AN INVESTIGATION INTO TOTAL VOLATILE ORGANIC COMPOUND EXPOSURE LEVELS IN HOMES AND CLASSROOMS OF ASTHMATIC CHILDREN IN SELECTED SITES IN DURBAN

By

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ABSTRACT

INTRODUCTION

Indoor air quality has become an important health concern due to the number of indoor pollutants and the realization that even minimal exposures to volatile organic compounds may produce direct or indirect adverse health outcomes. Young people are most vulnerable to these poisonous chemicals as they spend much of their times indoors at homes, schools, nurseries and in day care centers. Exposure to volatile organic compounds indoors has been related to asthma and other respiratory symptoms.

The adverse effects of air pollution on respiratory health in South Durban have been described in a number of studies. In 2000, a study in the South Durban Basin at Settlers Primary School demonstrated both a high prevalence of respiratory diseases amongst schoolchildren as well as an association between ambient air pollutants and other adverse health outcomes. The South Durban Health Study subsequently undertook a health risk assessment and an epidemiological study investigating this association further on behalf of the eThekwini Municipality. The study highlighted that relatively moderate ambient concentration of NO_2, NO, PM_{10} and SO_2 were strongly and significantly associated with a reduction in lung function among children with persistent asthma. Moreover, attending primary school in South Durban was significantly associated with increased risk from persistent asthma when compared to schools in North Durban.

METHODS

The descriptive study measured the total volatile organic compound levels within selected homes and schools of asthmatic children in South and North Durban. Recommendations for reducing or mitigating indoor total volatile organic compound exposures were made.

The study involved a secondary analysis of data obtained from the South Durban Health Study. The monitoring for total volatile organic compounds within homes and classrooms was undertaken using passive samplers during a 72-hour period and analyzed using a gas-chromatography/mass spectrometry method. Temperature and humidity was assessed using temperature and humidity sensors. Statistical analysis was performed using SPSS version 13. The dataset comprised 140 total volatile organic compound samples from homes and 14 from

classrooms. Total volatile organic compounds were measured in microgram per cubic meter ($\mu g/m^3$), temperature in degrees Celsius and relative humidity in percentage of moisture.

RESULTS

Total volatile organic compounds with levels in households ranging from 17$\mu g/m^3$ to 1440$\mu g/m^3$ and in classrooms ranging from 48$\mu g/m^3$ to 5292$\mu g/m^3$ were measured. The mean levels detected were significantly different in homes and classrooms [$p<0.01$]. The TVOC levels in the North ranged from 17$\mu g/m^3$ to 1357$\mu g/m^3$ and the South from 75$\mu g/m^3$ to 1440$\mu g/ m^3$. No significant difference in household total volatile organic compound level was noted between these areas [$p<0.325$]. TVOC levels in schools showed no significant difference between the North and South [$p<0.278$], but the North had more measures above recommended maximum level of 500$\mu g/m^3$. The sites with higher than recommended maximum TVOC levels for household and school exposure were from KwaMashu and Lamontville whilst the Bluff and Newlands West sites mostly recorded levels less than 500$\mu g/m^3$. A poor correlation was observed both between indoor temperature [0.110] and indoor humidity [0.183] and total volatile organic compound level.

RECOMMENDATIONS

Several proactive steps can be taken to improve and maintain good indoor air quality in homes and classrooms. Key interventions include education and awareness, development of policies and guidelines, building design, and rigorous indoor monitoring as a primary means of reducing morbidity in children with asthma.

DECLARATION

I, SANTOSH KUMAR MAHARAJ, declare that this is my own work. It is being submitted as part of the requirements for the Degree of Master of Public Health, at the Nelson R Mandela School of Medicine, University of KwaZulu-Natal, Durban, South Africa. This work has not been submitted previously to this or any other University.

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ACRONYMS

TVOC	Total Volatile Organic Compound
VOC	Volatile Organic Compound

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1 CHAPTER: INTRODUCTION

1.1 BACKGROUND INFORMATION

Air polluting industries in South Durban, are situated in close proximity to working class residential communities due to historically poor town planning associated with the previous apartheid settlement policies. The effect of air pollution on respiratory health outcomes at relatively low levels of exposure in South Durban has been reported in a number of studies. Robins *et al.* demonstrated both high prevalence of respiratory diseases in the South Durban-Basin amongst schoolchildren at Settlers Primary School in Merebank as well as an association between ambient air pollutants and other adverts health outcomes. The study reported an unusually high prevalence of asthma symptoms (54%) in, 133 schoolchildren and moderate to severe persistent asthma in 17% (42) schoolchildren. [1]

Other local studies have been conducted that examine the relationship between exposure to air pollutants and adverse health outcomes relationship, as well as the level of environmental pollutants in South Africa. In Cape Town schoolchildren, aged 7-8 years reported a relatively high prevalence of wheeze (27% as reported by 528 parents) and 11% with diagnosed asthma.[2] In a community-based study in South Durban, Nriagu *et al.* documented a 10% prevalence of doctor-diagnosed asthma in children and 12% amongst adults.[3] A study in Cato Crest, Durban reported that sensitive individuals were exposed to nitrogen dioxide and benzene.[4] The South Durban Health Study demonstrated strong evidence that attending primary school in South Durban, as compared to North Durban, was significantly associated with increased risk for persistent asthma and marked airway hyperreactivity. The study also showed the average indoor TVOC exposure level of 341µg/m³ to be higher than the outdoor TVOC exposure level of 100µg/m³, indicating a greater exposure due to indoor sources. In summary, the study highlighted that relatively moderate ambient concentration of NO_2, NO, PM_{10} and SO_2 were strongly and significantly associated with a reduction in lung function among children with persistent asthma.[5] Many of the studies focused on monitoring of ambient air pollutants including particulate matter, sulphur di-oxide and other common pollutants with little or no emphasis on indoor air quality and its impact on health. Accordingly, this study investigated indoor TVOCs exposure levels in homes and classrooms of selected asthmatic children in selected sites within Durban. Recommendations for the reduction or mitigation of indoor TVOCs are proposed. It is hypothesised that TVOC levels within homes and classrooms in South Durban was higher than North Durban.

Recently, indoor air quality has become a major focus of interest due to the number of pollutants found indoors as well as the realization that minimal exposure may produce direct or indirect adverse health outcomes, including asthma. Many inorganic and organic compounds including VOCs have being given particular notoriety due to their potential harmful effects on human health.[6] Considerable research has been undertaken investigating air quality in occupational and outdoor environment settings compared to indoor environments, such as homes, schools, nurseries and day care centres. Indoor settings are likely to be extremely important to the health and wellbeing of individuals. Poor indoor air quality may lead to an increased incidence of health related symptoms, which in turn can lead to absenteeism and loss of productivity. Keeping the school environment healthy and clean is a key to developing and maintaining a productive learning space where children can reach their full academic potential. Poor indoor air quality undermines the most engaging curriculum and the best effort of educators and staff.[7]

Asthma is a chronic obstructive lung disease caused by inflammation and increased reaction of the airways to various triggers. Symptoms include wheezing, coughing, chest tightness and shortness of breath. Both indoor environment and poor indoor air quality play a key role in the development and / or exacerbation of this disease. The number of cases of asthma in school-aged children in the United States of America has increased dramatically over the past 30 years. Nearly one in 13 school-aged children suffers from asthma, the leading cause of school absenteeism, accounting for 10 million missed school days each year. Indoor exposure to VOCs has been related to asthma and asthma symptoms, including nocturnal breathlessness, increased bronchial responsiveness and decreased lung function.[8] The prevalence of asthma in Australia is among the highest in the world, affecting between 14% and 16% of children.[9] VOCs are widely used as ingredients in building material, furnishing, and household products such as paint, varnishes, floor coverings, household cleaners, pesticides, photocopier chemicals, computers and printers.[10] These items are widely used within the home and school environment.

The study is important as it focuses on another likely source of indoor air pollutant namely, total volatile organic compounds. In addition, it investigates TVOC levels within homes and classroom, which has not received adequate investigation previously. The study should provide a stimulus towards changing perceptions that ambient air pollution is an important

cause of adverse health outcomes. Indoor TVOC levels constitute a concern for increased risk of asthma or the exacerbation of the disease as well. The outcome of the study will create awareness of the impact that indoor TVOC levels have on asthma. Interventions could be implemented in minimizing or mitigating TVOC exposure, thereby reducing hospital visits, school or work absenteeism and improving the quality of life for susceptible individuals.

This study builds on previous studies on indoor air quality and is important because everyone in our modern world is likely to have some exposure to total volatile organic compounds, and people have different individual susceptibility to adverse health outcomes within the population.

1.2 STATEMENT OF THE RESEARCH PROBLEM

1.2.1 Research Problem

Evidence continues to emerge indicating that indoor TVOCs exposure can trigger or exacerbate adverse health outcomes. Indoor TVOCs levels have been insufficiently quantified. There is a lack of understanding and awareness of indoor air pollutants, and how to reduce or mitigate indoor TVOC exposure in order to minimize the risk to health.

1.2.2 Research Hypothesis

The TVOC exposure levels within homes and classrooms of selected asthmatic children in South Durban were higher than North Durban.

1.3 AIM OF THE RESEARCH

The aim of the research was to measure total volatile organic compound levels in homes and classrooms of selected asthmatic children in North and South Durban during May 2004 and February 2005 and to recommend measures for the reduction and mitigation of indoor TVOC in order to improve indoor air quality.

1.4 OBJECTIVES OF THE STUDY

The specific objectives of this study were:

- To measure the TVOC level within selected homes and classrooms located in South Durban and North Durban.
- To compare the TVOC level within homes and classrooms of the study area.
- To investigate any association between indoor TVOC levels and the measured variables such as indoor temperature and humidity.
- To propose recommendations for the reduction or mitigation of TVOC levels within homes and classrooms.

1.5 ASSUMPTIONS UNDERLYING THE STUDY

- The data set obtained from the South Durban Health Study is reliable and valid.
- The selected learners reside and attend school within the same selected sites.
- The TVOC ($\mu g/m^3$) level, indoor temperature and humidity of the selected classroom are representative of the school within the selected site.

1.6 OPERATIONAL DEFINITIONS

The following definitions are solely used for this study:

- **Volatile Organic Compounds (VOCs)**

Organic compounds with a boiling point between 50°C - 260°C. These chemicals contain carbon and can evaporate into the air at room temperature.[34]

- **Total Volatile Organic Compounds (TVOCs)**

The sum of all VOCs measured in an air sample and expressed as microgram per cubic meter of air ($\mu g/m^3$).[34]

- **Indoor Air Quality**

Refers to the nature of the conditioned (hot / cold) air that circulates throughout the space / area where one works and lives, that is air we breath during most of our lives.[34]

- **Asthma**

A chronic obstructive lung disease caused by inflammation and increased reaction of the airways to various triggers. Symptoms can include wheezing, coughing, chest tightness and shortness of breath.[23]

- **Relative Humidity**

The measure of moisture in the atmosphere, expressed as a percentage of the maximum moisture the air can hold at a given temperature.[34]

- **Sites**

This refers to the geographic location of the study population that includes the following: Merebank, Lamontville, Austerville, Bluff, Newlands East, Newlands West and KwaMashu. [5]

- **Area**

This refers to the broader geographic location incorporating the sites of the study population. The areas are North Durban and South Durban. [5]

1.7 SCOPE OF STUDY

The study focuses on indoor total volatile organic compounds only and does not investigate individual VOCs. It describes indoor TVOC levels within homes and classrooms of selected asthmatics within South Durban and North Durban and relies on the data set obtained from the South Durban Health Study.

1.8 ORGANISATION OF THE REPORT

Chapter 1 contextualizes indoor air quality with special reference to TVOCs and asthma and includes the research problem and objectives. Chapter 2 incorporates the literature review. . Chapter 3 describes the research methods. Chapter 4 and 5 incorporates the result and subsequent discussion and Chapter 6 covers the conclusion. Chapter 7 concludes the report by providing recommendations.

1.9 SUMMARY

People spend the majority of their time indoors, mostly in homes, much of the attention to date relates to outdoor air pollution and its health effects. This descriptive study focuses on indoor total volatile organic compounds within homes and classrooms of selected asthmatic children within selected sites in Durban. The results of this epidemiological study should provide a description of the indoor TVOC levels in homes and classrooms and propose recommendations to reduce or mitigate indoor TVOC levels and exposure of people who occupied the spaces.

2 CHAPTER: LITERATURE REVIEW

INTRODUCTION

Concern has arisen, in recent years, about indoor air pollution as a risk factor for asthma. A number of studies examining domestic exposure of indoor TVOCs on adverse health outcomes have been conducted. Chapter 2 highlights the status of knowledge on indoor air pollution, as well as a critical analysis of the literature. The current study also builds and leverages on these studies.

2.1 INDOOR AIR QUALITY

Indoor air quality refers to the nature of the conditioned air that circulates throughout the space or area where one works or lives and is air that we breathe during most of our lives.[11] Indoor air pollution is responsible for 2.7% of the global burden of disease.[12] The United States Environmental Protection Agency studies on human exposure to air pollutants indicate the levels of indoor air pollutants to be 2 – 100 times higher than outdoor levels. For those children who suffer from asthma and spend a significant amount of time indoors these risk factors are magnified.[13] Most people spend up to 90% of their time indoors.[14]

The effect of air pollution on adverse respiratory health outcomes at relatively low levels of exposure in South Durban has been well established in numerous studies. Studies conducted by Robins *et al.* at Settlers Primary School in Merebank, located in South Durban industrial base and the site of the South Durban Health Study has demonstrated both a high prevalence of respiratory diseases in schoolchildren as well as an association between outdoor air pollutants and adverse health outcomes.[1, 5]

Simultaneous indoor and outdoor air monitoring of selected homes in Korea have shown that indoor levels of certain air pollutants were significantly higher than outdoor levels.[15] However, the sampling period in this report was of short duration. Long-term sampling which is more reflective and suitable to assess average air pollutant concentrations and the resultant chronic health effects is more suitable.

Evidence continues to emerge that poor indoor air quality causes illness resulting in absence from school as well as contributing to acute health symptoms that decrease performance at school. [10] In addition, the quality of indoor air can impede or assist a school in meeting its core mission namely that of educating children. Failure to prevent or quickly resolve problems can increase the potential for long and short-term health problems such as asthma, increase absenteeism of student and reduce productivity of teachers and staff. [10]

2.2 ASTHMA

Asthma is a chronic obstructive lung disease caused by inflammation and increased reaction of the airways to various triggers. Symptoms can include wheezing, coughing, chest tightness and shortness of breath. Asthma can be a life-threatening disease if not managed properly. Indoor environment and poor indoor air quality appear to play a key role in the development or exacerbation of this disease.[16] Indoor exposure to TVOCs has been related to asthma and asthmatic symptoms such as nocturnal breathlessness, increased bronchial responsiveness and decreased lung function. [8] Ware reported an association between ambient concentration of VOCs and asthma in children aged 7 – 13 years of age. [6] Two other experimental studies have shown that VOCs may affect the airways and induce inflammation[17] and airway obstruction. [18].

The number of cases of asthma in school-aged children has increased dramatically over the past 30 years. [8] Asthma related illness forms one of the leading causes of school absenteeism, accounting for more than 14 million missed school days per year.[19] In the United States, 9.1 million children under 18 years (12%) have been diagnosed with asthma. In 2002, 9.1 million asthma-related visits to hospitals were recorded at an estimated cost of $14 billion.[20]
The prevalence of asthma in Australia is among the highest in the world. Diagnosed asthma occurs in 14% – 16% of children and 10% - 12% of adults. Asthma is one of the most common problems managed by doctors and is a frequent reason for hospitalization of children. [9] The rising prevalence has coincided with modification to home environment including the introduction of soft furniture, fitted carpets, air conditioning and central heating.[21] Allergens and irritants such as environmental tobacco smoke, dust mites, household dust, moulds, pets, NO_2, cockroaches, fragrances, paint and fumes are known to trigger asthma. [20]

2.3 VOLATILE ORGANIC COMPOUNDS (VOCs)

"Volatile" is a term meaning that chemicals evaporate easily at room temperature and, hence, can pollute indoor air. "Organic" is a term meaning that these chemicals contain carbon.[22] The term volatile organic compounds (VOCs) encompasses a very large and diverse group of carbon containing compounds including aldehydes, ethers, esters, acid, alcohols and ketones. Examples of VOCs include formaldehyde, benzene, toluene and chlorofluorocarbons.[23]

The sum of all VOCs measured in an air sample is referred to as TVOCs. The TVOC concentration is expressed in micrograms per cubic meter of air ($\mu g/m^3$). TVOC levels in buildings are a good indicator of whether or not there are elevated levels of chemicals indoors. Most buildings will have TVOC levels ranging from $100\mu g/m^3$ - $500\mu g/m^3$. Most standards or guidelines consider TVOC levels between $200\mu g/m^3$ - $500\mu g/m^3$ as an acceptable level in buildings. [13]

VOCs are emitted by a wide array of products including paints, lacquers, cleaning supplies, pesticide, building materials, furnishing, office equipment such as copiers and printers, correction fluids, carbonless copy papers, graphics, craft materials, glues, adhesives, permanent markers and photographic solutions. [13] Synthetic polymers used in furnishing and decorative materials undergo slow degradation releasing small quantities of VOCs. Draperies, rugs and fabrics most of which are synthetic are sources of a variety of VOCs. [13] Some specific indoor sources of VOC are highlighted in Table 1.[24]

Table 1: Indoor Sources of Specific Volatile Organic Compounds. [24]

VOCs	Sources
Formaldehyde	**Environmental Tobacco Smoke, fabrics, household cleaners and chipboard.**
Benzene	**Environmental Tobacco Smoke**
Styrene	**Textile, disinfectants, plastics and paints**
Tetrachloroethylene	**Dry-cleaned clothes**
Aromatic hydrocarbons (Toluene, Xylene, etc.)	**Paints, adhesives and combustion products**
Terpenes	**Deodorisers, polishes, fabric softeners & Environmental Tobacco Smoke**
Ketones	**Lacquers, varnishes and polish removers**
Esters	**Dyes, soaps and cosmetics**

The United States Environmental Protection Agency Total Exposure Assessment Methodology (Team) studies uncovered levels of approximately a dozen common organic pollutants to be 2-5 times higher in homes than outside regardless of whether these were located in rural or highly industrial areas. [13] Studies undertaken by the Building Research Establishment in the United Kingdom identified TVOCs with a mean concentration of 415µg/m³ in bedrooms and 406µg/m³ in living rooms (Table 2) and levels indoors were tenfold higher than outdoors.[25]

Table 2: Mean Annual Concentration (µg/m³) of Total Volatile Organic Compounds in UK homes in 1996 [25]

Compounds	(n)	Mean	SD	Min	Max
TVOC:					
Bedroom	173	415	323	40	2051
Living room	173	406	314	51	1799
Benzene:					
Bedroom	173	8	4	2	32
Living room	173	8	6	2	46
Toluene:					
Bedroom	173	40	86	8	1044
Living room	173	47	124	10	1583
Formaldehyde:					
Bedroom	174	25	20	1	4
Living room	174	23	13	4	76

2.4 HEALTH EFFECTS

Children face a greater environmental health risk than adults. Their immune systems are still developing because of their lower body weight and they breathe a relatively greater volume of air as compared to adults. This results in a higher body burden of air pollutants than that of adults for the same exposure concentration of pollutants.[26] Health effects of VOCs on the skin and mucosal tissue (eye, nose and throat) are mostly irritating effects including dry sore throat, tingling sensation of the nose and watery painful eyes. Some VOCs such as acetone, benzene, toluene and formaldehyde are known to manifest themselves in the central nervous system. Besides being an odour nuisance, VOCs at sub threshold levels may cause non-specific health effects such as eye and upper respiratory airway irritation, headaches and weariness.[27]

As with other pollutants, the extent and nature of the health effects will depend on many factors, including the level of exposure and length of time exposed. At present, little is known in relation to what health effects occur from the levels of organics usually found in homes. [13]

Only 2% of the 60 000 chemicals that are widely used have been comprehensively studied for toxic effects and have rarely been studied as combined exposure which exist in the real world. The minimum exposure levels necessary for a specific toxic effect is rarely known and the minimum toxic dose for the general population grossly overestimates the dose that could affect sensitive individuals.[28] Although no regulated levels of TVOCs exist, there are guidelines or recommendations for an acceptable level arising from numerous health researchers and governmental programmes. Results are usually compared against the following guidelines as illustrated in Table 3.[29]

Table 3: Indoor Total Volatile Organic Compound Levels (mg/m³) and Related Health Effects [29]

Indoor TVOC (mg/m³)	Health Effects
< 0.20 mg/m³	**No irritation or discomfort**
0.2 mg/m³ - 3.0 mg/m³	**Irritation and discomfort possible**
3.0 mg/m³ - 25.0 mg/m³	**Discomfort expected and headache possible**
> 25 mg/m³	**Toxic range where other neurotoxic effects may occur**

The interpretation of VOCs measurement for indoor environments and its potential effects on health and comfort of the occupants, in general, is a difficult task. Of the hundreds of VOCs identified indoors, only limited toxicological information is available. In addition, only a few air quality guidelines for indoor concentration for VOCs exist. There is also a large difference in terms of sensitivities such as age, health outcomes, exposure levels and exposure periods with which individuals react to VOCs.

2.5 EPIDEMIOLOGICAL STUDIES

A study by Rumchev *et al.* entitled "Association of domestic exposure to volatile organic compounds with asthma in young children" supports the hypothesis that indoor environmental factors, especially VOCs, increase the risk of asthma. They studied 88 homes of toddler's that had been diagnosed with asthma and compared them with 104 toddler's homes without asthma. TVOC concentrations, as well as the concentration of 10 individual VOCs including benzene, toluene and xylene, were measured. Potential confounding variables *inter alia* age, sex, allergy, dust mites, socio economic status, smoking indoors, seasons, air conditioning and

gas appliance were controlled. The study revealed that children exposed to concentrations of TVOCs $\geq$ 60 $\mu g/m^3$ (median level) possessed a fourfold increased risk of having asthma. Children exposed to a single compound, such as benzene at levels of $\geq$ 20 $\mu g/m^3$ (median level of exposure), exhibited an eightfold increased risk of asthma although TVOC levels were lower than currently accepted guidelines. This case control study highlighted an interesting association. However, the results could possibly be biased due to misclassification of asthma, validity of diagnosis (young age), and recall or observational bias (different interpretation of question by parents) (Table 4).[30] The study clearly highlights that although TVOC levels may be lower than the acceptable guidelines the risk is also exacerbated at lower level.

Table 4: Concentration of Total Volatile Organic Compounds ($\mu g/m^3$) for Cases and Controls in Homes in 2004 [30]

Cases (n=88) Percentile				Control (n=104) Percentile			
25^{th}	75^{th}	90^{th}	Median	25^{th}	75^{th}	90^{th}	Median
45	125	204	78 (range: 10–622)	19	69	101	36 (range: 2.5-198)

A study conducted by Dales *et al.* entitled "Residential exposure to volatile organic compounds and asthma" critically analysed literature concerning exposure to VOC and asthma. The study concluded that observational studies have consistently found a relationship between VOCs and signs of asthma.[31] Pappas *et al.* in their study entitled, "The respiratory effects of volatile organic compounds," conducted a randomized, crossover design trial. Subjects were exposed to filtered air for four hours, VOCs at 25$\mu g/m^3$ for four hours and VOCs at 50$\mu g/m^3$ for four hours using a VOC mixture based sampling. The authors concluded that reducing levels of VOC to less than 25 $\mu g/m^3$ is required if a "non-irritating" work environment is desired.[32] Norback *et al.* in a study entitled "Asthmatic symptoms and volatile organic compounds, formaldehyde and carbon dioxide in dwellings" concluded that there were significant relationship between nocturnal breathlessness and the presence of VOCs existed, and that indoor VOCs and formaldehyde may cause asthma like symptoms [$p < 0.03$].[8]

The largest study of VOCs in homes in the United Kingdom was the Building Research Establishment indoor environment study. It discovered painting activity strongly influenced the mean VOC concentration. Formaldehyde was higher in new homes and benzene was

higher in homes of smokers.[33] The evidence cited above suggests an association between indoor TVOC exposure and various adverse respiratory health effects including exacerbation of asthma, increased respiratory symptoms, wheezing and coughing. Most studies to date have been conducted on single chemicals or based on literature reviews. Less is known as regards the health effects of synergistic chemical exposure, as is the case in residential and classroom settings.

2.6 STANDARDS AND GUIDELINES

An air quality standard constitutes a description of a level of air quality that is adopted by a regulatory authority and is enforceable. At its simplest, an air quality standard should be defined in terms of one or more concentrations and averaging times.[34] Guidelines are formulated with the objective of protecting human health including susceptible sub-groups. Legally, they are unenforceable.

Domestic indoor VOCs levels are not regulated. However, a national organization such as the National Health and Medical Research Council in Australia recommend an advisory goal in order to protect public health. It recommends a maximum level of 500μg/m³ for indoor TVOCs and 250μg/m³ for any individual VOC (one hour average).[35] These guidelines were established in 1993 and, with the emergence of new products and VOCs, there is a need to review these guidelines based on scientific justification. However, these guidelines were used as an indicator to determine the level of exposure in this study. The World Health Organisation provides guidelines for indoor and outdoor air threshold values of TVOCs. For example, the threshold value for formaldehyde to be a health issue is 100μg/m³ for 30 minutes. Some authors have proposed TVOC exposure level guidelines of 300μg/m³ - 500μg/m³.[36]

There is a need to develop and approve local TVOC standards or guidelines to assist individual and local enforcement agencies in making consistent judgments about the need for remedial measures. Indoor environmental conditions such as temperature, humidity, ventilation rates and building standards may differ from local, national and international settings, which may influence the development of guidelines. It is anticipated that guidelines will be used as a basis for developing and modifying building codes, product standards for construction materials and furnishing and ventilation requirements. Guidelines may be more

appropriate for residential and classroom settings as the objective is protecting health. Standards may be difficult to enforce or to ensure compliance in indoor settings.

2.7 MONITORING AND ANALYSIS OF VOCS

Comparing of VOC exposure levels between studies may prove difficult as different sampling techniques and method of analysis are used. According to Wolkof, the use of passive sampling may underestimate the exposure levels of VOCs.[37] For example, in monitoring benzene levels in dwellings in Germany using passive sampling, the median concentration of benzene was 7.8μg/m³ lower than the levels of 15μg/m³ - 16μg/m³ found in US dwellings using active sampling.[38]

A compendium of methods is available for the determination of toxic organic compounds in ambient air. However, most of the current methods used are published in an approved United States Environment Protection Agency publication. The methods include:

- Compendium method T0- 17: Determination of VOC in ambient air using active sampling in sorbent tubes.[39]
- Compendium method T0-14: Determination of VOC in ambient air using specially prepared canister with subsequent analysis by gas chromatography.[40]

The method used for monitoring and analysis of indoor TVOC in the South Durban Health Study was a passive (diffuser) sampling method. It is a well established technique. Diffuse samplers are small and convenient tubes or badges. The diffuser samplers provide a measure of the mean concentration over periods of days or weeks in building under normal condition of occupation. They do not provide information on changes in concentration that may occur around the mean value. After sampling the tubes were analyzed by thermal desorption / gas chromatography with detection by flame ionization and mass spectrometry.

2.8 INFLUENCE OF INDOOR ENVIRONMENTAL PARAMETERS

In existing, occupied residential units, seasonal trends in VOC concentration have been observed in a cross-sectional study in three German cities and in a longitudinal study of ten apartments.[41] The seasonal variations, with generally lower concentrations in summer months, might be due primarily to seasonally varying air change rates. The occupant's behavior is a likely determinant of house ventilation since the opening of doors and windows

has a dominant effect on house air change rates.[42] Concentration of VOCs generated indoors may be presumed to decrease proportionally in response to increase in house ventilation.[43] In addition to ventilation, indoor temperature and humidity conditions, which can change both diurnally and seasonally, have the potential to substantially affect the emission of VOCs from building material and alter occupant's exposure. In a large scale chamber experiment with a new carpet system, vinyl sheet flooring and wall paint, the air temperature was increased from 23°C to about 30°C over a period of 60 hours. Concentration and emission of target VOCs quickly increased with increasing temperature.[44]

The influence of indoor temperature and relative humidity on the emission and concentration of formaldehyde has been studied and modeled in chamber experiments.[45] Modeling data for these studies indicated that changing the indoor temperature and humidity from 20°C and 30% to 26°C and 60% results in a two to four fold increase in formaldehyde concentration at the same air change rate.[46] Temperature and humidity represents two important indicators of indoor air quality in buildings. They are also extremely important to the occupant's perception of indoor air quality. Achieving thermal comfort for all the occupants remains a difficult task, if not impossible. Added to this is the challenge of achieving this without VOC concentration fluctuating. The American Society of Heating, Refrigeration and Air Conditioning Engineers have published acceptable temperature and humidity range for thermal comfort as indicated in Table 5.[47]

Table 5: Acceptable Temperature and Humidity Range for Thermal Comfort Indoors. [47]

Measurement Type	Winter	Summer
Dry Bulb at 30% Relative Humidity	**20.3°C – 24.4°C**	**23.3°C – 26.6°C**
Dry Bulb at 50% Relative Humidity	**20.3°C – 23.6°C**	**22.7°C – 26.1°C**
Wet Bulb max	**17.7°C**	**20°C**

2.9 STEPS TO REDUCE TVOCS EXPOSURE

Although there is presently no cure for asthma, it can be controlled through medical treatment and management of environmental triggers. Educating the public about asthma, how the environment can affect asthma patients and how to manage environmental asthma triggers is important. Rumchev, in his study, recommended parents keep homes well ventilated and

choose products with low VOC content. [30] More rigid use of product labeling, careful selection of building products, furnishing and fittings are of major importance in reducing indoor air pollutants to the lowest possible levels. [28] Ventilation rates in most schools are below the recommended level, both in the United States and Europe.[48] In a study in California, one third of the schools recorded ventilation rates that were less than half the recommended levels.[49]

Several proactive steps can be taken to improve and maintain good indoor air quality in school. A strong indoor air quality management plan is essential. The school indoor air quality best management practice manual prepared by the Washington State Department of Health provides a comprehensive guide to practicing good indoor air quality in schools.[50] Some of the key components include:

- Facility Planning: Establishing procedures and guidelines for building operations and maintenance. It should incorporate cleaning and maintenance procedures, the use of low emitting products, furnishing and construction material.
- Monitoring Pollutants: Periodic monitoring should be undertaken. The use of air quality school test kits is recommended.
- Good Communication Plan: This allows prompt and accurate indoor air quality information to be exchanged to all stakeholders. The plan should address dissemination of education information and releasing and discussing information on indoor air quality events.

Thus, low ventilation rates and the growing evidence that poor indoor air quality has on health and human performance, suggest a clear opportunity for improving indoor air quality through management of environmental triggers.

2.10 FOLLOW ON FROM THE LITERATURE REVIEW

From the literature review it is evident that this study consolidates aspects of previous studies with a view to providing a more detailed picture of indoor TVOCs exposure level and the health risks to asthmatics. Previous studies have focused on one particular indoor setting whereas this study incorporates home and classroom exposures. Indoor environmental parameters, such as indoor temperature and humidity, which influence TVOC exposure level, are also considered. There nevertheless exists a distinct lack of emphasis on intervention strategies in previous studies. This study proposes to improve on this aspect.

2.11 STRENGTHS AND WEAKNESSES OF OTHER STUDIES

- Previous studies have contextualized TVOC and its impact on health, in particular, asthma. This is clearly illustrated in the Building Research's Indoor Environmental Study [25] and the South Durban Health Study. [5]
- Indoor environmental parameters such as temperature, humidity and ventilation have not received adequate attention during indoor TVOC monitoring. The Rumchev Study [30], Hodgson Study [43] and South Durban Health Study [5] have monitored these in comparison to a simulated laboratory experiment by Matthews *et al.* [45]
- A number of studies have assessed a few individual VOCs and collectively classed them as TVOC, in particular studies by Rumchev *et al.* [30], Norback *et al.* [8] and Maria *et al.*[51].
- The cornerstone of many studies is to provide interventional strategies to reduce exposure or improve health outcomes. The Norback Study, [8] Rumchev Study [30] and South Durban Health Study [5] have largely achieved this.
- The results and conclusion of some studies, including studies by Dales *et al.* [31] and Papas *et al.*, [32] are based on laboratory extrapolation of indoor VOC levels, as opposed to actual field monitoring. These may not be a true reflection of indoor settings.
-

2.12 SUMMARY

Scientific evidence exists on indoor total volatile organic compounds and its impact on health outcomes such as asthma. There is a need for health professionals to understand the health effect of TVOC and how and what factors affect indoor TVOC emissions and what can be done to mitigate or reduce indoor TVOC emissions in order to improve health.

3 CHAPTER: RESEARCH METHODS

3.1 INTRODUCTION

The study was a descriptive study, designed to obtain a snapshot of levels of TVOCs within homes and classrooms of selected asthmatic children in North Durban and South Durban. It was based on a larger study titled the South Durban Health Study, which focused on environmental pollution and health outcomes in Durban. The study involved a secondary analysis of data on indoor TVOC levels obtained from the monitoring programme of the South Durban Health Study.

3.2 TYPE OF RESEARCH

The research constituted an epidemiological study.

3.3 STUDY DESIGN

An observational descriptive study design was used.

3.4 ETHICS

Ethical approval for this study was granted by the University of KwaZulu-Natal Biomedical Research Ethics Committee (Ref H072/06) [Annexure 4]. In addition permission was obtained from the Centre for Occupational and Environmental Health of the University of KwaZulu-Natal for the utilization of the indoor TVOC level data set for this particular study [Annexure 4].

3.5 RESEARCH POPULATION

3.5.1 Selection of communities, schools and schoolchildren [5]

In order to characterize exposure and health outcome, a broad geographical coverage of the South Durban Basin was necessary allowing for a better understanding of socio-economic and racial / ethnic factors. The following residential areas were selected in South Durban: (a) Merebank, (b) Wentworth / Austerville, (c) Bluff, and (d) Lamontville. Comparative communities in North Durban included (a) Newlands East, (b) Newlands West, and (c) KwaMashu. The comparative study population in North Durban was selected because of their

close proximity to each other (enabling the use of a single monitoring site to estimate ambient air pollutant levels for all three communities). These communities share a similar socio-economic profile to the study communities in South Durban that were considered to be exposed to a lower level of ambient air pollution.

The location of the monitoring sites was determined by the Air Quality Management System of the eThekwini Metropolitan Council and was a critical factor in deciding the selection of the study schools. In addition, to ensure that the study sample was representative of the immediate geographic location of the monitoring station, only schools at which the bussing in of schoolchildren from surrounding communities was a minimal (<15%), were selected. Meteorological factors and location of nearby industries were also considered in school selection. Among those schools meeting the specified criteria, one school was chosen at random in each of the seven participating communities. In the comparison area in North Durban only one monitoring station was available to characterize exposure in all the communities. Accordingly the monitoring station was located at one school in one of the communities, with the other two schools located as close as possible.

Four (4) schools were randomly selected using a sampling frame from the selected sites in South Durban. The selected schools were Nizam Primary (Merebank), Assegai Primary (Austerville), Dirkie Uys Primary (Bluff) and Etuthukweni Primary (Lamontville). Three schools were randomly selected from North Durban. These were Briardale Primary (Newlands West), Ferndale Primary (Newlands East) and Ngazana Primary (KwaMashu).

At any given school, the sampling strategy for pupil recruitment was to:

- Randomly select two grade 4 classes as classroom 1 and classroom 2.
- All schoolchildren in grade 4 and grade 5 in the school completed a screening questionnaire. Herein were included questions related to known asthma, frequency of symptoms and details of household adult membership.
- The prevalence of known or probable persistent asthma among the two selected grade 4 classrooms was reviewed based on the screening questionnaire.
- in instances where at least 20 cases of persistent asthma in the two combined classrooms prevailed, then all the schoolchildren in those selected classrooms formed the study sample until the target number of 65 – 70 children per school was reached, or

- where the target of 20 persistent asthmatics was not reached, then all schoolchildren in the previously randomly selected classroom 1 were selected with children with persistent asthma being added from among all the remaining grades 4 and 5 classrooms.

The choice of the two grades (4 and 5) was driven by the following considerations:

- the expectation that learners in grades lower than grade 4 would find difficulty in completing the bi-hourly diaries and correctly performing peak flow maneuvers;
- the likelihood that the overall prevalence of asthma would be somewhat higher among schoolchildren in lower grades; and
- preference for learners who would still be at school in the 2004 school year in the event of any follow-up studies.

The purpose of guaranteeing the inclusion of an adequate number of schoolchildren with known or probable persistent asthma was to ensure ample statistical power to address whether such schoolchildren were at any particular increased risk for any measurable adverse health effects of exposure to ambient air pollution. In the event of such selective sampling being required, only the schoolchildren in classroom 1 were included when estimating prevalence of asthma, as the schoolchildren still represented a random, population-based sample. The purpose of including schoolchildren with asthma was that it formed part of the larger study i.e. South Durban Health Study, and to determine whether such schoolchildren were at any particular risk for any measurable adverse health risk from exposure to TVOCs. Without a control group of non-asthmatic children there is no way of demonstrating an association between TVOC exposure and asthma is possible. In addition, in selecting asthmatics one cannot generalize on the greater population.

3.5.2 Sample Size

The total number of schoolchildren recruited for this study was 140. The 140 homes selected represented those belonging to the asthmatic children who were recruited for the South Durban Health Study. Twenty TVOCs were sampled in households of each of the seven sites, whilst two samples for TVOCs were taken in each school. The study involved secondary analysis of primary data comprising of 140 TVOCs sample results in homes and 14 TVOCs sample results in classrooms. This constituted a valid subset.

3.6 DATA SOURCES

3.6.1 Measurement Instruments

The researcher of this study did not participate in the sampling of indoor VOCs. However, field observation was undertaken in the company of field staff involved in the South Durban Health Study. TVOC measurements were made using a passive (diffuser) sampling method [Annexure 1] to monitor indoor VOCs within homes and classrooms. The method utilized a tenax sorbent tube, which, was exposed to indoor air, and the compound of interest (TVOCs) was absorbed during the sampling period. Indoor VOC monitoring was conducted during the periods of May 2004 and February 2005. All samples were collected over 3 days (72 hours) between Monday and Friday. Sampling for indoor VOC were taken from the selected grade 4 asthmatic schoolchildren living-room or bedrooms in homes and from their classrooms. Indoor temperature and humidity were simultaneously monitored using HOBO temperature and humidity sensors over a 24 hour period in homes and 7 hour period during the day in classrooms. The difference in the time used for monitoring temperature and humidity did not make any difference to the TVOC exposure levels.

All TVOC samples were sealed, stored at room temperature and shipped to the laboratory for analysis. Dates, times and additional information about sampling were recorded in a field data sheet [Annexure 2]. The tenax tubes were then sent to the University of Michigan for analysis. All samples were analysed using gas chromatography/mass spectrometry method for the identification and quantification of the absorbed TVOCs.

3.6.2 Variables

The numerical (quantitative) variables analysed were TVOC in microgram per cubic meter ($\mu g/m^3$), temperature in degrees Celsius (°C) and relative humidity in percentage of moisture (%) for homes and classrooms. Categorical (qualitative) variables included the area (North and South), sites (1-7), schools (1-7) and classrooms (1-2) as per the data collection sheet [Annexure 3]. The exposure (independent) variables were the sites, temperature and humidity in South Durban and North Durban and the outcome (dependent) variable was TVOC.

3.6.3 Reliability of Measurement Instrument

A detailed quality assurance plan was developed as part of the larger South Durban Health Study. The overall objective of the quality assurance was to ensure that methods and procedures used in measurement were adequate to meet the objectives. The data obtained needed to be valid, defendable and to quantify the precision, accuracy, representativity, completeness and comparability of the collected data.

The components of the quality assurance plan included 1) personnel training and supervision, 2) standard operating procedures for the internal assessments, sampling, sampling control, analytical methods, instrument maintenance and calibration, data handling and record keeping, 3) quality assurance, 4) facility adequacy, 5) corrective action, 6) laboratory safety, 7) specification of detection and quantification limits, 8) calibration procedures, 9) quality control (audits), and 10) maintaining log books for all personnel.

3.6.4 Measures to Reduce Bias

Selection bias was controlled in the South Durban Health Study by application of a random sampling strategy. Information bias including measurement bias and fieldwork bias were reduced by the quality assurance plan. Information bias was further reduced by ensuring that all data was double entered into the database. The two sets of data were compared for discrepancies and inaccuracies corrected.

3.6.5 Pilot Study

The study involved a secondary of the data. The researcher had no control over the primary data collection.

3.6.6 Data Collection

All indoor TVOC monitoring within homes and schools was undertaken during the period of May 2004 to February 2005. Indoor temperature and humidity was also undertaken simultaneously. Indoor VOC was measured over a period of 72 hours whilst indoor temperature and humidity was measured over 24 hours for households and 7 hours for classrooms. All data obtained from the South Durban Health Study was entered into a data collection sheet [Annexure 3]. The data was entered and analysed using SPSS version 13. Household and classroom data was entered onto the same data file and linked to a unique

index case (asthmatic child). All data was entered, as in Annexure 3. All data was double entered to detect any errors in the data capture programme. Where discrepancies were noted reference was made to the source document i.e. data capture sheets. The correct data was then selected and the final data sheet was amended.

3.6.7 Statistical Analysis

SPSS, version 13 statistical computer software programme was used for data entry and analysis (SPSS Inc, Chicago, III, USA). The key outcome (dependent) variable was indoor TVOCs and the exposure (independent) variable were the area, sites, temperature and humidity in North Durban and South Durban. The data comprised quantitative and categorical variables. The quantitative variables included TVOC, temperature and humidity and the categorical variables included area and sites. The standard reference level for indoor TVOC level of the Australian National Health and Medical Research Council was used [35] It recommends a maximum TVOC exposure level of 500µg/m³. Exposure were considered low if TVOC levels were <500µg/m³, and high where TVOC levels were ≥500µg/m³.

Univariate Analysis included analysing descriptive statistics such as the mean, maximum, minimum, quartiles, median and range for all variables. Quantitative variables were tested for normality and those that were normally distributed were subject to analysis using parametric tests. Quantitative variables were checked for normality using skewness statistics and standard error. If the skewness statistic was more than twice the standard error, skewness was confirmed. Where results were positively, skewed non-parametric tests were used to analyze the data as these tests provide an alternate set of statistical techniques for analyzing numerical data that makes no assumption about the underlying distribution of the normality of the data.

Bivariate Analysis was performed to determine statistical significance for measures of association. In order to:

- Compare TVOC between area and sites for household and classroom, independent t-test for the area North and South was used and ANOVA was used for comparing the sites within each area.
- Assess whether levels differed between sites and area, the chi-squared (x^2) test was conducted.

- Compare the means of TVOC exposure levels (quantitative) in homes and classrooms between the areas [North and South], the independent t- test was conducted and for the sites, ANOVA was employed.

Data that was not normally distributed was subjected to non-parametric tests. The Kruskal-Wallis test was used to test for significant differences between sites for household TVOC exposure. Where a significant difference was detected, the Dunn's Multiple Comparison test was post hoc performed using Graph Pad Instat version 3.05 (2000) to determine where the significance lay. The Mann-Whitney test was utilized to test for significant association between TVOC exposure and the selected areas. The Pearson's chi-square test was employed to compare the proportion of sites and areas in terms of exposure and under-exposure. The Chi-square test was undertaken to assess whether there was an association between under-exposure and over-exposure between the sites and area. A p value<0.05 was considered as statistically significant.

Multivariate Analysis: The data collected for this particular study included TVOC, temperature and humidity. Data relative to important covariates (potential confounders) in particular environmental tobacco smoke, use of biomass fuel and ventilation were not available. Accordingly, this study did not consider multivariate analysis.

3.7 SUMMARY

The epidemiological study investigated the level of indoor TVOC in homes and classrooms of selected asthmatic children in sites in Durban by a secondary analysis of existing data obtained from a larger study known as the South Durban Health Study. The obtained data was analyzed to evaluate TVOC levels.

4 CHAPTER: RESULTS

4.1 HOUSEHOLD TVOC EXPOSURE LEVEL

4.1.1 HOUSEHOLD TVOC EXPOSURE LEVEL FOR THE SELECTED AREAS

TVOC levels were measured in a total of 87 households of which 48 were from South Durban and 39 from North Durban (Table 6). Data on TVOC levels were missing from 53 households, due to failure or malfunction of the sampling equipment. The median household TVOC level in the South was 180µg/m³ with a range from 35µg/m³ to 1440µg/m³. The North had a median household TVOC level of 185µg/m³ with a range from 17µg/m³ - 1357µg/m³.

Austerville homes had the lowest average TVOC level (35µg/m³) in the South and the site with the highest average TVOC level was Merebank (1440µg/m³). In comparison, the site in the North with the lowest average household TVOC level was Newlands West (17µg/m³) and houses in Newlands East recorded the highest average household TVOC level (1357µg/m³).

A low number of household TVOC levels were recorded for the Bluff (n=2), Lamontville (n=8) and KwaMashu (n=7) in comparison with Merebank (n=19), Austerville (n=19), Newlands West (n=20) and Newlands East (n=12).

Table 6: Descriptive Data for Household Total Volatile Organic Compound Exposure Levels for North and South Durban, 2005

Area	(n)	Median	Percentile %		Min	Max
		(µg/m³)	25%	75%	(µg/m³)	(µg/m³)
South	**48**	**180**	**86**	**428**	**35**	**1440**
North	**39**	**185**	**71**	**456**	**17**	**1357**

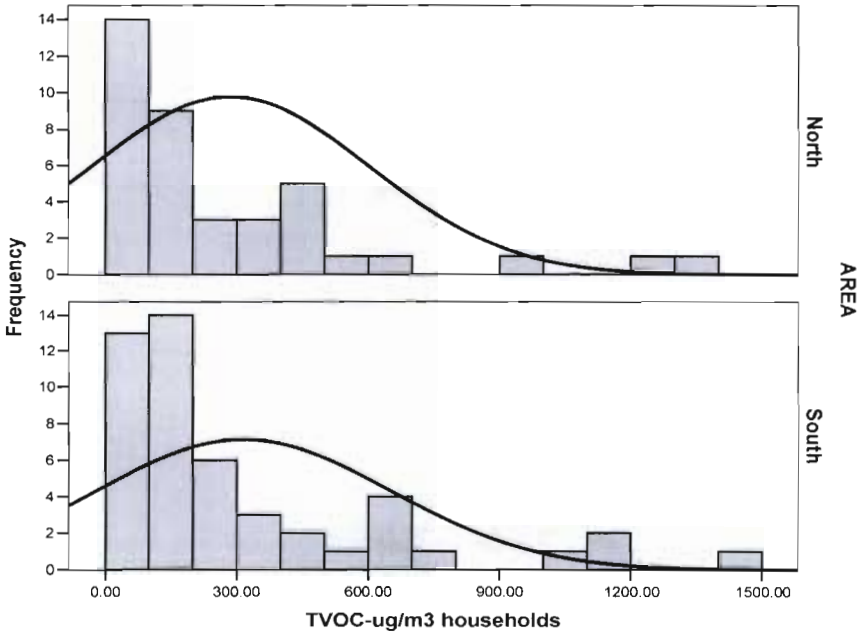

Figure 1: Frequency Distribution of Household Total Volatile Organic Compound-µg/m³ for Sites in North and South Durban, 2005

The household levels of TVOC reveal highly skewed distribution both in the North and South (Figure 1), although the median TVOC level was very similar. Three households in the North had outlying TVOC levels. These were recorded in Newlands East (1357µg/m³), and in KwaMashu (1228µg/m³ and 955µg/m³). The outliers recorded from 4 households in the South where in Merebank (1440µg/m³), Lamontville (1034µg/m³) and Austerville (1171µg/m³ and 1194µg/m³).

The Mann-Whitney Test was undertaken to test for significant association between TVOC levels and the selected areas [p<0.468]. More households [n= 10; 20.8%] in the South had TVOC levels greater than 500µg/m³ compared with the North [n= 5; 12.8%]. A Chi-square test showed that the difference was not statistically significant [p<0.325].

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4.1.2 Household TVOC Level for the Various Sites

The median TVOC levels for sites in the North ranged from 82µg/m³ to 471µg/m³ and for sites in the South it ranged from 108µg/m³ to 280µg/m³ (Table 7). Newlands West recorded the lowest median for all sites whilst KwaMashu recorded the highest median for all sites. The lowest TVOC level in the North occurred at Newlands West, followed by Newlands East

and KwaMashu. Austerville recorded the lowest TVOC level in the South, followed by Merebank, Lamontville and Bluff. Newlands West recorded the lowest minimum TVOC exposure level whilst KwaMashu had the highest minimum TVOC level for all sites.

The site with the highest median TVOC level (471µg/m³) in the North was KwaMashu followed by Newlands East and Newlands West. Newlands West in the North was the site with the lowest household TVOC level. In the South the lowest recorded maximum TVOC level was Bluff (125µg/m³) followed by Lamontville (1034µg/m³), Austerville and Merebank (1440µg/m³).

Overall, the site with the lowest maximum TVOC level was Bluff whilst the site with the highest maximum TVOC level was Merebank. The median ranged from 82µg/m³ - 471µg/m³ and minimum TVOC level ranged from 17µg/m³ - 188µg/m³ for all sites.

A Kruskal-Wallis Test was performed to test for significant differences between sites for household TVOC exposure levels. In addition the Dunns Multiple Comparison Test was also performed post hoc to the Kruskal-Wallis Test to determine where the significant differences lay in terms of site exposures. For the sites Newlands West vs. Newlands East [p value < 0.05] and Newlands West vs. KwaMashu [p value<0.01]. No other sites were significantly different. A significant difference between the sites Newlands West vs. Newlands East and Newlands West vs. KwaMashu was noted.

Table 7: Household Total Volatile Organic Compound Exposure Level for the Selected Sites in Durban, 2005

Area and Site	TVOC Samples monitored (n)	TVOC Samples analyzed (n)	Median (µg/m³)	Range (µg/m³)
Area: North				
▪ Newlands West	20	20	82	17 – 492
▪ Newlands East	20	12	364	63 – 1357
▪ KwaMashu	20	7	471	188 - 1228
Totals	60	39	185	17 - 1357
Area : South				
▪ Merebank	20	19	155	53 - 1440
▪ Lamontville	20	8	280	84 - 1034
▪ Austerville	20	19	216	35 - 1993
▪ Bluff	20	19	108	92 - 125
Totals	80	48	180	35 - 1440

The proportion of homes where the TVOC level was greater than the recommended maximum level was calculated (Figure 2). Ninety percent of households in Merebank were exposed to TVOC levels below 500µg/m³. In Lamontville 75% of TVOC levels were below the reference level, whilst Austerville recorded 68% below the reference value for TVOC. The Bluff and Newlands West recorded no TVOC exceedance greater than 500µg/m³ level. Households in Newlands East had 82% below TVOC reference level and KwaMashu had a 57%. Merebank, Lamontville, Bluff, Newlands West and Newlands East all had 70% below the TVOC standard allowable maximum of 500µg/m³. Households in Lamontville, Austerville and KwaMashu recorded the most TVOC levels above 500µg/m³.

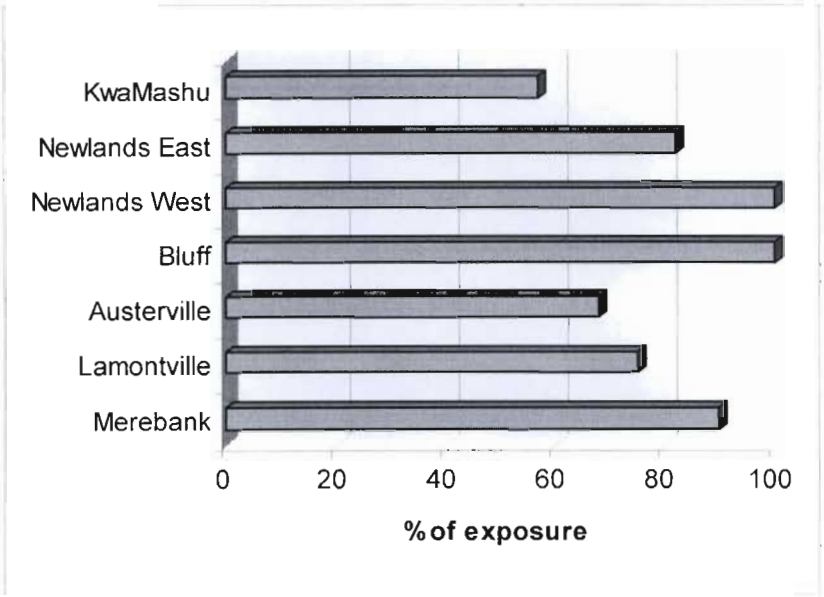

Figure 2: Percentage Total Volatile Organic Compound Level within Selected Sites below the Standard Allowable Maximum in Durban for 2005

4.2 SCHOOL TVOC LEVELS

The mean value of TVOC for the two classrooms was used to represent school TVOC levels for each site.

4.2.1 School TVOC exposure level per site

The school with the lowest mean TVOC (μg/m³) level was Briardale Primary followed by Nizam Primary, Dirkie Uys Primary, Assegai Primary, Ferndale Primary, Etuthukweni Primary and Ngazana Primary (Table 8). The mean TVOC level in schools ranged from 48μg/m³ to 5292μg/m³. School TVOC exposure levels were low (<500μg/m³) at Nizam Primary, Assegai Primary, Dirkie Uys Primary, Briardale Primary and Ferndale Primary with a range from 48μg/m³ to 336μg/m³. Etuthukweni Primary and Ngazana Primary recorded TVOC levels of 888μg/m³ and 5292μg/m³ respectively.

Table 8: School Total Volatile Organic Compound Levels per Site for South and North Durban in 2005

Site	School	Classroom 1	Classroom 2	Mean (x) µg/m³	School TVOC level *≥500 µg/m³*
Merebank	Nizam Primary	101	109	105	No
Lamontville	Etuthukweni Primary	888	F	888	Yes
Austerville	Assegai Primary	247	F	247	No
Bluff	Dirkie Uys Primary	221	140	180	No
Newlands West	Briardale Primary	48	F	48	No
Newlands East	Ferndale Primary	336	F	336	No
KwaMashu	Ngazana Primary	6170	4414	5292	Yes

4.2.2. School TVOC exposure level per area.

Two out of 7 schools had TVOC levels below the standard allowable maximum of 500µg/m³, one school in each of the areas.

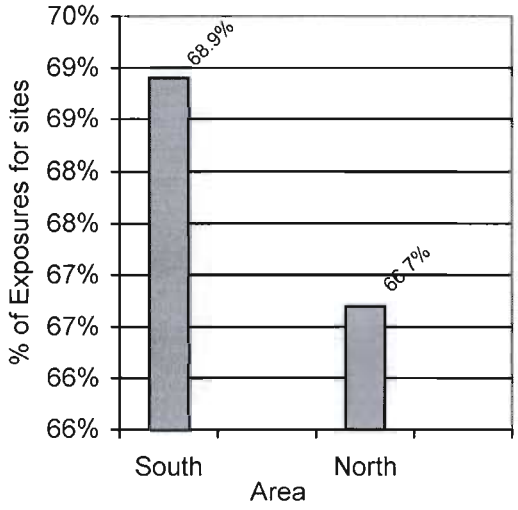

Figure 3: School Total Volatile Organic Compound Exposure Level for Selected Areas in Durban for 2005

4.3 HOUSEHOLD AND SCHOOL TVOC EXPOSURE LEVEL

Table 9 below illustrates household and school TVOC exposure for the selected sites. The Bluff and Newlands West recorded TVOC levels below the standard allowable maximum of 500µg/m³ for household and school exposure. Merebank, Newlands East and Austerville were subjected to household TVOC above the standard allowable maximum of 500µg/m³. Lamontville and KwaMashu recorded exposure in excess of the standard allowable maximum 500µg/m³ for household and school TVOC level.

Table 9: School and Household Total Volatile Organic Compound Exposure Levels for the Selected Sites for Durban in 2005

Site	Households (n)	Households <500µg/m³ (n)	Household <500µg/m (%)	Classrooms (n)	Classrooms <500µg/m³ (n)	Classroom <500µg/m (%)
Merebank	19	17	90	2	0	100
Lamontville	8	6	75	1	0	0
Austerville	19	13	68	1	1	100
Bluff	2	2	100	2	2	100
Newlands West	20	20	100	1	1	100
Newlands East	12	10	82	1	1	100
KwaMashu	7	4	57	2	0	0

The Pearson Chi-squared test was performed to determine if the selected areas were any worse off in terms of household and school TVOC exposure level [$p<0.278$]. The results indicate no significant difference between South Durban and North Durban.

4.4 TEMPERATURE AND HUMIDITY ON TVOC EXPOSURE LEVEL

4.4.1. Indoor temperature

Indoor temperature (mean and median) for classrooms was substantially higher than households.

Table 10: Descriptive Data of Indoor Temperature for Households and Classrooms in Durban for 2005

Temperature	Mean	Median	Min (°C)	Max (°C)
Household	22	22	18	26
Classroom	25	26	22	28

The relationship between household TVOC exposure level and household temperature was plotted as a scattergram (Figure 4). There was no observed double relationship between household temperature and household TVOC exposure level. .

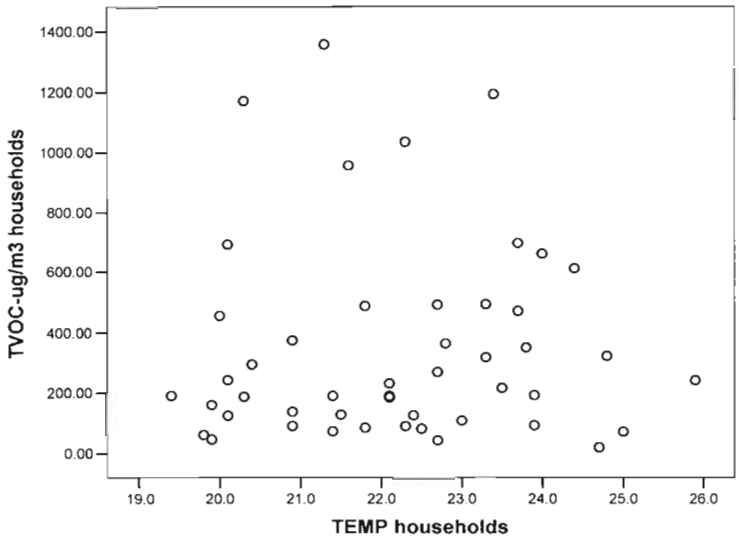

Figure 4: Median Household Total Volatile Organic Compound (μg/m³) Level and Household Temperature Over 24 Hours in Durban for 2005

The scatter plot shows no relationship between average classroom temperature and average classroom TVOC level (Figure 5). The outlier represents Ngazana Primary in KwaMashu, which had a high average classroom TVOC exposure level and a relative low average classroom temperature.

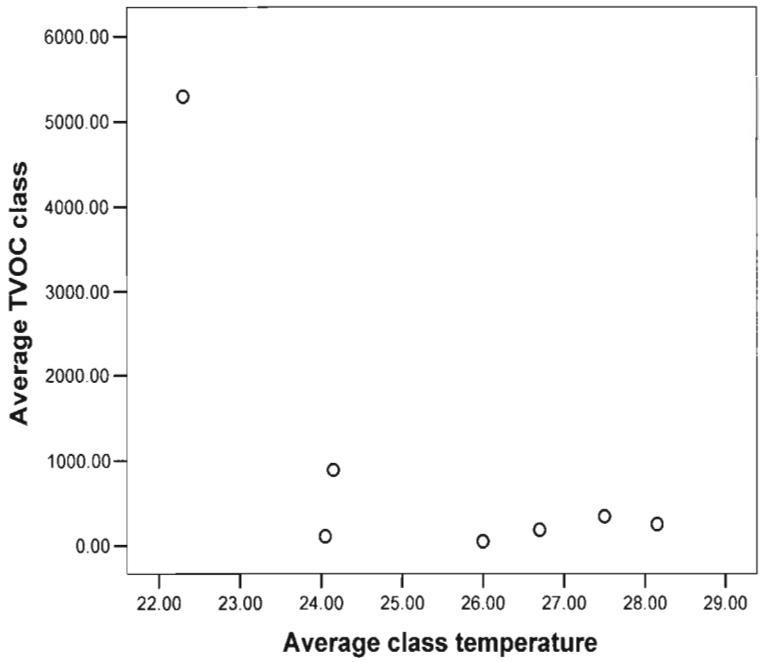

Figure 5: Average Classroom Total Volatile Organic Compound (μg/m³) Levels and Average Classroom Temperature for 7 Hours in Durban for 2005

4.4.2 Indoor Humidity (%)

The mean indoor humidity for households was 60% and for classroom was 62% (Table 11). The minimum recorded humidity for households was 36% and for classrooms 48%. The maximum humidity for households was 81% and for classroom 91%. Household humidity ranged from 36% to 81% in comparison to classrooms that ranged from 48% to 91%.

Table 11: Indoor Humidity for Households and Schools in Durban for 2005

Humidity	Mean (%)	Median (%)	Min	Max
Household (24 Hours)	**60**	**60**	**36**	**81**
Classroom (7 Hours)	**62**	**60**	**48**	**91**

No observable relationship exists between household TVOC level and household humidity (Figure 6).

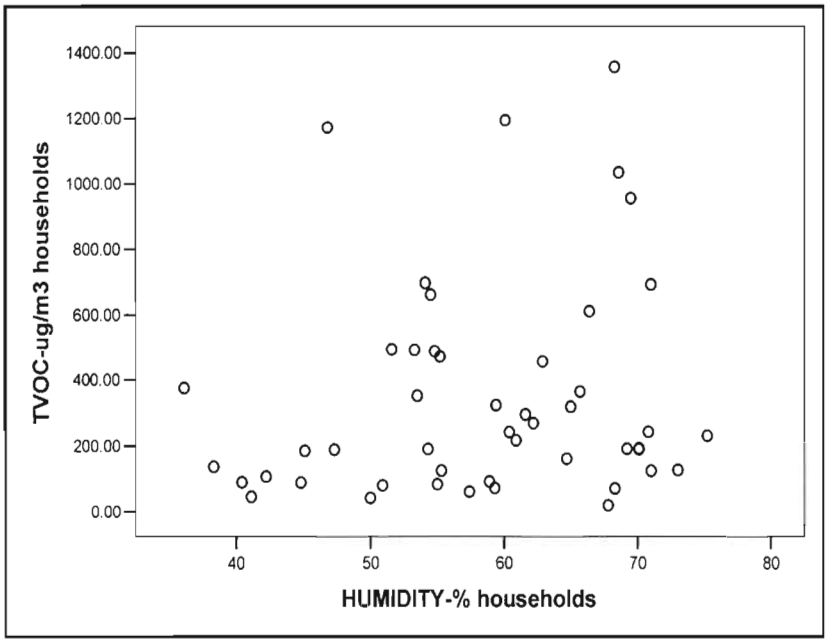

Figure 6: Relationship between Household Total Volatile Organic Compound Levels and Household Humidity in Durban for 2005

There is no observable relationship between classroom humidity levels and TVOC levels (Figure 7). The outlier represents Ngazana Primary School in KwaMashu.

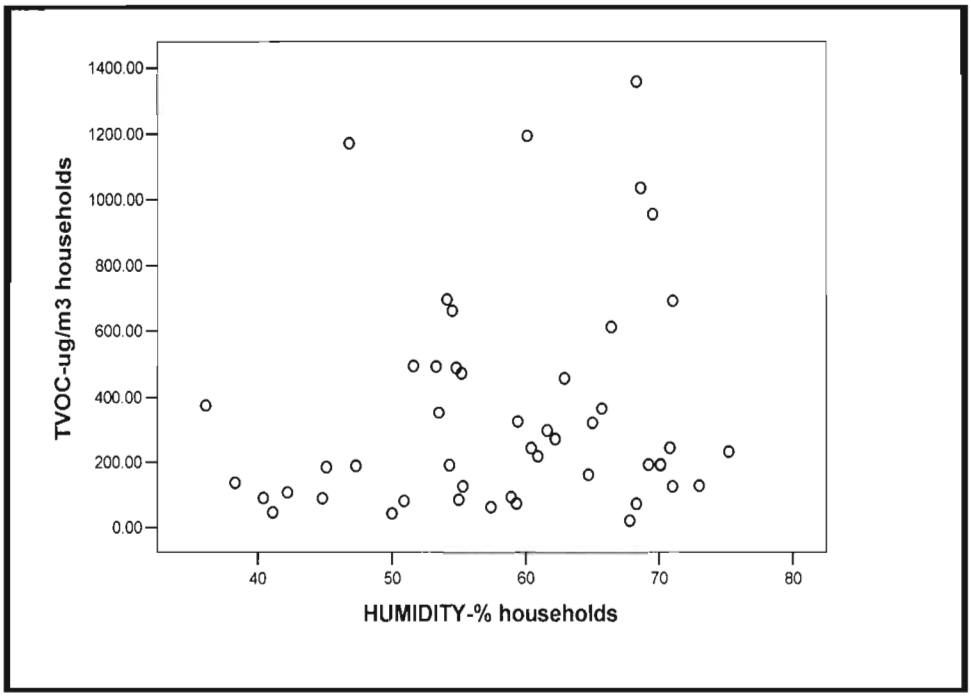

Figure 7: Average Classroom Total Volatile Organic Compound Level and Average Classroom Humidity in Durban for 2005

The Spearman's Correlation Test was performed to determine the correlation coefficient between indoor temperature, humidity and household TVOC exposure levels. The correlation coefficient between household TVOC exposure level and household temperature was 0.110 and between household TVOC exposure level and household humidity was 0.183. These values indicated a weak correlation for household TVOC exposure level and household temperature and household humidity. The Spearman's Correlation Coefficient for average classroom TVOC exposure level and average classroom temperature was –.309 and average classroom TVOC exposure level and average classroom humidity was .509. A negative correlation was noted for average classroom TVOC exposure level and average classroom temperature whilst a medium correlation was noted between classroom TVOC exposure level and classroom humidity.

5 CHAPTER: DISCUSSION AND LIMITATIONS

5.1 DISCUSSION

5.1.1 HOUSEHOLD TVOC EXPOSURE LEVEL

5.1.1.1 Household TVOC exposure level for the selected area

The South had a wider range with a higher minimum and maximum TVOC level but a slightly lower median when compared to the North. Both areas recorded a maximum TVOC exposure level, which were higher than the reference guideline of 500μg/m³. The site in the South enjoying the lowest minimum exposure level was Austerville whilst the site with the highest maximum TVOC level was Merebank. In comparison, the site in the North with the lowest minimum exposure level was Newlands West. The site with the highest maximum exposure level was Newlands East.

The small data set obtained in some sites could possibly influence the outcome of TVOC levels within the areas and sites. The missing data sets may possibly be due to failure of the sampling equipment and may have skewed the data in a positive direction. However, during data analysis the valid percentage data set was used, thereby discounting all missing data. One cannot eliminate the role of chance when comparing outcomes by sites, if some sites had a small data set. This could have possibly resulted in a low statistical power and non-significant difference between sites, when a possible clinically important difference was detected. There may be a possibility of a type 2 error when comparing sites. In the Rumchev Study [30] the median concentration for TVOC was 78.5μg/m³ with a range from 10.8μg/m³ - 622.7μg/m³ for cases and 36.2μg/m³ with a range from 2.5μg/m³ - 198.2μg/m³ for control. In comparison, this study recorded higher median, minimum and maximum exposure levels. The British Research Establishment study [25] recorded a higher mean TVOC exposure level of 406μg/m³ with a range from 51μg/m³ - 1799μg/m³ than this study.

The frequency distribution of TVOC (μg/m³) exposure level is highlighted in Figure 1. The median TVOC exposure level was higher in the North in comparison to the South. In addition, the North experienced a higher percentage of exposures below the standard allowable maximum value. TVOC levels ≥500μg/m³ was higher in the South than the North. The histogram (Figure 1) shows highly skewed distribution of TVOC in the North and South.

Not much difference in the median and distribution of TVOC exposure was noted between the North and South.

In Figure 1, seven (7) outliers of note were recorded. If one compares these household TVOC exposure outliers to school TVOC exposure data then two asthmatic children from KwaMashu and one child from Lamontville will be exposed to household and school exposure above the standard allowable maximum of 500µg/m³.

One of the salient findings in the Rumchev Study [30] was that children exposed to TVOC level >60µg/m³ (median level of exposure) had a fourfold increased risk of asthma. In comparison the median TVOC level recorded in this study ranged from 180µg/m³ - 184µg/m³. This factor coupled with the fact that an elevated level of exposure higher than the reference level was observed, as illustrated in (Fig 1), can only exacerbate asthma in the children. It may also increase the risk of asthma in non-asthmatic children. In addition, exposure levels greater than 200µg/m³ may subject children to health effects such as irritation, discomfort, headache and neurotoxic effect. [29] This increases further health risk to asthmatic children. Papas *et al.* [32] concluded that reducing exposure level of VOC to substantially less than 25µg/m³ is required to prevent non-irritating effects.

In testing for significant association between TVOC levels within the selected areas, an 8% difference in TVOC exposure was noted. The difference may be attributed to a non-significant trend to higher exposure levels in the South than the North or may be due to chance. A [$p<0.468$] indicated that no significant association existed for TVOC exposure level between the areas. In addition no significant differences existed for TVOC exposure levels and the selected areas [$p<0.325$].

5.1.1.2 Household TVOC - µg/m³ exposure levels for sites

Overall, the site with lowest maximum TVOC level was Bluff and the site with the highest maximum TVOC exposure level was Merebank. The median range and the minimum TVOC exposure level range for all sites were within the acceptable guideline value of 500µg/m³. In relationship to the maximum TVOC level, with the exception of Bluff (129µg/m³) and Newlands West (492µg/m³) all other sites ranged from 1034µg/m³ - 1440µg/m³ in relation to maximum TVOC level. These exposure levels were 2-3 times higher than the acceptable

guidelines, thereby exacerbating the risk for asthma. Indoor TVOC exposure levels spanned a very wide range, with some homes experiencing a much higher TVOC exposure level than others do. This is substantiated by a positive skew and some significant outliers.

Four sites, namely Merebank, Bluff, Newlands East and Newlands West, had exposure below 500μg/m³ and could be categorised as less exposed sites. The higher exposed sites were KwaMashu, followed by Austerville and Lamontville .The higher exposure in KwaMashu and Lamontville may be due to these being considered as low socio-economic sites. Households at these sites may be using paraffin (or similar fuels) as combustible sources. Poorly ventilated dwellings may further increases kerosene levels within these dwellings. In addition, the high TVOC levels in KwaMashu and Lamontville may also be due to the selection of households with high TVOC exposure sources whilst the low TVOC exposure levels in the Bluff may be due to the selection of households with the least TVOC exposure sources.

In the British Research Establishment Study [25] (UK) TVOC levels ranged from 51μg/m³ – 1799μg/m³ with a mean of 406μg/m³. The Hippelin Study (Germany) recorded TVOC levels ranging from 33μg/m³ – 1600μg/m³ with a median of 289μg/m³.[52] In comparison this study recorded TVOC levels ranging from 17μg/m³ – 1440μg/m³ with a median of 184μg/m³. This is lower than the aforementioned studies. However, TVOC levels can vary significantly, depending upon the sampling and analysis method used.[53] In addition, indoor environmental parameters such as temperature, humidity and ventilation can also influence TVOC levels.

In relation to health effects, with an indoor TVOC exposure levels ranging from 200μg/m³ – 300μg/m³ one may experience irritation and discomfort. [29] In this particular study the TVOC exposure levels ranged from 17μg/m³ – 1440μg/m³. Postulating from the Molhave Study [29], one will expect the study population to be subjected to sensory irritation and discomfort. In the German Study [52], 47% of all samples revealed concentration exceeding the threshold value of 300μg/m³ for TVOC, as set by the German Federal Environmental Agency as a target for indoor air quality. In comparison 27% (n=27) of samples in this study exceeded the German guideline. 17% (n=17) of TVOC exposure above the reference value of 500μg/m³ was recorded in this study in comparison to the German study. In addition 16% (n=14) of all household samples in this study exceeded the adopted advisory goal of 500μg/m³.

5.1.2 SCHOOL TVOC EXPOSURE LEVELS

For school TVOC - $\mu g/m^3$ exposure levels the means of the two classrooms was used to represent school exposure for each site. It is also assumed that those living in the selected sites also attended the school located in the same site.

5.1.2.1 School TVOC exposure level per site

School TVOC exposure level below $500\mu g/m^3$ was recorded within five schools namely Nizam Primary, Assegai Primary, Dirkie Uys Primary, Briardale Primary and Ferndale Primary. In comparison high levels of TVOC exposure above the standard allowable maximum of $500\mu g/m^3$ were experienced at Etuthukweni Primary and Ngazana Primary. The schools with the lowest TVOC levels were Briardale Primary followed by Nizam Primary and Dirkie Uys Primary. Some of the children selected from Etuthukweni Primary and Ngazana Primary were also subjected to TVOC levels above $500\mu g/m^3$ in homes, thereby placing them at greater risk to asthma. Ngazana Primary School represents a case in point, which exhibits a tenfold TVOC level in relation to the adopted guidelines. Ngazana Primary and Etuthukweni Primary are schools located in low socio-economic areas and the classrooms may be poorly ventilated or subjected to other sources of TVOC exposure. This may need to be investigated further.

5.1.2.2 School TVOC level per area.

The South had a marginally higher percentage (2.2%) of above $500\mu g/m^3$. From visual observation (Figure 3) no real difference in school TVOC exposure between the selected areas can be discerned. However, these values may be related to an insignificant trend occurring during the sampling period.

Black and Worthan reported average TVOC exposure levels ranging from $200\mu g/m^3$ – $450\mu g/m^3$ for a problem school in Washington State (US) after mitigation [57].[54] Norback (1995) reported average TVOC exposure levels from 36 classrooms in Swedish primary schools, ranging from $70\mu g/m^3$ – $180\mu g/m^3$.[55] In this study, school TVOC exposure level ranged from $47\mu g/m^3$ – $5292\mu g/m^3$ with a mean TVOC exposure level of $1013\mu g/m^3$. Although this particular study recorded the lowest minimum TVOC exposure level, it also simultaneously recorded the highest upper range and median to schools in the United States

and Sweden. TVOC exposure levels in some schools in this study were higher in comparison with schools in Sweden and the United States.

5.1.3 HOUSEHOLD AND SCHOOL TVOC EXPOSURE LEVEL

Bluff and Newlands West were within the reference guideline for both household and school TVOC exposure. These two sites are considered as possessing the lowest TVOC levels. The Bluff was the subject of a small data set for household exposures and the results might not be totally representative of this site. Merebank, Newlands East and Austerville were the subject of only household TVOC exposure above the standard allowable guideline. Lamontville and KwaMashu recorded both household and school TVOC levels above 500μg/m³. Household TVOC level above 500μg/m³ was higher (n=14) than school TVOC level (n=3) above 500μg/m³. In the Rumchev Study, [30] the TVOC over-exposure was low 0.01% (2 out of 192) samples exceeding 500μg/m³, for households. In this study 14 out of 87 (16%) samples exceeded the advisory goal of 500μg/m³ thereby indicating a higher percentage of exposure above 500μg/m³.

The two worst sites in terms of school exposure above the reference guideline occurred at KwaMashu and Lamontville. Sites in the South are located close to industrial settings and the TVOC emissions from these may be a contributing factor. However, this aspect does not appear to reflect in the TVOC levels. The selected household and school sites can be ranked in terms of TVOC levels from low to high. Bluff and Newlands West would be followed by Merebank, Newlands East, Austerville, Lamontville and KwaMashu.

5.1.4 TEMPERATURE AND HUMIDITY ON TVOC EXPOSURE LEVEL

5.1.4.1 Indoor temperature

The average classroom temperature was determined by calculating the means of the two readings recorded in the classrooms. The study by Hodgson *al.*[43] recorded indoor temperature ranging from 20°C-24°C for households. In comparison, this study recorded a lower minimum and a higher maximum temperature. Classroom temperature was noted to be higher than household temperature. This may be because the temperatures recorded in the classroom were monitored during the day whilst household temperatures were recorded over a 24 hour period. The temperatures recorded lay within the acceptable range for thermal comfort

(23.3°C-26.6°C) as stipulated by the American Society of Heating, Refrigeration and Air Conditioning Engineers Guidelines. [47] The higher temperature may possibly also be due to poorly ventilated classrooms, windows being closed or seasonal temperature variations. Visual observation [Figure 4] indicates no distinct relationship between household temperature and household TVOC exposure levels. There appears to be a negative correlation (i.e. lower temperatures yielding higher TVOC - $\mu g/m^3$). This is in contrast to chamber experiments [44] results wherein VOC concentrations increased with increasing temperature. The result of this study shows no correlation and is contrary to studies by Hodgson [44] and Matthews *et al.* [45].

5.1.4.2 Indoor Humidity (%)

The average classroom humidity was calculated by determining the means of the humidity values for both classrooms. Classroom humidity was noted to be higher than household humidity for all descriptive data (Table 11). In a study by Hodgson *et al.*, [43] the indoor relative humidity ranged from 21%-70% for households. This study recorded higher humidity levels for households. No real relationship was noted between household TVOC and household humidity [Figure 6]. These results are not consistent with Chamber experiments [44] where an increase in humidity resulted in an increase in TVOC concentrations. Figure 7 demonstrates the relationship between average class TVOC ($\mu g/m^3$) exposure level and average class humidity. It is evident that lower humidity levels yielded higher TVOC exposure levels. There is no real relationship between average classroom TVOC exposure level and average classroom humidity. Indoor relative humidity exceeded the recommended guidelines for comfort (40% - 60%).[47] In addition, the high indoor relative humidity may be sufficient to encourage growth of mildew and dust mites, thereby further exacerbating asthma episodes.

5.1.4.3 Indoor temperature and humidity on TVOC exposure level

A slight correlation was recorded for household TVOC exposure level and household temperature and household TVOC exposure levels and household humidity. A negative correlation was noted for classroom TVOC exposure level and classroom temperature, whilst a moderate correlation was noted between classroom TVOC exposure level and classroom humidity.

Data relating to potential confounders in particular ventilation was not available for the purposes of this study. Ventilation is a likely determinant to the concentration of indoor pollutants including TVOCs. The opening of doors and windows has a dominant effect on air change rates and the concentration of TVOCs generated indoors may be presumed to decrease proportionally in response to increase in home or classroom ventilation.

5.2 LIMITATIONS AND BIAS

5.2.1 LIMITATION

Without a control group of non-asthmatic children there was no way of demonstrating an association between TVOCs exposure level and asthma or generalizing the findings to the greater population. Due to the unavailability of certain important data such as environmental tobacco smoke, ventilation and bio-mass fuel, one could not determine the significant contribution of these confounders to TVOC exposure level. Beyond temperature and humidity, it was difficult to make recommendation on these important and possibly confounding issues.

5.2.2 BIAS

5.2.2.1 SELECTION BIAS

In terms of primary data each site, household and school was randomly selected with the sampling frame being proportional to the size and distribution of the population. During data analysis all raw data were entered into data collection sheets [Annexure 3]. Household and classroom data was entered into the same data file and linked to a unique case index. The selected areas and sites were coded.

5.2.2.2 INFORMATION BIAS

The primary data collected in the South Durban Health Study was undertaken in terms of the Quality assurance project plan in order to minimize fieldwork and measurement bias. The overall objective was to ensure:

- that methods and procedures used in measurement were adequate to meet the objectives
- the data were valid and defendable
- quantifying with precision, accuracy, representitiveness, completeness and comparability of the collected data.

During analysis all data was double entered to detect errors and negative values indicative of an error were rejected. The data base was subjected to extensive validity and accuracy checks. Back-up systems were used to protect the data and to recover lost or missing information.

5.2.2.3 CONFOUNDING

Ventilation and smoking could possibly influence indoor TVOC exposure levels. This aspect was not covered in this particular study. In the absence of such data, no adjustments were considered during analysis to accommodate for these confounders.

6 CHAPTER: CONCLUSIONS

6.1. CONCLUSIONS

This study has found that, among other things:

- Indoor TVOC was recorded in both households and schools within the selected sites with levels varying between areas and sites in the South and North. The TVOC exposure levels for households ranged from 17μg/m³ - 1440μg/m³ and for school exposure ranged from 48μg/m³ - 5292μg/m³.
- There was no significant difference between household TVOC exposure level and the selected areas. There was a non-significant trend to higher TVOC levels in the South than North. There was a significant difference in household TVOC exposure within the sites in the North (i.e. KwaMashu, Newlands East and Newlands West) in comparison with sites in the South. In terms of school exposure there was no significant difference between the areas although there was a slightly higher exposure above 500μg/m³ in the South than North.
- In terms of household TVOC exposures above 500μg/m³, KwaMashu was the worst site in the North and Austerville in the South. School TVOC levels above 500μg/m³ were recorded in Lamontville in the South and KwaMashu in the North. KwaMashu and Lamontville were worse off in terms of school and household TVOC exposure above the reference guideline, with KwaMashu being the worst. The sites, in terms of low TVOC levels, were the Bluff and Newlands West. Considering that the levels of TVOC found in some households and schools were above the recommended guidelines, these findings support the hypothesis that exposure to indoor TVOCs at these levels might be important in the exacerbation of asthma.
- Higher indoor temperature and humidity were recorded within schools. The likely explanation is that classroom temperatures were recorded during the day for 7 hours. Higher indoor temperatures and humidity did not significantly increase indoor TVOC exposure levels. This study could not conclusively prove any correlation or association between indoor temperature and humidity on household or classroom TVOC-μg/m³ exposure.
- Despite the limitation of this study, the TVOC exposure level recorded in some households and schools may increase the risk of asthma in young children or may exacerbate the condition. This is supported by the findings of the Rumchev Study [30]

wherein children exposed to TVOC at levels $\geq$ 60 $\mu g/m^3$ were four times more likely to have asthma than those that were not expos to such levels .

7 CHAPTER: RECOMMENDATIONS

7.1. GENERAL RECOMMENDATIONS

Although this study suggests that the health risks at current levels are low at some sites, other sites are subjected to elevated TVOC exposure levels. Proactive steps to manage indoor TVOC to levels as low as reasonably practical in order to reduce the risk or exacerbation of asthma is important.

Some of the guidelines for management of indoor TVOC exposure are discussed below:

7.1.1 Proper Ventilation

Ventilation has a significant impact on indoor air quality. The fact that poor ventilation is associated with poor health and other human outcomes is well documented. There is a need to increase ventilation by opening windows and doors, which in turn has a residual effect on temperature and, humidity and indoor VOC levels. There is a need for regular maintenance and inspection of air-conditioning units to maintain them in good operating condition. A need exists to ensure that there is adequate ventilation when undertaking activities such as painting, remodeling, and hobbies, which involve volatile organic compounds. Indoor combustion sources, particularly kerosene, gas and wood, should be discouraged in poorly ventilated indoor settings. When planning homes, ensure that the design has good cross-flow ventilation to maximize the air exchange rate.

7.1.2 Control of indoor TVOCs and their sources

- Integrate indoor VOC concerns into purchasing decision. Use less toxic or substitute maintenance material (adhesives, paints, sealant, chalks, and cleaners) and art, writing and graphic material (formaldehyde-free carbonless paper, and odour free transparencies). Alternatively, water-based or low VOC emitting products may be used. These products are becoming more common, thus widening consumer choices.
- Use furnishing and indoor material such as adhesive, carpets, hard surface flooring, desks, wall coverings and textiles that emit low levels of VOCs. Furniture and materials that contain large quantities of VOCs should be aired out.
- Use equipment such as printers, photocopiers and computers that emit low levels of VOCs.

- Avoid the use of carpets as floor tiles provide a good substitute.
- Do not rely on widespread use of pesticide to control pests. Manage sources of pests and, if pesticides are needed, choose environmentally friendly alternatives and use during unoccupied periods.
- Use household products according to manufactures direction. Potentially hazardous products often have warning labels aimed at reducing exposures.
- Discard partially full containers of old or unwanted chemicals safely as gases can leak even from closed containers. This single step could help lower concentration of organic chemical in the home.
- Buy limited quantities. Products that are used occasionally or seasonally, such as paints, paint strippers, kerosene for heaters, gasoline for lawn mowers, should be bought in limited quantities.
-

7.1.3 Maintaining good Indoor Air Quality in Schools. [50]

Several positive steps can be taken to improve and maintain good indoor air quality in school. A strong indoor air quality management plan is essential.

Key components include:

- Establishing procedures and guidelines for building operations and maintenance. This should include cleaning and maintenance procedures, appropriate scheduling of these activities and use of low emitting cleaning products. Also of importance are the procurement specification for the selections and use of low emitting furnishings and construction materials, office equipment, as well as the use and storage of classroom items such as art supplies and laboratory chemicals.
- Baseline monitoring of pollutants during school occupancy will be useful in tracing indoor TVOC.
- A good communication plan is important for allowing prompt and accurate indoor air quality information exchange among school officials, learners, community and media. The plan should address educational information on TVOC, and releasing and discussing information of monitoring results.
- Other measures should include:
    - Provision of clean and controlled outdoor air.
    - Undertaking fumigation when school is not in session.
    - Other generic measures highlighted above.

7.2 SPECIFIC RECOMMENDATIONS

In terms of this particular study the following specific measures are recommended:

- To obtain a more accurate and valid picture of TVOC levels in schools and households , long term TVOC monitoring programmes should be developed and implemented.
- Considering that some of the high risk sites are not located close to an industrial setting, an indoor environmental survey within households and schools in these sites need to be undertaken to assess possible indoor sources of TVOCs as well as the adequacy of ventilation in these indoor settings.
- Increasing awareness on asthma, indoor TVOC sources and indoor TVOC management is crucial in the high risk sites, in particular KwaMashu and Lamontville.
- There is a need to discourage and phase out the use of combustion fuel sources such as kerosene in poorly ventilated indoor settings, especially in the high risk sites.

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9. Appendices

Appendix 1: Standard operating protocol for VOC sampling

Standard Operating Protocol for Outdoor Active VOC Sampling

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October 23, 2013

Contents

1 Overview

This Standard Operating Procedure (SOP) details the handling and placement of thermal desorption adsorbent sampling tubes for active sampling of VOCs outdoors. The active method provides a sample that produces more precise results than passive methods, however, pumps, power supplies, etc., are needed and the method is suitable for relatively short-term samples (~10 min – 8 hrs). Proper site selection is important so that tubes are located in areas that are representative of the home environment used by most family members (e.g., living rooms, family rooms, etc.). Ambient levels of VOCs sampled are expected to be relatively low, therefore exercising proper clean technique is critical to prevent contamination of sample tubes.

2 Definitions

VOC:	Volatile organic compound
SOP:	Standard operating procedure
CPC:	Constant pressure controller
LFH:	Adjustable low flow holder

3 Background

Active sampling for VOCs have a number of advantages over passive sampling. For example, active sampling typically gives higher precision than passive sampling, and captures a larger number of VOCs on the sorbent. Some potential disadvantages of active sampling include the need for pumps, and occasionally power supplies, sampling noise from the pump, and the relatively short sampling time. In order to avoid loss of VOCs due to diffusion, the sample flow rate should not go below 10ml/min, so the maximum time for collecting a 1 and 4 liter sample is 100 and 400 minutes, respectively. Typical sampling rates are 25-30 ml/min, which reduces the maximum sampling period to ~2.6 hours (for 4 liters sampled at 25 ml/min). This is a much shorter time period for integrated sampling than provided by the passive method.

4 Materials and supplies

Conditioned sorbent tubes wrapped in foil in poly bag or glass jar
Stainless steel tube barbs in foil and packed in plastic Ziplok® poly bags
AirCheck 2000 Air Sampling Pump (SKC Inc., 750-3250 ml/min)
Flow meter. DryCal and/or precision bubble meter with stopwatch, depending on target flow rate
Adjustable Low Flow Holder and small screwdriver
Constant Pressure controller (CPC)
Plastic (poly) Tubing
Latex gloves
Sampling stand (metal laboratory ring stand with clamp for holding tubes)
Pre-baked aluminum foil in poly bags
Extra poly "zip-lock" bags
Portable thermometer/hygrometer
Data sheet and pencil/pen
Extra Teflon® washers in small foil square (for use in tube barbs)
These instructions (this SOP)

5 Procedures for active sampling

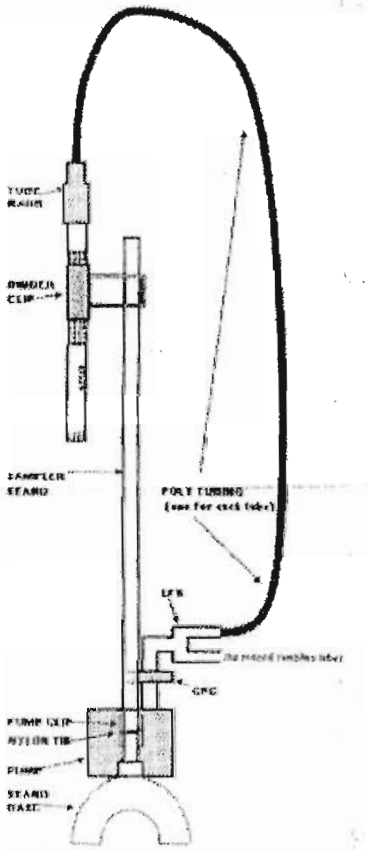
5.1 *Selecting the site and placing the sampler*

The sampling site should be located in an area protected from exposure to direct sunlight and the elements, while a the same time allowing for good circulation of air in the vicinity of the sampling tubes. Place the sampler in a secure and inconspicuous location where it will be out of the way of children, traffic, etc., and at the same time no closer than approximately 1.5 feet from any given structure. Enter a brief description of the sampling site onto the data sheet.

5.2 *Assemble the sampling array*

Find a location that is protected from wind, rain, etc. to conduct the following procedures. Insert the stand upright and if needed, the extension into the stand base, attach the sampling pump to base using a nylon tie (Figure 1). Unpack the pump, CPC, LFH, poly tubing, etc., and set aside for now.

Figure 1: Setup for active sampling



5.3 *Deploying the sampling tubes*

a Record the date, temperature and relative humidity onto the data sheet.

h. Use poly tubing to connect the pump inlet to the CPC outlet, connect the inlet of the CPC to the LFH, and connect the stainless tube barbs to the LFH ports (Figure 1). **Do not alter any settings on the LFH.**

i. Record the ID of the pump, CPC and LFH onto the data sheet.

j. Turn on the pump and pause it (see pump instructions, Appendix B). Set the sample duration time (e.g., 20 minutes) on the pump but don't start it yet.

k. Put on a pair of latex gloves.

l. Connect a calibration tube to each of the ports on the LFH, put a tube barb on the numbered end and record their IDs on the data sheet.

m. Either connect the precision bubble meter (for low flows) or DryCal flow meter (for high flows) to the tube barb on the numbered end of the calibration tube, and measure the flow rate of each tube. If using the precision bubble meter, take 2 readings and average them; if using the DryCal, start the meter in repeat mode and take a 5-reading average (See Appendix C for detailed instructions). Record the flow rate onto the data sheet and the remove the calibration tubes and store them for future use.

n. Remove a sampling tube from the plastic bag and foil, reseal the unused tubes back in the foil and bag, and record the number of the tube in the appropriate field on the data sheet. Leave the small packet containing activated carbon inside the container.

o. Remove the cap from the inlet end of the tube (the end closest to the number and furthest from the knurling) and place the cap and Teflon washer onto a clean piece of foil. Place the foil with the cap and washer back inside the clean poly bag but do not re-seal the bag yet.

p. Remove the cap from the outlet end of the tube (opposite end from the number and closest to the knurling), place it onto the foil with the other cap, wrap the two caps and washers loosely in the foil and then place the foil packet back into the poly bag. If one is not already in place, place a Teflon washer inside the tube barb.

q. Attach the tube barb to the outlet (open) end of the tube, ensuring that there is a Teflon washer in place inside the barb and then place the tube into one of the binder clips on the stand (Figure 1). Connect an appropriate length of poly tubing between the tube barb and one outlet of the LFH. Record the letter of the port that you connected the tube to on the data sheet.

r. Repeat steps e - i for each tube deployed.

s. Remove your gloves and then start the pump.

t. Record the time that you began sampling on the data sheet.

5.4 Obtaining a blank

This procedure is easily completed while taking the active samples. Be sure to move away from the direct vicinity of the active sampling array so as not to contaminate or otherwise interfere with the samples.

a. If you don't already have gloves on, put a pair on now.

b. Remove a tube from the glass container and its foil wrapping and record the number of the tube.

c. Briefly remove the caps from the tube (i.e., ~15 seconds) and then replace them. Be careful not to drop the Teflon® washers on the ground.

d. Place the blank tube back into its foil packing and then into the glass container.

e. Remove gloves.

f. Complete the data sheet.

5.5 Collecting the tubes

Collecting the tubes at the end of the sampling period involves reversing the procedure for deploying the tubes. Be sure to have the poly bag(s) containing the caps and Teflon® washers, the glass jar for transporting the tubes and the data sheet(s) with you when you collect the sampling tubes.

In the interim period between deploying and collecting the tubes, the poly bag containing the tube caps, Teflon® washers and foil, and the glass transport jar should be stored in a place that is as contaminant-free as possible. For example, do not store these items in a car, garage, etc.

a. Record the elapsed time of sampling (i.e., sampling duration) onto the data sheet.

b. Put on a pair of latex gloves.

c. Connect a calibration tube to each of the ports on the LFH, put a tube barb on the numbered end and record their IDs on the data sheet.

c. Either connect the precision bubble meter or DryCal flow meter (whichever you used before) to the tube barb on the numbered end of the calibration tube, and measure the flow rate and measure each tube. If using the precision bubble meter, take 2 readings and average them; if using the DryCal, start the meter in repeat mode and take a 5-reading average (See Appendix C for detailed instructions). Record the flow rate onto the data sheet and then remove the calibration tubes and store them for future use.

d. Open the ziplok bag, remove the foil with caps and O-rings. Leave the activated carbon pack inside.

e. Carefully open the foil keeping the caps and orient them with their open ends up. Make sure that the white Teflon O-rings are inside the caps; place them back inside if necessary.

f. Remove a tube from the binder clip on the stand, orient it with the open end down and then screw a cap (containing a Teflon o-ring) onto the tube.

g. Invert the tube so that the capped end is now facing upward, remove the tube barb and place it into a clean piece of foil. Be careful not to loose the Teflon washer. Cap the end in the manner as before, place the tube onto clean foil and set it in the poly bag for the moment.

h. Repeat steps e and f for the second tube, then wrap the tubes in foil and seat them in the poly bag. You may now remove your gloves.

i. Dissemble the sampling array and stand and pack it away for safe transport.

5.6 Storing and transport

The tubes should be kept in the glass jar and out of direct sunlight at all times. Additionally, you should avoid exposing them (and the jar) to extreme conditions where they might be directly exposed to, e.g., exhaust and/or other combustion gases, raw gasoline or other VOC vapors, etc.

5.7 Returning to the lab

Once the sample tubes are collected they should be returned to the lab as soon as possible. Upon returning to the lab, immediately place them in the refrigerator dedicated to sample tube storage and turn in the tube data sheets to the laboratory technician so that they may analyze the tubes as soon as possible.

6 Quality Assurance

All technicians will be thoroughly trained in all of the procedures contained in this SOP before deployment in the field, and are responsible for reporting any irregularities and/or deviations from SOPs. The field technician completing a given procedure will initial the appropriate data sheet next to the date field so that chain-of-custody may be tracked. All data sheets will be placed in notebooks that are kept in the lab under the supervision of the PI.

7 References

Compendium Method TO-17, Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes, US EPA, January 1999

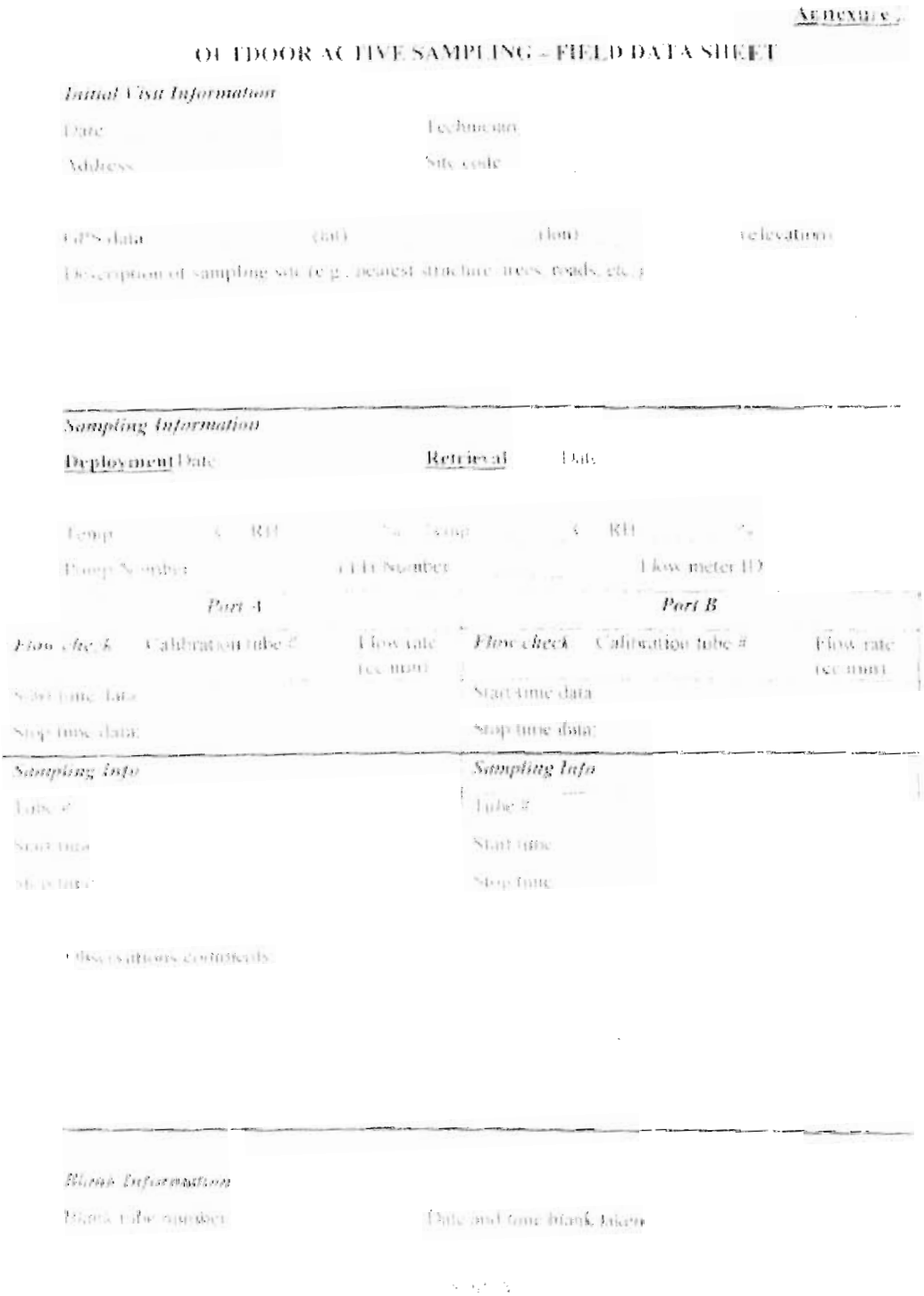
8 Appendices

Appendix A: Sorbent Tube Sampling Field Data Sheet

Appendix B: Air Check pump instructions.

Appendix C: DryCal flow meter instructions.

1.1 Appendix 2: Sampling field data sheet



Appendix 2

OUTDOOR ACTIVE SAMPLING – FIELD DATA SHEET

Initial Visit Information

Date: Technician:

Address: Site code:

GPS data: (lat) (lon) (elevation)

Description of sampling site (e.g., nearest structure, trees, roads, etc.)

Sampling Information

Deployment Date: Retrieval Date:

Temp: °C RH: % Temp: °C RH: %

Pump Number: CCU Number: Flow meter ID:

Port A			*Port B*		
Flow check	Calibration tube #	Flow rate (cc/min)	*Flow check*	Calibration tube #	Flow rate (cc/min)
Start time, late:			Start time data:		
Stop time, data:			Stop time data:		

Sampling Info	*Sampling Info*
Tube #	Tube #
Start time	Start time
Stop time	Stop time

Observations/comments:

Blank Information

Blank tube number: Date and time blank taken:

DATA COLLECTION SHEET FOR EXPOSURE LEVELS OF TOTAL VOLATILE ORGANIC COMPOUNDS[ug/m3] WITHIN HOMES AND SCHOOLS WITHIN SOUTH DURBAN AND NORTH OF DURBAN

			HOME						SCHOOL				
INDEX CASE	AREA	SITE	TVOC-ug/m3	EXP	TEMP-C	HUMIDITY-%	SCHOOL	CLASS ID	TVOC-ug/m3	EXP.	TEMP-C	HUMIDITY-%	Total Exp
141007100	1	1					1	S-NI-R17					
133506100	1	1					1	S-NI-R18					
141026100	1	1					1						
141006100	1	1					1						
141030100	1	1					1						
133502100	1	1					1						
142305100	1	1					1						
133504100	1	1					1						
134706100	1	1					1						
142312100	1	1					1						
153511100	1	1					1						
141011100	1	1					1						
141023100	1	1					1						
134715100	1	1					1						
141019100	1	1					1						
141002100	1	1					1						
141016100	1	1					1						
142307100	1	1					1						
141028100	1	1					1						
141025100	1	1					1						
241035100	1	2					2	S-EN-C1					
234757100	1	2					2	S-EN-C2					
241066100	1	2					2						
241061100	1	2					2						
233528100	1	2					2						
233520100	1	2					2						
241050100	1	2					2						
241060100	1	2					2						
241046100	1	2					2						
243519100	1	2					2						
241033100	1	2					2						
241040100	1	2					2						

241042100	1	2	2		
243609100	1	2	2		
243611100	1	2	2		
241045100	1	2	2		
243518100	1	2	2		
243610100	1	2	2		
241036100	1	2	2		
233530100	1	2	2		
241034100	1	2	2		
241051100	1	2	2		
233521100	1	2	2		
341098100	1	3	3	S-AS-RM36	
353617100	1	3	3	S-AS-RM34	
342533100	1	3	3		
342538100	1	3	3		
343541100	1	3	3		
341088100	1	3	3		
342542100	1	3	3		
341106100	1	3	3		
342381100	1	3	3		
343537100	1	3	3		
341081100	1	3	3		
343539100	1	3	3		
341101100	1	3	3		
341105100	1	3	3		
343540100	1	3	3		
341074100	1	3	3		
343535100	1	3	3		
341087100	1	3	3		
333613100	1	3	3		
341085100	1	3	3		
441269100	1	4	4	S-DU-5T	
441264100	1	4	4	S-DU-5V	
441258100	1	4	4		
441261100	1	4	4		
442282100	1	4	4		
442293100	1	4	4		

[illegible]	1	4				4									
441421100	1	4				4									
[illegible]	1	4				4									
442282100	1	4				4									
441286100	1	4				4									
541148100	2	5				5	S-BR-R40								
541140100	2	5				5	S-BR-R44								
541155100	2	5				5									
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542347100	2	5				5									
541116100	2	5				5									
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541115100	2	5				5									
542333100	2	5				5									
542351100	2	5				5									
541144100	2	5				5									
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543561100	2	5				5	S-FE-R24								
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533526100	2	6				6									
641169100	2	6				6									
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641198100	2	6						6									
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642416100	2	6						6									
653620100	2	6						6									
630627100	2	6						6									
641178100	2	6						6									
741251100	2	7						7	S-NG-G3								
741224100	2	7						7	S-NG-G4								
741247100	2	7						7									
741201100	2	7						7									
741215100	2	7						7									
741214100	2	7						7									
741215100	2	7						7									
741206100	2	7						7									
741200100	2	7						7									
741232100	2	7						7									
741230100	2	7						7									
733565100	2	7						7									
733575100	2	7						7									
733566100	2	7						7									
733568100	2	7						7									
733574100	2	7						7									
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733567100	2	7						7									
741208100	2	7						7									
741233100	2	7						7									
741216100	2	7						7									

KEY	AREA:	SCHOOL:	SITE
	SOUTH=1	NIZAAM PS=1	MEREBANK=1
	NORTH=2	ETUTHUKWENI=2	LAMONTVILLE=2

ASSEGAI PS=3
DIRKE UYS PS=4
BRIARDALE PS=5
FERNDALE PS=6
NGAZANA PS=7

AUSTERVILLE=3
BLUFF=4
NEWLANDS WEST=5
NEWLANDS EAST=6
KWA-MASHU=7

EXP=EXPOSURE
UNDER=0
OVER=1
EXPTOT1=TOTAL EXPOSURE

TVOC=TOTAL VOLATILE ORGANIC COMPOUNDS
ug/m3=microgram per cubic meter
P= SAMPLE FAILED&UNACCEPTABLE
TEMP=TEMPERATURE(Degree Celcius)
HUMIDITY(%)= PERCENTAGE MOISTURE

Appendix 4: Ethical approval and letter approving the use of TVOC data

UNIVERSITY OF
KWAZULU-NATAL

Research Office
BIOMEDICAL RESEARCH ETHICS ADMINISTRATION
Nelson R Mandela School of Medicine
Private Bag 7, Congella 4013
Kwazulu-Natal, SOUTH AFRICA
Tel: 27 31 2604769
Fax: 27 31 2604609
Email:
Website:

26 May 2006

Mr S Maharaj
Community Health
Nelson R Mandela School of Medicine

EXPEDITED REVIEW

Dear Mr Maharaj

PROTOCOL: An investigation into the prevalence of volatile organic compounds within homes and classrooms in selected asthmatic children in Durban. S Maharaj, Community Health. Ref: H072/06

At a meeting of the Biomedical Research Ethics Committee considered the above-mentioned application and the protocol was approved. The study is given full ethics approval and may begin as at today's date 26 May 2006.

This approval is valid for one year from 26 May 2006. To ensure continuous approval, an application for recertification should be submitted a couple of months before the expiry date. In addition, when consent is a requirement, the consent process will need to be repeated annually.

I take this opportunity to wish you everything of the best with your study. Please send the Biomedical Research Ethics Committee a copy of your report once completed.

Yours sincerely

UNIVERSITY OF KWAZULU-NATAL
Chair: Biomedical Research Ethics Committee

University of KwaZulu-Natal
Nelson R Mandela School of Medicine
Centre for Occupational and Environmental Health
Private Bag 7
Congella
4013

To whom it may concern

This is the letter authorising Santoshkumar Maharaj, student number 203515344, to use data collected for my study project for his masters' project. His study will compliment the present study I am conducting, which is looking at indoor air quality of selected South and North Durban residences.

My study already had an ethical approval from the University of KwaZulu-Natal, which its reference number is E 117/03.

Yours sincerely

Nkosana Jafta
(Masters Student)