interview with the caretaker of the building confirmed that most of the complaints are being received by employees from all six floors in the building, but that the number of complaints received are more during the summer than during winter months. The caretaker also confirms that the sixth floor recently started complaining about their eyes and noses. The caretaker also indicated that he has not got the knowledge of what to do to solve these problems. There is also no money available on the budget for maintenance. The caretaker also confirms that not much maintenance has been done on the air conditioning system for the last two years. He stated that the filters had not been cleaned or replaced, for the last two to three years.

10.4. Sample contaminants

10.4.1 Carbon Monoxide, Carbon Dioxide, Temperature and Relative Humidity

To obtain information on contaminants in the air and to evaluate the results obtained from the questionnaire, a TSI $^R$ Q-Trak $^R$ direct reading Indoor Air Quality Monitor was used for a continuous sampling period of seven days. The TSI $^R$’s Q-Trak $^R$ measures CO$_2$, Temperature, Relative Humidity and CO and log the data in a data logger.
The results are summarized in Table 6.

The graphs obtained from the instrument is shown in Figure 4.
TABLE 6 : CASE STUDY

TEST STATISTICS

Test ID : 1  Model : Q-Trak with CO
Test Abbreviation :  Serial Number : -15301

Test Start :  09:23:52 on 12/02/99
Test Stop :  08:48:32 on 12/09/99
Test Length = 6 days, 23 hours, 1116 minutes, 56 seconds
Logging interval (mm:ss) = 32:56
Time constant (seconds) = 10

Channel 1 : Carbon Dioxide (ppm)
  Average = 537 ppm
  Minimum = 503 ppm at 03:31:54 on 12/07/99
  Maximum = 929 ppm at 08:29:11 on 12/03/99

Channel 2 : Temperature (°C)
  Average = 26 °C
  Minimum = 23.7 °C at 04:40:06 on 12/07/99
  Maximum = 28.6 °C at 15:23:19 on 12/04/99

Channel 3 : Relative Humidity (%)
  Average = 53.6%
  Minimum = 38 % at 12:22:25 on 12/06/99
  Maximum = 74 % at 08:38:45 on 12/09/99

Channel 4 : Carbon Monoxide (ppm)
  Average = 0 ppm
  Minimum = 0 ppm at 10:23:14 on 12/02/99
  Maximum = 1 ppm at 09:24:01 on 12/02/99
FIGURE 4: VARIATION IN CO$_2$, TEMPERATURE, RELATIVE HUMIDITY AND CO AT THE MUNICIPALITY BUILDING
Discussion of results

From the graphs the cyclic variation in temperature can be observed for day/night differences. A maximum of over 28°C was measured on the third day of measurement.

The temperature maximum of all seven days exceeded 25°C. Relative humidity levels of higher than 60% were obtained at the start and end of the study. CO and CO₂ variations occurred. The levels are not particularly high.

From the results it is clear that the comfort levels of temperature and relative humidity were exceeded. This is due that there is a lack of air movement and fresh air circulation in the office areas. Heat was generated by the following; the sun entering the building through windows, ballistic computer and office machinery. High temperature and relative humidity can contribute to headaches.

10.4.2 Volatile Organic Compounds

Traceair® organic vapour monitoring badges were used for monitoring VOC’s. The badges were removed from the tube, the covers on both ends were removed and attached in the forensic laboratory and the administration office at the breathing zone level for 48 hours. After sampling, the covers were replaced and
returned to the package and sent to the laboratory for GC-MS analysis according to the NIOSH No 34 (1980).

The results obtained from the laboratory are shown in Table 7:

**TABLE 7 : RESULTS OF VOC’s**

<table>
<thead>
<tr>
<th>Building</th>
<th>Sample No.</th>
<th>VOC</th>
<th>Concentration mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forensic Laboratory</td>
<td>1</td>
<td>toluene</td>
<td>3.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ethyl benzene</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>xylene</td>
<td>1.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trimethyl benzene</td>
<td>not quantified</td>
</tr>
<tr>
<td>Administration Office</td>
<td>2</td>
<td>toluene</td>
<td>3.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ethyl benzene</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>xylene</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trimethyl benzene</td>
<td>not quantified</td>
</tr>
</tbody>
</table>

**Discussion of results**

The presence of VOC levels could be due to the fact that the laboratory was painted recently and that extensive shelving, floor covering and office furniture possible containing VOC’s, were
installed. The laboratory was for most of the day and night locked and was thus not properly aired.

10.4.3 Formaldehyde

Two K & M Environmental\textsuperscript{R} HCHO passive badges were used, one in the forensic laboratory and one in the administration office. Measurements were conducted over a 48 hour period. The results were quantified by using a K & M Environmental\textsuperscript{R} comparator. The results are showing in Table 8.

**TABLE 8 : RESULTS OF FORMALDEHYDES**

<table>
<thead>
<tr>
<th>Badge no.</th>
<th>Location</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forensic Laboratory</td>
<td>10.5 ppm/hour</td>
</tr>
<tr>
<td>2</td>
<td>Administration Office</td>
<td>10 ppm/hour</td>
</tr>
</tbody>
</table>

**Discussion of results**

The new office furniture and melamine shelving in the laboratory contained high concentrations of formaldehyde in the glue. The high concentrations of formaldehyde detected in the administration office is most probably due to the levels ventilating from the
laboratory into the office through the door. The summary of the measured results from the case study be shown in Table 9.

TABLE 9: SUMMARY OF MEASURED RESULTS FROM CASE STUDY

<table>
<thead>
<tr>
<th>POLLUTANT</th>
<th>CASE STUDY BUILDING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARBON MONOXIDE</strong></td>
<td>Average 0 ppm</td>
</tr>
<tr>
<td></td>
<td>Minimum 0 ppm</td>
</tr>
<tr>
<td></td>
<td>Maximum 1 ppm</td>
</tr>
<tr>
<td><strong>CARBON DIOXIDE</strong></td>
<td>Average 537 ppm</td>
</tr>
<tr>
<td></td>
<td>Minimum 503 ppm</td>
</tr>
<tr>
<td></td>
<td>Maximum 929 ppm</td>
</tr>
<tr>
<td><strong>TEMPERATURE</strong></td>
<td>Average 26.0 °C</td>
</tr>
<tr>
<td></td>
<td>Minimum 23.4 °C</td>
</tr>
<tr>
<td></td>
<td>Maximum 28.6 °C</td>
</tr>
<tr>
<td><strong>RELATIVE HUMIDITY</strong></td>
<td>Average 53.6%</td>
</tr>
<tr>
<td></td>
<td>Minimum 38%</td>
</tr>
<tr>
<td></td>
<td>Maximum 74%</td>
</tr>
<tr>
<td><strong>VOLATILE ORGANIC COMPOUNDS</strong></td>
<td>Sample 1 toluene 3.43</td>
</tr>
<tr>
<td></td>
<td>Sample 1 ethyl benzene 0.78</td>
</tr>
<tr>
<td></td>
<td>Sample 1 xylene 1.43</td>
</tr>
<tr>
<td></td>
<td>Sample 1 trimethyl benzene Nq</td>
</tr>
<tr>
<td></td>
<td>Sample 2 toluene 3.20</td>
</tr>
<tr>
<td></td>
<td>Sample 2 ethyl benzene 0.66</td>
</tr>
<tr>
<td></td>
<td>Sample 2 xylene 1.17</td>
</tr>
<tr>
<td></td>
<td>Sample 2 trimethyl benzene Nq</td>
</tr>
<tr>
<td><strong>FORMALDEHYDE</strong></td>
<td>Sample 1 10.5 ppm/h</td>
</tr>
<tr>
<td></td>
<td>Sample 2 10 ppm/h</td>
</tr>
</tbody>
</table>
10.5 Questionnaire

The questionnaire, specifically designed for this study, was handed out to thirty four of the employees on the sixth floor. The next day the questionnaires were collected and only thirty employees responded. The results were verified and are summarized in Table 10.

**TABLE 10 : SUMMARY OF QUESTIONNAIRE RESULTS**

<table>
<thead>
<tr>
<th></th>
<th>Case Study Building</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>1 TOTAL NO OF RESPONDENTS</td>
<td>30</td>
</tr>
<tr>
<td>2 SEX</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18</td>
</tr>
<tr>
<td>Female</td>
<td>12</td>
</tr>
<tr>
<td>3 AGE</td>
<td></td>
</tr>
<tr>
<td>under 20</td>
<td>2</td>
</tr>
<tr>
<td>21-25</td>
<td>2</td>
</tr>
<tr>
<td>26-30</td>
<td>4</td>
</tr>
<tr>
<td>31-35</td>
<td>6</td>
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<tr>
<td>36-40</td>
<td>12</td>
</tr>
<tr>
<td>41-45</td>
<td>4</td>
</tr>
<tr>
<td>46-50</td>
<td>0</td>
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<tr>
<td>51-55</td>
<td>0</td>
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<tr>
<td>56-60</td>
<td>0</td>
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<tr>
<td>4</td>
<td>RACE</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>DO YOU PARTICIPATE IN SPORT AT LEAST ONCE A WEEK?</td>
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<td></td>
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</tr>
<tr>
<td>6</td>
<td>INDICATE YOUR FLOOR NO.</td>
</tr>
<tr>
<td>7</td>
<td>ARE YOU SHARING A OFFICE?</td>
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<td></td>
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<tr>
<td>8</td>
<td>ARE YOU WORKING IN AN OPEN OFFICE?</td>
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<td></td>
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<tr>
<td>9</td>
<td>FOR HOW MANY YEARS ARE YOU WORKING IN THE SAME BUILDING?</td>
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<tr>
<td>10</td>
<td>FOR HOW MANY YEARS ARE YOU DOING THE SAME WORK IN THE SAME BUILDING?</td>
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<td>13</td>
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<td>14</td>
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<td>15</td>
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<td>16</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LIGHTNING</td>
<td>UNCOMFORTABLE</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------</td>
</tr>
<tr>
<td>HUMIDITY</td>
<td>COMFORTABLE</td>
</tr>
<tr>
<td></td>
<td>UNCOMFORTABLE</td>
</tr>
</tbody>
</table>

17. **DO YOU SUFFER FROM ANY ALLERGIES?**
   - **YES** | 7 | 23 |
   - **NO**  | 23| 77 |

18. **IF KNOWN, PLEASE SPECIFY**
   - **POLLEN** | 4 | 13 |
   - **GRASS**  | 1 | 3  |
   - **HOUSE DUST** | 1 | 3  |

19. **DURING THE PREVIOUS TWO WEEKS WHILE WORKING IN YOUR AREA HAVE YOU EXPERIENCED ANY OF THE FOLLOWING?**
   - **HEADACHE**
     - **YES** | 28 | 93 |
     - **NO**  | 2  | 7  |
   - **BURNING EYES**
     - **YES** | 26 | 87 |
     - **NO**  | 4  | 13 |
   - **SNEEZING**
     - **YES** | 10 | 33 |
     - **NO**  | 20 | 67 |
   - **RUNNY NOSE**
     - **YES** | 24 | 80 |
     - **NO**  | 6  | 20 |
   - **NAUSEA**
     - **YES** | 11 | 37 |
     - **NO**  | 19 | 63 |
   - **DRY COUGH**
     - **YES** | 13 | 43 |
     - **NO**  | 17 | 57 |
   - **CONGESTION**
     - **YES** | 21 | 70 |
     - **NO**  | 9  | 30 |
   - **SINUS**
     - **YES** | 14 | 47 |
     - **NO**  | 16 | 53 |
<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fever</strong></td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>NO</td>
<td>26</td>
<td>87</td>
</tr>
<tr>
<td><strong>Dry nose</strong></td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>NO</td>
<td>27</td>
<td>90</td>
</tr>
<tr>
<td><strong>Sore throat</strong></td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>NO</td>
<td>25</td>
<td>83</td>
</tr>
<tr>
<td><strong>Watering eyes</strong></td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>NO</td>
<td>25</td>
<td>83</td>
</tr>
<tr>
<td><strong>Dry eyes</strong></td>
<td>27</td>
<td>90</td>
</tr>
<tr>
<td>NO</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>20 HAVE YOU EXPERIENCED THE SAME CONDITIONS IN THE MORNING BEFORE WORK?</td>
<td>YES</td>
<td>3</td>
</tr>
<tr>
<td>NO</td>
<td>27</td>
<td>90</td>
</tr>
<tr>
<td>21 DO YOU SMOKE?</td>
<td>YES</td>
<td>3</td>
</tr>
<tr>
<td>NO</td>
<td>27</td>
<td>90</td>
</tr>
<tr>
<td>22 DO YOU PERCEIVE YOURSELF AS OVERWEIGHT?</td>
<td>YES</td>
<td>4</td>
</tr>
<tr>
<td>NO</td>
<td>26</td>
<td>87</td>
</tr>
<tr>
<td>23 DOES ANYONE IN YOUR IMMEDIATE VICINITY SMOKE?</td>
<td>YES</td>
<td>27</td>
</tr>
<tr>
<td>NO</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>24 IS THERE A DESIGNATED SMOKING AREA ON YOUR FLOOR?</td>
<td>YES</td>
<td>30</td>
</tr>
<tr>
<td>NO</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>25 IS THERE A SMOKING POLICY IN YOUR OFFICE?</td>
<td>YES</td>
<td>1</td>
</tr>
<tr>
<td>NO</td>
<td>29</td>
<td>97</td>
</tr>
<tr>
<td>26 IF YES, PLEASE SPECIFY?</td>
<td>TOTAL BAN ON SMOKING</td>
<td>1</td>
</tr>
<tr>
<td>PARTIAL BAN ON SMOKING</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
10.6 Formulation of problem statement

From the above survey, questionnaire and measurements of contaminants the following problems can be identify:

* Inadequate ventilation, resulting in headaches, dry and burning eyes and uncomfortable working conditions.

* Newly installed furniture, cupboards and carpeting, floor covering and wall paint can emit VOC and Formaldehyde which will build up to uncomfortable/acceptable levels.

* Temperature levels in the office and laboratory are uncomfortable due to the following proximity of ballistic computer, sun penetrating offices, lack of enough diffusers and office designs.

By analysing the results of the questionnaire and the interviews with the thirty employees who responded to the questionnaire it is clear that all the respondents experience discomfort with temperature and humidity. Most of the people working in the laboratories complaining about headaches, runny noses and burning eyes. The four people working in the administration office are also complaining about severe headaches and much more of the people are also experiencing runny noses and burning eyes.
10.7 *Recommendations for Case Study*

The following recommendations were made to the caretaker and discussed with the owner of the building;

* Conduct thorough maintenance and cleaning of the entire ventilation system by a competent ventilation engineer.
* Redesign the layout of the offices especially on the sixth floor to ensure that all offices have at least two diffusers.
* Ensure that all the diffusers are open and that the air flow is not blocked.
* Install vertical blinds or curtains to limit the heating of the offices by the sun.
* Relocate the printers, fax machine and photostating machine in the administration office to a separate room or area outside the office.
* Install an additional wall mounted air conditioning system in the ballistic laboratory to compensate for the access heat generated by the Ballistic computer.
* Ensure that the extraction unit is installed at the opposite side of the building away from the ventilation system’s inlet and equipped with a filter.
* Clean all filters on a regular basis.
* Ensure proper ventilation and air movement in the laboratory by leaving the doors open day and night for at least two weeks.
* Provide additional air movement in the laboratory and administration office by putting two or three office fans in the laboratory to increase the rate of
off gassing and to dilute the VOC and formaldehyde concentrations in the air.

* Remember in future to order formaldehyde treated products, or treat the particle wood with heat before installation.

* Keep the door between the forensic laboratory and the office closed at all times by providing a self closing device to the door.

11. **FUTURE RECOMMENDATIONS**

Solving indoor air quality complaints is a very practical issue if one is experienced in the field and knows how to conduct investigations. One should keep investigations straight forward and simple. A fair amount of problems could be solved without the need for sampling with expensive equipment or to appoint consultants to eradicate the problems. Environmental Health Officials and Building Managers could well be trained to investigate and resolve many of these indoor air quality complaints. Tertiary institutions should put more emphasis on indoor air quality in the syllabus for Environmental Health Officers which could in return present similar courses to Building Managers. Indoor environments are on par with outside environments as far as pollution and health are concerned.

Environmental Health Officers can play a major role in providing expert advice when scrutinizing building plans for office lay outs. Building managers or caretakers can attend courses to prevent Indoor Air Quality problems and/or solving their own problems. It is also important to have a budget for proper maintenance to the ventilation system of a building because this is the lifeline in any building.
Environmental Health Officers should educate the public and building managers by presenting courses and giving lectures on how to solve Indoor Air Quality problems in office buildings. The public should also be informed that treated materials are available on the market which can reduce the levels of VOC’s and formaldehyde levels in office environments considerably.

Since the mid nineties human beings are becoming more and more concerned about the environment and their health. People also know that in terms of the new South African Constitution they have the right to a clean and healthy environment, being indoors and outdoors.

It will be to developers advantage to build *green buildings* in future, because it will be much more cost effective to correctly design buildings which address the allege indoor air quality complaints than to rectify possible problem areas at a later stage. Building managers responsibility should be to rectify possible sources before complaints are being received.

Indoor air quality in South Africa is a very neglected subject and with the low productivity figures it should be addresses as one of the priority issues. The Environmental Health profession has the knowledge to enrich building managers, interior designers, cabinet makers, mechanical ventilation engineers/technicians, architects and developers with the necessary information and advice. There should be intersectorial collaboration amongst these professions to enable them to achieve a collective goal to ensure a clean and healthy indoor or office environment for people to work.
Environmental Health Officers should empower themselves with the knowledge to do inspections or investigations in office buildings by means of a walk through survey and identify possible indoor air quality sources. These routine inspections or evaluations of office environments should be a responsibility similar to food handling premises evaluations done by the environmental health officer whereby building managers are requested to rectify identified problem areas. Although environmental health officers employed by local authorities could not do consultation on these identified problems, one could always assist in suggestions and presenting workshops to the relevant professions involved.

The step-by-step method employed in this case study provided a more systematic approach at solving IAQ problems at the building of interest.

Invaluable information is obtained by investigating all aspects of air quality in a sealed building. Recommendations made can then address the causes directly and preventative measures can be employed.

12. CONCLUSION

The following conclusions can be derived from this study:

* Pollutant contaminants are present in old and new buildings. The characteristics of these contaminants was shown to vary significantly. New buildings contained higher concentrations of the more volatile organic compounds while respirable particulate matter in the older buildings are more prominent.
* Poor Indoor Air Quality regarding temperature and humidity levels can also result from poorly designed and out of date ventilation systems.

* To combat Indoor Air Quality problems do not necessarily require an investment of expensive high technology equipment, but might merely require a practical approach, for instance by lowering temperature by installing blinds to shield the penetrating sun.

* Off-gassing from newly purchased furniture and decorative material was evident from the results obtained in new buildings. A practical solution to this problem and to prevent similar situations in future will be to purchase formaldehyde treated materials.

* Well-designed questionnaires can indicate problem areas prior to conducting measurements. In addition it can also focus to the measurements required to solve Indoor Air Quality problems.

* From this study the most prominent SBS symptoms encountered were headaches. Several indoor air pollutants can cause this symptom.

* A minor change in the working environment, such as painting of the office or purchasing new furniture, can have a major effect on the Sick Building Syndrome symptoms experienced by office occupants.

* As discovered from this study, most of the indoor air quality pollutants are present in office environments to a more or lesser extent. Some office workers are more susceptible than others to the medical reactions cause to human beings by these pollutants.

* Poor IAQ can result in personnel being dissatisfied in the working environment resulting in lower productivity.

* By addressing these indoor air quality problems productivity can increase with
lasting effects on a company’s bottom line.
13. **REFERENCE**


21. Feeley, J.C., Gibson, R.J., Gorman, G.W., Langford, N.C., Rasleed, J.K., Mackel, D.C.


The filling in of this exercise will only take minutes of your valuable time. It would be appreciated if you could assist in completing this anonymous questionnaire as accurately as possible. This information will be used in a research project regarding indoor air quality.

Most of the questions can only be answered by making a tick next to the appropriate answer.

eg. : Do you smoke?

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2√</td>
<td></td>
</tr>
</tbody>
</table>

Thank you

................................................

F. JANSE VAN RENSBURG

PROJECT LEADER
I  PERSONAL INFORMATION

1  SEX
   MALE  FEMALE
   1     2

2  AGE
   UNDER 20  20-25  26-30  31-35  36-40  41-45  46-50  51-55  56-60  OVER 60
   1     2     3     4     5     6     7     8     9     10

3  RACE
   AFICAN  EUROPEAN  ASIAN  OTHERS
   1     2     3     4

IF OTHERS PLEASE SPECIFY............................................

4  DO YOU PARTICIPATE IN SPORT AT LEAST ONCE A WEEK?
   YES  NO
   1     2

II  WORKING RELATED

5  INDICATE YOUR FLOOR NO.

6  ARE YOU SHARING A OFFICE?
   YES  NO
   1     2
9 FOR HOW MANY YEARS ARE YOU DOING THE SAME WORK IN THE SAME BUILDING?

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<th>11-15</th>
<th>16-20</th>
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<td>4</td>
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10 DO YOU WORK ON A COMPUTER?

<table>
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11 HOW MANY HOURS ARE YOU WORKING ON A COMPUTER PER DAY?

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<th>2-3</th>
<th>3-4</th>
<th>4-5</th>
<th>5-6</th>
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<td>4</td>
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<td>7</td>
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12 DO YOU WORK ON A COMPUTER AT HOME?

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<th>NO</th>
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<tr>
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13 IN YOUR OPINION HOW STRESSFUL IS YOUR JOB?

<table>
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<tr>
<th>VERY STRESSFUL</th>
<th>MORE THAN AVERAGE STRESS</th>
<th>LESS THAN AVERAGE STRESS</th>
<th>NOT STRESSFUL AT ALL</th>
</tr>
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III  MEDICAL HISTORY

16  DURING THE PREVIOUS TWO WEEKS WHILE WORKING IN YOUR AREA HAVE YOU EXPERIENCED ANY OF THE FOLLOWING?

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<tr>
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</tr>
<tr>
<td>H</td>
<td>SINUS</td>
<td>1</td>
</tr>
<tr>
<td>I</td>
<td>FEVER</td>
<td>1</td>
</tr>
<tr>
<td>J</td>
<td>DRY NOSE</td>
<td>1</td>
</tr>
<tr>
<td>K</td>
<td>SORE THROAT</td>
<td>1</td>
</tr>
<tr>
<td>L</td>
<td>WATERING EYES</td>
<td>1</td>
</tr>
<tr>
<td>M</td>
<td>DRY EYES</td>
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</table>

17 HAVE YOU EXPERIENCED THE SAME CONDITIONS IN THE MORNING BEFORE WORK?

<table>
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<th></th>
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18 DO YOU SUFFER FROM ANY ALLERGIES?

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<th></th>
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19 IF KNOWN, PLEASE SPECIFY

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<tr>
<th></th>
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<th>GRASS</th>
<th>HOUSE DUST</th>
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20 DO YOU SMOKE?

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<tr>
<th></th>
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<th>NO</th>
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<tbody>
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21 DO YOU PERCEIVE YOURSELF AS OVERWEIGHT?

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
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<td></td>
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22 DOES ANYONE IN YOUR IMMEDIATE VICINITY SMOKE?

<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
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<td></td>
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OR OFFICE USE ONLY
23. IS THERE A DESIGNATED SMOKING AREA ON YOUR FLOOR?
   - YES
   - NO
   - 1
   - 2

24. IS THERE A SMOKING POLICY IN YOUR OFFICE?
   - YES
   - NO
   - 1
   - 2

25. IF YES, PLEASE SPECIFY?
   - TOTAL BAN ON SMOKING
   - 1
   - PARTIAL BAN ON SMOKING
   - 2
   - SMOKING ONLY IN SMOKING ROOMS
   - 3
### SUMMARY OF QUESTIONNAIRE RESULTS

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<th>Municipal Building</th>
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<td>Male</td>
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<td>AGE</td>
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<td>OTHERS</td>
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<td>DO YOU PARTICIPATE IN SPORT AT LEAST</td>
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<td>Question</td>
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<td>No</td>
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<td>-----------------------------------------------</td>
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<tr>
<td>Once a week?</td>
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<td></td>
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<td>Indicate your floor no.</td>
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<tr>
<td>Are you sharing an office?</td>
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<tr>
<td>Are you working in an open office?</td>
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<td></td>
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<tr>
<td>For how many years are you working in the same building?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For how many years are you doing the same work in the same building?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you work on a computer?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How many hours are you working on a computer per day?</td>
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<td></td>
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297
<table>
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<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
<th>Very Satisfied</th>
<th>Satisfied</th>
<th>Dissatisfied</th>
<th>Very Dissatisfied</th>
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<td></td>
<td>7</td>
<td>41</td>
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<td>56</td>
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<td>6</td>
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<td>More than average stress</td>
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<td>Not stressful at all</td>
<td>2</td>
<td>12</td>
<td>2</td>
<td>2</td>
<td>22</td>
<td></td>
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<tr>
<td>To what extent are you satisfied with your job?</td>
<td></td>
<td></td>
<td>1</td>
<td>6</td>
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<td>22</td>
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<tr>
<td>Very satisfied</td>
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<td>53</td>
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<td>How do you experience the following?</td>
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<tr>
<td>Ventilation</td>
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</tr>
<tr>
<td>Comfortable</td>
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<td>71</td>
<td>7</td>
<td>7</td>
<td>77</td>
<td></td>
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<tr>
<td>Uncomfortable</td>
<td>5</td>
<td>29</td>
<td>2</td>
<td>2</td>
<td>22</td>
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<tr>
<td>Artificial lightning</td>
<td></td>
<td></td>
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<td>88</td>
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<td>1</td>
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<tr>
<td>Do you suffer from any allergies?</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>DURING THE PREVIOUS TWO WEEKS WHILE WORKING IN YOUR AREA HAVE YOU EXPERIENCED ANY OF THE FOLLOWING?</td>
<td></td>
<td></td>
<td></td>
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<td>GRASS</td>
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<td>11</td>
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<td>5</td>
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<td>71</td>
<td>7</td>
<td>77</td>
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<tr>
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METHODS FOR MEASURING THE AMOUNT OF OUTSIDE AIR 
REACHING OCCUPIED SPACES

Whether or not an HVAC system is operating as intended can be determined by measuring how much outside air is reaching the occupied spaces. This can be done two ways; by directly measuring the outside air volume at the intake and at the supply diffusers or by estimating the amount of outside air using air temperature measurements.

Using the first method, the amount of outside air entering the system at the intake louvers and the total ventilation air (fresh + recirculated) are measured using an anemometer. To do this, divide the intake air opening into approximately six or nine equally distributed measuring points and calculate the average air velocity. Next, measure the dimensions of the air intake opening and use the following equation to determine the volumetric flow rate (Q) in cubic feet per minute (cfm) at the intake:

\[ Q = VA \]

Where

\[ Q = \text{volumetric flow rate (cubic meter air per minute or cfm)} \]
\[ V = \text{average air velocity (meter per minute or m/min)} \]
\[ A = \text{area of the intake opening (m}^2\text{)} \]

The units of measurement should be kept constant. Because outside air is usually mixed with return
(“used”) air, the amount of return air that is being recirculated must also be determined. This can be measured where a return/recirculation air louver enters the outside air intake stream. If that louver is inaccessible, try to measure the total volume of the main supply duct, either before or after the fan. Then calculate the volume of outside air as a percentage of the total air stream (outside + recirculated).

Next, the amount of air being delivered to a particular work area or work space should be measured at the supply diffusers. To do this, measure the flow rate at about six or nine points across the face of the diffuser, or use an anemometer that integrates (if one is available). The measurements need not be completely accurate for this purposes; however, be aware that the intake volume may change as fan speeds change or as VAV controls automatically open and close in response to heating and cooling demands. Multiply the air supplied at the diffusers by the percent of outside air (previously determined to be in the air stream) in order to determine the amount of outside air being supplied to a given work area.

Another way to estimate the percent outside air in the total ventilation air stream is to use a thermal mass balance equation:

\[
\text{Outside air required (%) } = \frac{T_{\text{return air}} - T_{\text{mixed air}}}{T_{\text{return air}} - T_{\text{outdoor air}}} \times 100
\]

where \(T\) = temperature in degrees Celsius. Once the percentage of outside air is known, the rest of the process for determining how much is delivered to occupants is the same.

For offices, 20 changes of fresh air per minute (cfm) of outside air per person has been recommended by ASHRAE (ASHRAE Standard 62-1989). Some systems, especially in large buildings or those employing VAV systems that adjust airflow in response to heating and cooling needs, are more difficult
to assess. VAV’s restrict and govern airflow near the supply diffusers and may shut air off entirely for brief periods. VAV louvers should have minimum settings to avoid complete shutoff of air. A ventilation or maintenance engineer should be able to describe how the system works and should be able to gauge the appropriateness of the measurements.