LABORATORY FUME HOOD PERFORMANCE

Peter-John Jacobs

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Master of Public Health

in

Occupational Hygiene

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DECLARATION

I, Peter-John Jacobs declare that this research report is my own work. It is being submitted for the degree of Master of Public Health: Occupational Hygiene in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University.

Signed this _________**26th**___________day of _______**May**__________2008

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Peter-John Jacobs

To all the workers who have been harmed

as a result of unsafe and unhealthy

working conditions while trying to earn an honest living.

ABSTRACT

Introduction

Laboratory fume hoods are mechanical devices used to extract harmful vapours from indoor workplaces in order to prevent human exposure thereto. Laboratory fume hoods are considered an engineering control in the hierarchy of control and are ubiquitous in the modern laboratory. Protection offered by the fume hood depends on whether it is performing according to its original design. This performance needs to be maintained for as long as the fume hood is in use. Gaining a better understanding of this performance and the limitations of the fume hood are essential in ensuring constant operator protection.

No performance or measurement standard to which fume hoods need to comply exists in South Africa. The Occupational Health and Safety Act, 1993 (Act no. 85 of 1993) requires engineering controls to be evaluated every 24 months. The Act does not stipulate how such evaluations need to be conducted.

The Forensic Science Laboratory (FSL) of the South African Police Service has 49 fume hoods installed in its facility in Silverton, Pretoria. The FSL set a performance standard for its fume hoods at 0.51 $m.s^{-1}$ ± 20% average across the face of the fume hood. The FSL selected the ANSI/ASHRAE 110 test method to evaluate the performance of its fume hoods against this standard.

Objectives

The first objective of the study was to measure face velocities of fume hoods as installed in a forensic science laboratory and calculate the averages, and to determine whether these comply with the set standard.

The second objective was to measure face velocities of fume hoods as installed in a forensic science laboratory and calculate the average in order to determine their performance over time.

The third study objective was to observe laboratory fume hoods as installed in a forensic science laboratory to see whether fans were operational each month for 11 months (i.e. down time).

Methods

10 Observations and 10 tests were carried out on each fume hood. Observations related to whether fume hood fans were functioning or not. Testing was a measure of performance and required the actual measurement of face velocities. A calibrated thermal anemometer was used to take velocity measurements. Measurements taken represent standard velocities. Fume hood faces were divided into imaginary grids not exceeding 30 cm x 30 cm. Velocity measurements were taken at the centre points of these grids. The arithmetic means were calculated for these measurements. The mean of the test means was then

calculated for every fume hood. This, so that a comparison could be made between the mean and the set standard.

Observations indicated that at the onset of the study 14% of fume hoods were not operational. By the end of the study 27% were not operational. A decline of 13% over the study period. At one point during the study 47% of the fume hoods were not functioning.

Results

82% of the fume hood population performed outside the standard. 12% underperformed at less than 0.41 $m.s^{-1}$ while 70% overperformed at velocities exceeding 0.61 $m.s^{-1}$.

ANOVA and regression analyses revealed that performance of the fume hoods over time remained fairly constant (e.g. regression analyses p-value = 0.8538).

Discussion and conclusion

Fume hood operability and performance results indicate the need for urgent investigation into the correct use of this resource within the FSL. Results are less than satisfactory with the health of laboratory personnel being potentially compromised. Comprehensive procurement, installation, operating and testing procedures need to be compiled, or if available, reviewed and implemented. Further study into the performance of the fume hoods may also be necessary using additional performance indicators.

Face velocity measurements provide a good indication of the speed at which air enters a fume hood. Face velocity does not indicate whether the fume hood is able to contain harmful vapours or not. Additional testing such as containment and tracer gas testing may be required for this. Judging fume hood performance solely on face velocity measurements is a limiting factor of this study.

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TERMS, DEFINITIONS AND ABREVIATIONS

AIA	Approved Inspection Authority, an inspection authority approved by the Department of Labour.
ASHRAE	American Society for Heating, Refrigeration and Air-conditioning Engineers.
˚C	Degrees Celsius.
Carcinogenic	A substance or material capable of producing cancer.
cm	Centimetres.
Dry bulb thermometer	This thermometer measures the ambient air temperature.
Face velocity	Average velocity of air moving perpendicular to the fume hood, expressed in metres per second.
fpm	Foot per minute.

Fume	Minute solid particles generated by condensation from the gaseous state, generally after volatilization from melted substances.
Globe thermometer	The globe thermometer gives an indication of the radiant heat exposure to either direct light or hot objects in the environment.
HSE	Health and Safety Executive, UK.
$km.h^{-1}$	Kilometres per hour.
Laboratory fume hood	A boxlike structure enclosing a source of potential air contamination, with one open or partially open side, into which air is moved for the purpose of containing and exhausting air contaminants, generally used for bench scale laboratory operations. “Fume hood” has a corresponding meaning. Variable-Air-Volume (VAV) Fume Hoods are excluded from this definition.
mm Hg	Millimetres of mercury.
$m.s^{-1}$	Metres per second.

Natural wet bulb thermometer	The natural wet bulb thermometer gives an indication of the effect of humidity on an individual. Relative humidity and wind speed are taken into account by measuring the amount of evaporative cooling taking place at a thermometer covered with a moistened wick.
Operational	This is defined as a fume hood fan operating when turned on and air subsequently being extracted, irrespective of the volume or velocity of extraction.
SANAS	South African National Accreditation System.
Scrubber	A device attached to a fume hood system in order to clean extracted, contaminated air before expelling it into the outside atmosphere.
Vapour	Gaseous phase of a substance ordinarily liquid or solid at 25 °C and 760 mm Hg.

CHAPTER 1

1.0 INTRODUCTION

Chapter 1 sets about explaining why laboratory fume hoods are needed, their place in the hierarchy of control, what a laboratory fume hood is, how and to what standards it should function, and equipment used during the study and the reasons for such. The chapter further looks at the importance of the study, its aims and objectives and ends with an overview of the rest of the report.

1.1 Background

The South African Police Service (SAPS) established a laboratory to assist with the investigation of crime by analysing material found at crime scenes. The laboratory is known as the Forensic Science Laboratory (FSL).

The FSL analyses many diverse materials requiring a number of different analytical techniques. Most of these techniques require the use of chemicals. A specific technique may further require a large quantity of different types of chemicals. Chemicals have certain inherent properties which may cause harm to man upon exposure. The degree of harm depends upon the level of toxicity of the chemical and the dose received by the person being exposed thereto.

1.2 Controlling Chemical Exposure

There are various means of controlling personal exposure to hazardous chemical substances in the workplace. Within the Occupational Hygiene profession it is accepted that in seeking the best means of controlling such exposure a hierarchy of control in order of effectiveness, should be followed. The hierarchy of control begins with the most effective means of controlling chemical exposure ending in the least effective means.

The hierarchy of control used by the FSL is as follows:

- Elimination;
- Substitution;
- Engineering controls;
- Administrative controls, and;
- Personal protective equipment (PPE).

1.2.1 Elimination

A process whereby the hazardous chemical is removed in its entirety from the process and the particular process requiring the use of such chemical is ceased.

1.2.2 Substitution

The hazardous chemical is substituted with one less hazardous.

1.2.3 Engineering Controls

Engineering methods such as ventilation systems and laboratory fume hoods are brought about to reduce the amount of hazardous chemical released into the workplace air.

1.2.4 Administrative Controls

This type of control relies on work methods in order to reduce exposure and may include such aspects as job rotation and proper training.

1.2.5 Personal Protective Equipment

This involves the use of respirators and other protective clothing in order to protect persons from hazardous chemicals.

All organizations working with hazardous chemicals need to follow the hierarchy of control in an effort to control exposure to such as prescribed by legislation (1). In its endeavour to protect its employees the FSL instituted engineering controls in the form of laboratory fume hoods to reduce hazardous chemical vapours being released in workplace air, as elimination and substitution of hazardous chemicals was not possible due to prescriptive analytical techniques.

In recent years the FSL has expanded dramatically consequently increasing its chemical usage with a resultant need to increase fume hoods. The FSL has in excess of 150 fume hoods in operation in its various facilities throughout South Africa.

1.3 History of the Fume Hood

A laboratory fume hood can be described as a type of workbench that has been enclosed and only has one open, or partially open side. Attached to this enclosure are a set of pipes or ducting to which a fan is connected that literally sucks the air from the enclosed workbench. The ducts usually lead from inside a laboratory to the outside air and the air is thus sucked from the laboratory and pumped into the outside air where it is dispersed into the atmosphere.

As described in Saunders (2), hoods to control toxic or noxious fumes and vapours can be traced back to the invention of the chimney for the fireplace. During the Industrial Revolution (mid 1800's) mechanical fans were invented to assist with the removal of airborne contaminants. Gradually additions were made. In the 1940's the Harvard School of Public Health developed fume hoods for the United States Atomic Energy Commission. These fume hoods were the predecessors to modern day fume hoods with the latter still using the original basic design.

There is a wide variety of fume hood designs and a number of different fume hood manufacturers in the marketplace. Fume hoods, however, generally show a number of similar characteristics and components. Figure 1.1 shows the major components of laboratory fume hoods.

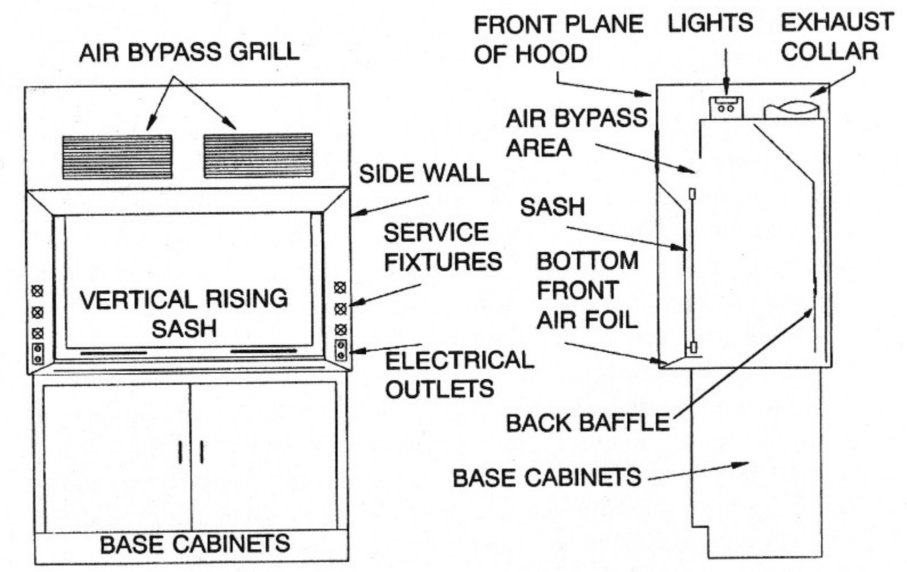


Figure 1.1 Typical components of a laboratory fume hood (2)

Figure 1.2 Typical laboratory fume hood as installed at the FSL

1.4 Main Components of a Laboratory Fume Hood

1.4.1 Hood Exterior and Interior

The hood exterior and interior are usually made of steel. The exterior front design is an important element of the fume hood. Properly designed fume hoods will have a contoured entry, which assists airflow into the hood, improving performance. The interior of the hood may be lined with material that will resist attack from the type of chemical being used inside the fume hood. The inner material should also be flame retarded (3).

1.4.2 Sash

The sash is a moveable, transparent panel set in the fume hood face to restrict the opening of the fume hood. It moves either vertically or horizontally depending on the fume hood design. The sash acts as a barrier between the operator and the chemical being used inside the hood (2)(3).

1.4.3 Air Foil

This is the bottom front part of a fume hood. It is important that this component is aerodynamically designed in order to facilitate the smooth flow of intake air over the working surface of the fume hood thus reducing air turbulence inside the hood (2)(4)(5).

1.4.4 Face

The face is the front opening of the fume hood which can be opened and closed using the sash (2).

1.4.5 Back Baffle

The back baffle is situated in the rear of the fume hood and is designed to control airflow distribution within the hood and through the face opening. By controlling airflow it assists in reducing turbulence inside the fume hood. The baffle is fitted with bottom, center and top slots which may be adjustable to compensate for lighter- and heavier than air gases (2).

1.4.6 Air Bypass Area

Bypasses are generally designed to limit the increase in face velocity. This is important because too high a face velocity causes turbulence affecting the fume hood's ability to perform properly (3). It also happens that fume hood operators adjust the sash of the fume hood to various operating heights depending on the work they may be doing in the fume hood. A fume hood fan extracts a specific volume of air and if the sash is in a closed position the fan would have no air to extract and subsequently starve. An air bypass helps overcome this eventuality and makes provision for air to bypass the face of the hood should the sash be fully closed.

1.4.7 Ducting

Ducting is a set of pipes that contains and transports air from the fume hood via the fan into the atmosphere. If an air cleaning device is installed, the ducting will transport the contaminated air to such a device before expelling it into the atmosphere (6).

1.4.8 Fan

Although the fan cannot be considered a part of the fume hood because it usually sits some distance away and is separated from the fume hood by ducting, it needs mentioning because without it no or very little air would be drawn into the fume hood. The fan is essentially a motor with blades attached to it. It draws air by creating a negative pressure on its inlet side, the side where the fume hood is situated. Air is drawn through the fan and expelled on its outlet side where a positive pressure exists (6).

A fan blade moving through air is like a paddle wheel, pushing air forward. As the blade moves through the air, it physically moves a finite amount of air a few centimetres forward. New air immediately takes the place of air moved forward. The fan can be thought of as a bucket brigade, each blade representing a bucket of air (7).

1.4.9 Stack

This is the final component in a ventilation system. It is attached to the ducting, an extension if you like, and is that portion that extends to the outside of a building above the roof (4).

1.5 Fume Hood Performance Requirements

As with any piece of equipment, there needs to be some sort of standard according to which such equipment needs to perform and against which such performance can be measured. These standards need to ensure that the desired and stated performance is in actual fact being achieved and the subsequent elimination of airborne contamination ensured. Contaminants may be carcinogenic and if they are not properly removed by the fume hood because of the fume hood performing poorly, laboratory personnel may be exposed resulting in serious consequences to their health.

No mandatory requirement or standard exists within South Africa for testing the performance of fume hoods. Local legislation does however require that control measures instituted in the prevention of personal exposure to hazardous chemical substances be thoroughly examined once every 24 months (1). As to how this examination needs to take place and what performance criteria needs to be applied, is not clear.

In the United States a number of standards exist which prescribe velocities for laboratory fume hoods. These velocities including the standard velocity set by the FSL are listed in table 1.1.

Table 1.1 Face velocity standards for laboratory fume hoods

ORGANISATION	STANDARD		
	foot per minute	**metres per second**	**source**
Federal OHSA	60 - 100	0.30 – 0.51	3, 8, 9, 10
California OHSA	70 – 100	0.35 – 0.51	8, 9
	125 – 150 (carcinogens)	0.63 – 0.76	
NRC	80 – 100	0.41 – 0.51	8, 10
	120 (highly toxic)	0.61	
NFPA	80 – 120	0.41 – 0.61	3, 8, 9,
ANSI	80 – 120	0.41 – 0.61	8, 11
AIHA	80 – 120	0.41 – 0.61	8, 11
SEFA	100	0.51	8, 11
NIH	100	0.51	8, 10
NIOSH	100 – 150	0.51 – 0.76	8, 10
ACGIH	60 – 100	0.30 – 0.51	4 (p13-41), 6, 10
FSL	100	0.51	

OHSA:	Occupational Safety and Health Administration
NRC:	National Research Council
NFPA:	National Fire Protection Agency
ANSI:	American National Standards Institute
AIHA:	American Industrial Hygiene Association
SEFA:	Scientific Equipment and Furniture Association
NIH:	National Institute of Health
NIOSH:	National Institute for Occupational Safety and Health

ACGIH:	American Conference of Governmental Industrial Hygienists
FSL:	Forensic Science Laboratory of the South African Police Service

1.6 Standard Setting

Setting too low a face velocity will result in contaminants not being extracted from the fume hood. Too high a face velocity is also inappropriate because it brings about added energy requirements with no increased worker protection. The indraft at the hood face creates eddy currents around the worker's body that can drag contaminants in the hood along the worker's body and up to the breathing zone. The higher the face velocity, the greater the eddy currents (4). Given these considerations and using the standards set in the Unites States as a reference, the FSL set a performance standard for its fume hoods at 0.51 $m.s^{-1}$ averaged across the face of the hood.

1.7 Measurement Standard

In order to evaluate and test to see whether fume hoods were performing to the standard set by the FSL, a recognized test method needed to be used. After an extensive literature review using the "Google" search engine on the internet with the key words "testing local exhaust ventilation systems" and interviewing local fume hood manufacturers, two international standards were found dealing with the testing of fume hoods. British Standard BS 7258 – 1994 (12) (partially replaced by BS EN 1475:2003) (13) deals with amongst others laboratory fume cupboard containment determination while the ASHRAE standard: ANSI/ASHRAE 110-1995 provides a method for the testing of laboratory fume hoods (14). Saunders (2, p. 81) states that the ASHRAE standard is the worldwide recognised basis for determining safe fume hood performance. One of the world leaders in ventilation standards, the ACGIH, refers to the ASHRAE standard in their ventilation manual as the fume hood performance test which may be used (4, p. 13 – 40). Further, the ASHRAE standard is easy to understand and use.

1.8 ASHRAE Test Method

The ASHRAE test method (14) specifies three types of tests to be performed on fume hoods to determine their efficiency and compliance to set standards. These are briefly described below.

1.8.1 Flow Visualization

This entails a visual test to see whether the hood contains the air being extracted. Smoke may be released on the periphery of the face or the inside and the movement thereof then observed.

1.8.2 Face Velocity Measurements

This requires the face of the fume hood to be divided into 30 cm imaginary grids and measurements taken at the centre point of each of these grids.

1.8.3 Tracer Gas Test Procedure

Here a tracer gas is released inside the hood. A manikin simulating a fume hood operator, is placed outside the hood with a detector probe placed in its breathing zone. The detector is capable of detecting the tracer gas. The concentration of gas detected by the probe is monitored.

1.9 Measurement Influencing Factors

A number of environmental and other factors influence a fume hood's performance. The sections below expand on these factors.

1.9.1 Temperature

Studies have shown that heat output can compromise fume hood performance (15). Temperature has an effect on gas volume as discovered by the French scientist Jacques Charles in 1787. He found that a fixed quantity of gas at a constant pressure increased when temperature increased (16). An increase in temperature therefore could result in a stronger air current at the face of the fume hood because of the hot air rising which will rise more rapidly as the temperature increases because warm air is lighter than cooler air. The rising air is replaced by cooler air continuously, thereby creating air flow vertically (17).

1.9.2 Air Turbulence

1.9.2.1 Air Diffusers and Air-conditioners

Air from the central ventilation system of a building usually enters a room or laboratory via an air diffuser. An air diffuser can be described as a device used to distribute air from a ducting system into a room. The exit discharge velocity from a diffuser should not exceed 60% of the face velocity assigned to fume hoods. Further, their placement in relation to the face of the fume hood is important. They should not be too close otherwise they will blow air directly across the face of the hood (2). Both these aspects can negatively influence face velocities if incorrect. Air-conditioners inside laboratories recirculate air either heating or cooling it down. During this process, air is moved and can influence fume hood performance in a similar fashion to air diffusers.

1.9.2.2 Doorways, Windows and Human Traffic

Open doorways and windows may cause cross draughts influencing airflow at the face of the fume hood. A door that opens outward (most laboratory doors open this way), pulls a large volume of air from the laboratory space and has an effective velocity of from 3.22 to 8.05 $km.h^{-1}$. Human traffic in front of the hood may further negatively influence fume hood performance. A person walking both pushes and pulls a significant volume of air (2)(3).

1.9.2.3 Laboratory Fume Hoods

More than one fume hood in the same laboratory implies that there will be a competition between them for air if they are operated simultaneously. This influences fume hood performance particularly if there is not enough supply or make-up air to the laboratory (5). Saunders (2, p. 120) describes make-up air as air needed to replace the air exhausted from the room by fume hood/s.

1.9.2.4 Location of Equipment and Apparatus

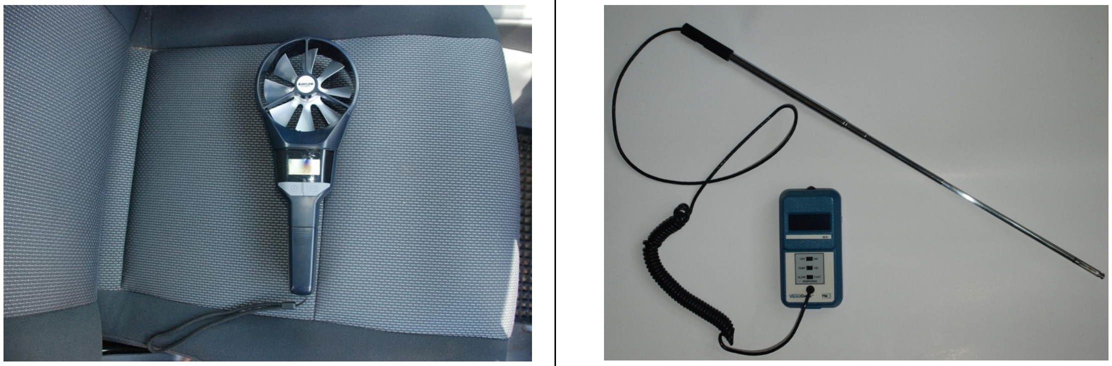
The testing of fume hoods can be in an “as found” condition or fume hoods can be manipulated to represent optimal conditions prior to testing. The “as found” condition reflects actual operating conditions and for this reason is the preferred method of testing. What this implies is that test conditions are not simulated. If a fume hood or fume hoods in a laboratory are off then they would need to be switched on individually, tested and switched off again before the next hood is tested. If hoods are operating they need to be tested and left operating. The same applies to the ventilation and air-conditioning systems in laboratories. If on, they should be left on, if off they should be left off. Materials found in fume hoods should be left as found and the fume hoods tested irrespective of this.

The location of equipment and apparatus affects the airflow patterns within fume hoods. Reverse flow and turbulence are increased as a result of poor equipment location, resulting in poor airflow across the face (3). As air flows around an object a phenomenon known as “boundary layer separation” occurs with a resultant turbulence wake on the downstream side of the object. If the object in question is a person who is busy working with a contaminant source, recirculation of the contaminant into the breathing zone is likely (4).

1.10 Test Instrumentation

1.10.1 Air Velocity Meters

In order to accurately assess fume hood performance, specialized equipment is required. Instruments used to measure air velocity are known as anemometers. An important consideration in selecting the most appropriate piece of equipment to perform fume hood testing is whether the instrument can be calibrated to national and international standards. Other considerations include required accuracy, ease of use, whether equipment can provide immediate readings and the robustness of equipment (18). Figure 1.3 illustrates two variations of anemometers namely a thermal anemometer and a rotating vane anemometer.



Vane anemometer

Thermal anemometer

Figure 1.3 Examples of air velocity measuring devices

Thermal anemometers respond to the amount of heat removed by an air stream passing a heated probe located in the front tip of a probe wand. The rate of heat removal corresponds to air velocity (18). The faster the air moves across the thermal probe the quicker will be the rate of cooling with the instrument recording this as an increase in air velocity. Thermal anemometers are the most frequently used instruments to measure velocities at fume hood faces. This is because they are convenient and have quick response times. The wand and probe are thin enough to have little effect on airflow patterns and the wand’s length allows one to keep one’s body out of the air stream near the probe (18).

1.10.2 Standard Velocity versus Actual Velocity

Standard velocity is the velocity the air would be moving if the temperature and pressure were at standard conditions. Standard conditions are assumed to be 21 ˚C and 760 mm Hg (17). It is usually the most useful measure of airflow because it defines the heat-carrying capacity of air. Actual velocity is the velocity at which a microscopic particle of dust would be traveling if it were in the airstream.

Because actual air density is rarely equal to air density at standard conditions, actual velocity usually differs from standard velocity (19).

1.10.3 Air Current Indicators

An anemometer measures air velocity, it does however not indicate the direction of air-flow. In order to establish wind patterns and the direction of airflow during testing, smoke can be used to provide visible evidence. Airflow patterns are important to establish in order to confirm that air is actually being drawn into the fume hood and not being pushed out. An anemometer will provide a reading in both instances and unless the direction of airflow is confirmed, erroneous deductions can be made. Dräger air current tubes are used to generate smoke. These tubes are made of glass, the tube itself is sealed and filled with a material that is impregnated with fuming sulphuric acid. In order to use the tube, the two ends are broken off, air is pumped into the tube by means of a rubber bulb with the water vapour in air reacting with the fuming sulphuric acid, producing a sulphuric acid aerosol, which emerges in the form of a white smoke (20). Figure 1.4 shows a Dräger air current tube and a bulb aspirator.

Figure 1.4 Dräger air current tube with a bulb aspirator

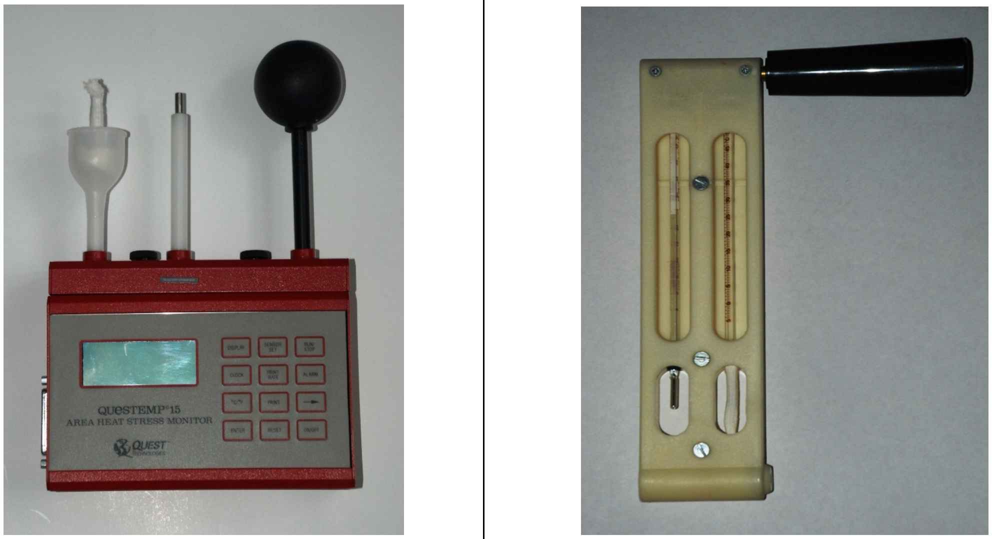
1.10.4 Temperature Measurement Devices

A number of instruments can be used to measure ambient climatic conditions. It is important to measure the humidity in air and ambient temperature because these parameters relate back to standards used when calibrating equipment and can also influence fume hood performance. Mechanical, as well as electronic devices, are available to measure temperature parameters. The instrument one uses needs to be calibrated at least annually to traceable national and international standards.

Figure 1.5 illustrates a psychrometer and a digital heat stress monitor. The psychrometer is a mechanical device requiring an operator to physically rotate the device for a period of time before temperature readings are taken. It then requires the use of a nomogram or psychrometric charts where the readings are plotted in order to establish the relative humidity. The psychrometer is fitted with two mercury-in-glass thermometers that measure temperature.

The digital heat stress monitor displayed in figure 1.5 is a “Questemp 15” area heat stress monitor (21). This instrument is capable of measuring the dry bulb (DB), natural wet bulb (WB) and Globe (G) temperatures and combine these readings into an index known as the WBGT index, electronically. To measure relative humidity, the instrument uses a cotton wick immersed into a reservoir that is filled with distilled water. The instrument can calculate both the indoor and outdoor WBGT and does so according to the following formulas:

- **WBGT (indoor) = 0.70 WB + 0.30 G**
- **WBGT (outdoor) = 0.70 WB + 0.20 G + 0.10 DB**



"Questemp 15" area heat stress monitor

Psychrometer

Figure 1.5 Examples of temperature measurement devices

1.11 Importance of the Study

Fume hoods have become commonplace in laboratories worldwide. No mandatory performance or test standard for the laboratory fume hood exists in South Africa. The author observed, on separate occasions, a fume hood maintenance contractor and an AIA carrying out fume hood performance testing by solely measuring face velocities. Upon questioning their reasoning for performing this test, no clear answer with reference to any test standards mentioned in this report, was provided.

Once a performance standard has been set, manufacturers and suppliers need to supply fume hoods that perform according to this standard. Further, once installed, fume hoods need to perform according to the set standard indefinitely. The important questions to ask are thus: i) do the fume hoods in use within a company perform according to the set standard?; ii) what test method/s should be employed to test fume hoods? and; iii) is it sufficient to test them once every 24 months as required by South African legislation (1)?

It is envisaged that a study of fume hood performance over time would initiate further dialog amongst authorities responsible for the setting of laboratory fume hood performance standards in South Africa, the manner in which to test performance and the frequency of such tests. It is further hoped that such a study would assist health and safety legislators in South Africa to compile a set of guidance notes for the South African industry on the correct use of laboratory fume hoods.

1.12 Aims of the Study

The study presented in this research report aims to establish fume hood performance over a period of time. The performance will be evaluated against a set standard using a recognized performance measurement standard.

This study will provide valuable information on how a particular set of laboratory fume hoods performed over time. Findings can possibly be used to calculate time frames according to which fume hoods should be tested and to decide upon suitable method/s to use in order to carry out fume hood performance testing.

1.13 Research Objective

1.13.1 First Objective

To measure face velocities of fume hoods as installed in a forensic science laboratory and calculate the averages, and to determine whether these comply with a set standard.

1.13.2 Second Objective

To measure face velocities of fume hoods as installed in a forensic science laboratory and calculate the average in order to determine their performance over time.

1.13.3 Third objective

To observe laboratory fume hoods as installed in a forensic science laboratory to see whether fans and sashes were operational each month for 11 months (i.e. down time).

1.14 Outline of Report

Chapter one provided the reader with an overview of what a laboratory fume hood comprises and background information into standards and test methods and then moved on to chapter two where the methods employed to test the actual performance of the fume hoods that comprised the study groups, are discussed.

Results obtained can be found in chapter three. A discussion on the results, the study limitations and assumptions are provided in chapter four. Recommendations and concluding remarks can be found in chapter five.

The attached appendices contain data which provides the reader with all the measurement data obtained during the study and supporting documentation used.

CHAPTER 2

2.0 METHODS AND MATERIALS

Chapter two starts by identifying the study setting in which measurements took place. It moves on to the actual methods employed to take measurements, including preparatory work, instrumentation used and the steps in the measurement process. Thereafter how quality of methods and measurements were ensured and how data was managed and analysed are discussed and ends with the ethics approval and considerations for the entire project.

2.1 Study Design

A longitudinal study over 11 months.

2.2 Study Setting

The FSL has five sites throughout South Africa. These are Silverton and Arcadia in Pretoria, Durban, Port Elizabeth and Cape Town. The FSL head office is situated at the Silverton laboratory. The FSL forms part of the larger Criminal Record and Forensic Science Services Division within the SAPS. Within the Division there are numerous forensic field laboratories. Most of these also have fume hoods installed. In total there is close on 200 fume hoods installed in laboratories operating within the Division. The largest concentration of fume hoods is at the FSL in Silverton, Pretoria. A total of 49 fume hoods are installed here.

The Silverton, Pretoria, site was selected for the study because of the large number of fume hoods. It was felt that 49 fume hoods would provide sufficient data to work with. All 49 fume hoods were selected to form part of the study population, irrespective of whether they were working or not. The study was conducted over an 11 month period. In total, 10 tests, conditions permitting, were conducted and 10 observations made on each fume hood over the 11 months. It can therefore be said that 10 sets of data were collected for every fume hood.

2.3 Measurement Methods

2.3.1 Identification of Fume Hoods

Prior to the commencement of measurements, all fume hoods identified as part of the study population were labeled individually with unique numbers. These numbers were written with a permanent marking pen in a conspicuous location on the front part of the fume hood.

2.3.2 Test Procedure

To evaluate the performance of the fume hoods, the ASHRAE test method (14) was used as a guideline. Face velocity measurements in particular were used. Although the test method calls for three types of tests, face velocity measurements were preferred because tracer gas testing was impossible due to the expense and unavailability of such equipment whilst flow visualization can be very subjective and difficult to report on in a study of this nature.

2.3.2.1 Measurement Grids

Laboratory personnel who utilise the fume hoods were interviewed to establish at what height the sash is placed whilst the fume hood is in operation. The heights vary because certain fume hood’s dimensions differ and also the applications of fume hoods differ. Some fume hoods are for example used for distillations. In such instances the sash is opened, the distillation process started and the sash closed until the process is completed. Other processes require persons to work constantly inside the hood. In such cases the sash needs to be high enough to allow the operator’s arms to be placed inside the hood to work.

Once sash operation heights were established, a mark was made using a permanent marking pen on the horizontal plane in line with the lowest point of the sash. The opening was measured using a “Pro Tool” measuring tape in the horizontal and vertical planes and divided into squares so that any dimension of each square would not exceed 30 cm in line with the ASHRAE standard (14) requirements. The squares were then divided in half both vertically and horizontally in order to obtain the centre point of each square. These centre points were then marked out on the fume hoods with a permanent marking pen by drawing lines on both the vertical and horizontal planes of fume hoods. On the vertical plane, lines were drawn on the side wall of the fume hood and on the horizontal planes on the airfoil sill. Figure 2.1 illustrates these markings.

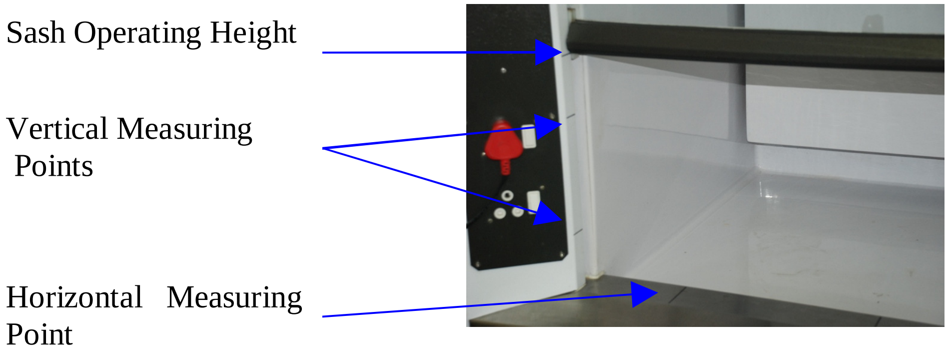


Figure 2.1 Horizontal and vertical measuring points including the marking point for the sash operating height

2.3.2.2 Material Evidence

Before each test was conducted, a photograph was taken of the fume hoods and a video recording of the laboratory in which the fume hoods were situated. This footage was used to assist with the evaluation of the fume hoods' performance should face velocity measurements of individual fume hoods have differed significantly over the test period. It provided visible evidence of actual environmental conditions in the laboratory and inside the fume hood in terms of work practices pertaining to the storage of material, at the time of testing. This footage was archived.

2.3.2.3 Temperature Measurements

Temperature measurements were taken using a “Questemp 15” electronic heat stress monitor. Measurements of the wet bulb, globe and dry bulb temperatures as well as a WBGT indoors reading, were taken. Measurements were taken as follows:

- The instrument was placed in a central position inside a laboratory where fume hoods were to be tested;
- The instrument was placed, where possible, in such a manner that air currents from diffusers and air-conditioners were avoided;
- The reservoir housing the wick for wet bulb measurements was filled with distilled water;
- The instrument was turned on and set to the “run” function to start recording measurements, and;
- The instrument was allowed to run for at least 10 minutes before any readings were taken.

2.3.2.4 Face Velocity Measurements

A thermal anemometer was used to measure face velocities. This was the instrument of choice because of its design and accuracy. The specific thermal anemometer used was a

“Velocicheck” model 8330. The measurement range of the instrument is 0.00 to 20.00 m.s^{-1} with a design accuracy of ± 5.00% of the reading or ± 0.02 m.s^{-1} whichever is greatest (19). The ASHRAE standard (14, p. 10) stipulates the use of an anemometer that can measure in the range of 0.25 to 2.00 m.s^{-1} with an accuracy of ± 5% of the reading. The instrument is fitted with an extention wand and probe. The length of the wand is 94 cm which allows for the person testing the fume hood to stand to the side of the fume hood’s face whilst taking measurements. This ensures that interference with the fume hood’s actual performance is kept to a minimum. Figure 2.2 shows the position of the person taking measurements in relation to the wand and probe position.

Figure 2.2 Measurements being made of the face velocity of a fume hood using a thermal anemometer

The face velocity measurement procedure executed during the study was as follows:

- A smoke test was performed to determine whether the fume hood was in fact exhausting air and not expelling it back into the laboratory. Figure 2.3 is a demonstration of this;

- The instrument was turned on and the velocity and the fast response modes selected;
- The probe was extended and care was taken to place it perpendicular to the face and in the plane at the center of the sash depth as recommended by the ACGIH (18, p. 3-14);
- A trained observer assisted in positioning the probe over the horizontal and vertical markings indicating the measuring points. This was done by the person standing approximately two meters from the face front and instructing the person taking the measurements in which direction to move the probe. Once the observer indicated that the probe was in position, the person taking the measurements would hold the position until measurements were taken;
- Avoiding distortion of the probe readings due to probe movement or obstruction to flow is also important. Arm tremor can introduce enough movement to the probe tip to inflate the instrument reading of air velocity (18). In order to avoid this, the base of the probe was held against one edge of the fume hood face;
- The observer would move away from the front of the face once he had indicated the probe position. This was done to avoid any interference with airflow patterns prior to taking measurements;
- The sensor was allowed to warm up for at least 20 seconds in the flow, and;
- The person taking the readings would check the reading on the instrument and convey it to the observer. The observer would record the reading on a form specifically designed for this purpose. An example of this form is attached as appendix A.

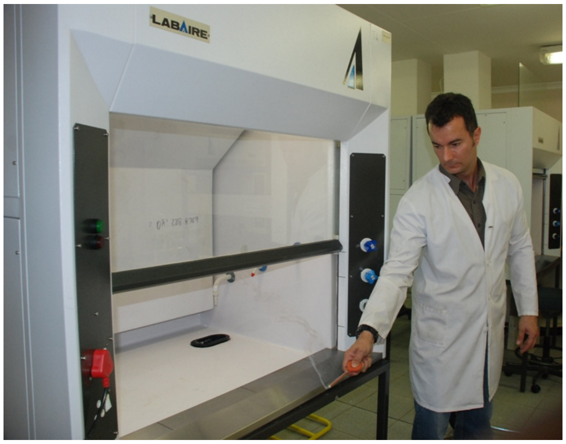


Figure 2.3 Determination of the direction of airflow at the face of a fume hood using smoke tubes

2.4 Quality Control

2.4.1 Instrumentation

2.4.1.1 “Questemp 15”

Calibration certificates for the “Questemp 15” are attached as Appendix B. The instrument was “externally” calibrated prior to the study commencing, and again once the entire study was completed. This was done to determine whether any drift occurred in the instruments accuracy from the time the study commenced until the end of the project. In this way, any inaccuracies that may have crept in during the study could readily be identified. Further, any drift in measurement accuracy could also be related back to the actual measurement values obtained during the study. The calibrations were carried out by SANAS accredited laboratories external to the SAPS hence the term “externally calibrated”. The instrument was also calibrated every morning prior to measurement taking using a calibration sensor module as supplied with the instrument. Readings had to match those printed on the module within ±0.50 °C. This type of calibration is referred to as “internal” calibration because it is performed by the user of the instrument and internal to the organisation.

2.4.1.2 “Velocicheck”

Calibration certificates for the “Velocicheck” are attached as Appendix C. This instrument was returned to the manufacturer for calibration both before and after the study. The instrument was calibrated to standard conditions. For this specific instrument this implies a temperature of 21.1 ˚C and a barometric pressure of 760.0 mm Hg as stated on the calibration certificates. Before each fume hood was measured, the thermal anemometer was checked for a zero reading by turning the instrument on with the measurement probe shielded. This implies that the instrument should give a zero reading because no air is flowing over the thermal sensor. This was deemed the “internal” calibration prior to each use.

2.4.1.3 “Dräger”

All the smoke tubes had expiry dates. They were used prior to the expiry dates reached. The smoke test in itself was also a quality check to see whether fume hoods were in actual fact extracting air and not blowing air back into laboratories.

2.4.2 Repeatability

The same test positions were used throughout the study. The author conducted all measurements during the study and followed the same test procedure every time measurements were taken.

2.5 Data Management and Analysis

2.5.1 Documentation

A form was specifically developed to record all measurements. An example of this form is attached as Appendix A. The form made provision for the recording of data under the following headings:

- Fume hood unique identity number;
- Date of measurement;
- Time of measurement;
- Width of fume opening;

- Height of fume opening;
- Width of measuring grid;
- Height of measuring grid;
- Average reading;
- Highest reading;
- Lowest reading;
- Readings;
- Visualisation challenge, and;
- Temperature measurements.

2.5.1.1 Fume Hood Unique Identity Number

This number, unique to every fume hood in the study, was pre-recorded so that every fume hood already had a set of forms available prior to the onset of the study. This particular example indicates that fume hood number “T1” was tested.

2.5.1.2 Date of Measurement

Here the day the actual measurements of the fume hood took place was recorded.

2.5.1.3 Time of Measurement

The exact time the face velocity measurements were taken of a particular fume hood was recorded.

2.5.1.4 Width of Fume Opening

The width of the face of the fume hood was recorded here. Once initially recorded, this information remained a fixture on the form because it is a constant given that the fume hood was constructed with this width as a standard feature.

2.5.1.5 Height of Fume Opening

This is the height of the face opening and was measured from the graduation mark at which the sash was set, based on operator use, down to the airfoil sill. This information remained fixed throughout the test period.

2.5.1.6 Width of Measuring Grid

Once the width of the face was determined it was divided into segments that did not exceed 30 cm in line with the ASHRAE standard (14). These divided lengths were permanently recorded on this form. In this particular instance a segment was 30 cm wide.

Three segments were thus created in that the width was 90 cm which was divided to get it into segments ≤ 30 cm thereby forming three segments of 30 cm each.

2.5.1.7 Height of Measuring Grid

As with the width of the fume opening, the height measured was divided into segments that did not exceed 30 cm. Two equal segments of 18 cm each were thus formed. This value was also recorded permanently on the form.

2.5.1.8 Average Reading

Once the face velocities at the centre of the grid points were measured and recorded, the arithmetic mean was calculated and recorded as the “mean face velocity”.

2.5.1.9 Highest Reading

Grid centre point readings were evaluated and the highest reading recorded as the “highest reading”.

2.5.1.10 Lowest Reading

Grid centre point readings were evaluated and the lowest reading recorded as the “lowest reading”.

2.5.1.11 Readings

A sketch was drawn based on the number of grids as determined by the height and width of the face opening. Measurements were taken at the centre point of each grid, recorded in ink as the “face velocity measurements” and, once the study was completed, typed.

2.5.1.12 Visualisation Challenge

All that was recorded for this variable was whether the fume hood actually extracted smoke or not. A cross was marked in the “yes” column if smoke was extracted. The “no” column was marked if smoke blew back into the laboratory or if no smoke was extracted.

2.5.1.13 Temperature Measurements

The wet bulb, globe, dry bulb and WBGT indoor readings were recorded. Provision was made for calibration readings to be recorded under the “internal calibration” heading.

2.5.2 Means and Percentages

The ASHRAE standard (14) requires the average velocity to be calculated and for the noting of the highest and lowest velocities. The average velocity was calculated by calculating the arithmetic mean. This was done using the following formula:

- $\sum xi / n$

Where:

$\sum xi$ = sum of all individual face velocities for the fume hood

n = number of all individual face velocities for the fume hood

The mean was calculated for every test period for every fume hood measured. The highest and lowest values were identified on every occasion by identifying them from the measurement grid. A velocity profile around the mean was ascertained by comparing the percentage difference of the highest and lowest readings to the mean. Ideally any one reading should not be 20% more or less than the average. This according to the ANSI/AIHA Z9.5 – 1992 standard (3) and guidance notes on the maintenance, examination and testing of local exhaust ventilation (22) issued by the HSE. The ACGIH (23) states that it is undesirable for velocities to deviate more than ± 20% from the mean velocity spatially. Fume hoods with mean velocities ≥ 0.62 $m.s^{-1}$ of the FSL standard were considered to be overperforming. Those with velocities of ≤ 0.40 $m.s^{-1}$ were considered to be underperforming. To further establish fume hood performance, deterioration in performance over the test period was determined by comparing the mean of the first set of tests for each fume hood with the lowest mean for that fume hood. Further, the difference between the highest and lowest mean for each fume hood was calculated to find the fume hoods with the biggest range.

2.5.3 Statistical Analyses of Data

2.5.3.1 Statistical Methodology

Data were entered into an MS Excel spreadsheet and analysed to obtain simple descriptive statistics reporting the mean, standard deviation, range and median.

Further analysis of the data was done by importing the data from the MS Excel spreadsheet into STATA 9. An analysis of variance (ANOVA) was used to assess for the effect of time and stations on velocity measurements.

Prior to analysis, a Bartlett test was performed which indicated that the null hypothesis of non-constant variance could not be rejected. This indicated that a non-constant variance between groups existed and could probably be attributed to a few groups in the population with small numbers of measurements. The data was not normally distributed. Despite this, ANOVA was used to assess data because it is generally agreed that parametric tests may be used if sample size is large enough. A non parametric Kruskal-Wallis test, which is the equivalent of an ANOVA, was also performed and showed similar results.

A regression analysis was also carried out to assess if there was an ordered direction in velocity measurements across months.

2.6 Ethical Consideration

The study did not involve human subjects. Because fume hoods were tested in an “as found” condition no disruption to normal use took place. Laboratory personnel who were using a fume hood directly prior to testing were merely asked to step aside so as not to influence measurements, and testing was then performed. All fume hoods found not to be working or found underperforming (‹ 0.41m.s^{-1}) were identified and the relevant laboratory supervisor informed thereof on the day of measuring.

A letter received from the Human Research Ethics Committee (Medical), indicating that this project did not require any clearance, is attached hereto as Appendix D.

CHAPTER 3

3.0 RESULTS

This chapter starts by looking at the results of the quality assurance measures employed during the study. It then sets out the actual results obtained starting off with a presentation of face velocity measurement results, the performance of the fume hoods in relation to the set standard and observation results. The chapter ends with the results of statistical analyses carried out on the data.

3.1 Quality Control Test Results

3.1.1 “Questemp 15”

The calibration certificate issued by “ABB Powertech” shows the uncertainty of measurement to be ± 0.5 ˚C. This certificate was issued prior to the study commencing. The calibration certificate issued by the “CSIR” after cessation of the study, indicates a ± 0.4 ˚C uncertainty of measurement. What this implies is that, at worst, any reading given by the instrument lay within ± 0.5 ˚C of the actual temperature.

When calibrated internally directly prior to using the instrument, all readings fell within the required parameters of ± 0.50 ˚C of the manufacturers specifications (21).

3.1.2 "Velocicheck"

The calibration certificates for the thermal anemometer indicate velocity tolerance limits to be ± 5% or 0.025 $m.s^{-1}$. This indicates that the true reading is within ± 5% or 0.025 $m.s^{-1}$ of that displayed by the instrument. The instrument passed its calibration testing in both instances. If one looks at the calibration certificates and takes the calibration standard closest to the FSL standard of 0.51 $m.s^{-1}$, the first certificate indicates a calibration standard of 0.502 $m.s^{-1}$ and the second certificate 0.504 $m.s^{-1}$. The instrument output was 0.495 $m.s^{-1}$ (-1.4%) and 0.499 $m.s^{-1}$ (-1.0%) respectively. Both readings are close to the calibration standard and indicate the instrument's accuracy around the FSL standard.

All internal calibration checks whereby the instrument's measurement probe was tested for functionality by obtaining a zero reading, were in order.

3.1.3 Smoke Tests

Smoke tubes worked well in generating visible smoke. All fume hoods satisfactorily extracted smoke when tested prior to taking face velocity measurements.

3.2 Face Velocity Measurement Results

Table 3.1 shows the face velocity measurements recorded over the entire measurement period for fume hood “T1”. “T1” was a typical fume hood and table 3.1 thus exemplifies the data collected for each fume hood over the study period of 11 months. 10 Sets of measurement data are presented representing the 10 test periods. All the face velocity data sets were taken and placed in a table where the mean for every data set was calculated and the highest and lowest measurements listed. This table is attached to the report as Appendix E. An excerpt of this table representing fume hood “T1” is presented below as table 3.2. Every mean value obtained was compared to the standard of 0.51 $m.s^{-1}$ as set by the FSL. If the calculated mean was less or greater than the set standard by more than 20% the value was highlighted in red. If it was within 20% of the set standard, it was highlighted in green. The highest and lowest readings were evaluated in relation to the calculated mean. If the two readings were within 20% of the mean then they were highlighted in green. If outside 20% then they were highlighted in red. To illustrate, if one looks at table 3.2, one will see that measurement number 1 (2006-04-04) has a highest value of 0.95 $m.s^{-1}$ and a lowest value of 0.64 $m.s^{-1}$. The calculated mean face velocity of 0.83 $m.s^{-1}$ was used as the value to which the highest and lowest readings were compared.

Temperature measurements are not mentioned and have not been factored into this report has no major temperature fluctuation, which may have had an influence on face velocity measurement results, occurred during the study period.

Table 3.1 Face velocity measurements for fume hood “T1” as recorded over 10 periods

Date	Grid of Face Velocities (m.s^{-1})		
2006-04-04	0.93	0.78	0.75
	0.95	0.64	0.90
2006-05-04	0.93	0.89	0.96
	0.94	0.90	0.99
2006-05-31	1.02	0.93	1.09
	1.09	0.98	1.04
2006-08-22	0.97	0.97	1.00
	0.84	0.97	0.99
2006-09-13	1.19	1.04	0.93
	1.24	0.68	0.73
2006-10-03	1.01	0.95	0.99
	0.96	0.92	0.93
2006-11-07	0.97	0.94	0.97
	0.91	0.92	0.97
2006-12-04	1.25	1.25	1.12
	0.78	0.47	0.47
2007-01-15	1.02	0.97	1.02
	1.02	0.89	0.90
2007-02-13	1.05	0.97	1.01
	0.93	0.86	0.94

Table 3.2 Highest, lowest and mean face velocities calculated for fume hood "T1" over the test period

Measurement Date	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
2006-04-04	0.83	0.95	0.64
2006-05-04	0.94	0.99	0.89
2006-05-31	1.03	1.09	0.93
2006-08-22	0.96	1.00	0.84
2006-09-13	0.97	1.24	0.68
2006-10-03	0.96	1.01	0.92
2006-11-07	0.95	0.97	0.91
2006-12-04	0.89	1.25	0.47
2007-01-15	0.97	1.02	0.89
2007-02-13	0.96	1.05	0.86

3.3 Fume Hood Performance

The face velocity measurement results were taken and all the mean values extracted and compared with one another. The mean of the mean face velocities per fume hood was calculated, the standard deviation, range and median mean readings determined and listed in table 3.3. The table indentifies fume hoods that formed part of the study and further indicates the number of data (measurement) sets used to calculate these means. Table 3.3's data was then taken and the frequency distribution of the face velocities (mean of mean) determined and presented in table 3.4. The eight fume hoods with the biggest deterioration in performance are represented in figures 3.1 (a) – 3.1 (h). Figures 3.2 (a) – 3.2 (h) represent the eight fume hoods with the biggest range between the highest and lowest means.

Table 3.3 Summary face velocities of 49 fume hoods over 11 months of measurement in a forensic science laboratory

Fume Hood	**n ***	**Mean of mean face velocities**	**Standard deviation**	**Median**	**Range**
T1	10	0.95	0.053166	0.96	0.83 – 1.03
T2	10	1.01	0.028694	1.01	0.97 – 1.05
T3	10	1.00	0.035528	1.01	0.93 – 1.03
T4	10	1.04	0.022632	1.04	1.00 – 1.07
T5	5	1.09	0.069857	1.12	0.98 – 1.16
T6	10	1.00	0.073212	1.03	0.81 – 1.08
T7	0	-	-	-	-
T8	10	1.04	0.051034	1.04	0.97 – 1.13
T9	1	1.09	-	1.09	1.09 – 1.09
T10	10	1.26	0.049035	1.25	1.17 – 1.34
T11	7	1.21	0.041173	1.20	1.16 – 1.26
KA	9	0.99	0.087892	1.01	0.83 – 1.09
K03	7	0.47	0.023401	0.48	0.44 – 0.51
115A	10	0.15	0.016997	0.16	0.12 – 0.17
130	9	1.35	0.074068	1.35	1.21 – 1.45
202	10	0.59	0.04492	0.60	0.51 – 0.63
211A	10	0.48	0.018738	0.47	0.46 – 0.51
211B	10	0.50	0.020248	0.50	0.47 – 0.53
310(1)	10	1.41	0.060562	1.42	1.29 – 1.49
311	3	0.72	0.055678	0.71	0.67 – 0.78
318	9	2.15	0.065	2.13	2.05 – 2.27
400A	6	0.73	0.031623	0.73	0.69 – 0.77
400B	10	0.72	0.027508	0.72	0.67 – 0.76
413	2	0.73	0.014142	0.73	0.72 – 0.74
425A	0	-	-	-	-
425B	8	0.68	0.086313	0.66	0.57 – 0.87
511	9	0.53	0.051235	0.53	0.48 – 0.65
517A	9	1.36	0.35082	1.26	1.16 – 2.28
520A	8	1.40	0.159172	1.44	1.15 – 1.64
520B	8	0.67	0.072198	0.69	0.54 – 0.78
520C	1	0.79	-	0.79	0.79 – 0.79
522B	9	0.51	0.028723	0.51	0.47 – 0.55
523	10	1.59	0.142049	1.58	1.36 – 1.82
601	10	1.17	0.045898	1.17	1.11 – 1.23
603	8	0.50	0.031053	0.51	0.45 – 0.53
612A	10	1.26	0.025473	1.27	1.21 – 1.30

Fume Hood	**n ***	**Mean of mean face velocities**	**Standard deviation**	**Median**	**Range**
612B	10	1.29	0.023214	1.29	1.24 – 1.31
618A	8	1.99	0.116082	1.93	1.85 – 2.23
619A	9	0.89	0.086023	0.85	0.81 – 1.02
619B	7	0.97	0.090921	0.92	0.88 – 1.09
622A	9	1.16	0.048218	1.15	1.10 – 1.24
622B	9	1.10	0.02421	1.10	1.07 – 1.14
622C	9	0.93	0.046398	0.92	0.86 – 1.00
624A	3	0.24	0.023094	0.23	0.23 – 0.27
624B	3	0.18	0.040415	0.20	0.13 – 0.20
624C	3	0.19	0.015275	0.19	0.18 – 0.21
624D	2	0.42	0.070711	0.42	0.37 – 0.47
627(2)B	9	0.99	0.021794	0.98	0.96 – 1.02
627(3)C	10	0.49	0.18705	0.59	0.20 – 0.65

* Number of mean face velocities used to calculate mean of mean.

“n” did not equal 10 in all instances as some fume hoods were out of operation at the time of measurement of face velocities.

Table 3.4 Distribution of face velocities (mean of means) of 49 fume hoods in a forensic science laboratory

Mean of mean face velocities ($m.s^{-1}$)	**Number of fume hoods**
0.00 – 0.40	6
0.41 – 0.61	9
0.62 – 0.99	13
1.00 – 1.50	18
1.51 – 2.15	3

From the above tables one can see that only nine out of 49 fume hoods performed within the FSL’s set standard. Two fume hoods were not operational over the entire test period.

The biggest difference recorded between the highest and lowest means (range) was 1.12 m.s^{-1} for fume hood “517A”. Large fluctuations also occurred between face velocity measurements.

The figures that follow (figures 3.1 (a) – 3.1 (h)) show the eight fume hoods the biggest deterioration in performance. Deterioration in performance is taken to be the difference between the mean of the first set of face velocity measurements for a fume hood and the lowest calculated mean for that fume hood. Fume hood “115A” has abnormally low velocities even though it was operational at the time of testing. This implies that the motor of the fan was working however it was generating very little pressure in order to extract air from inside the fume hood.

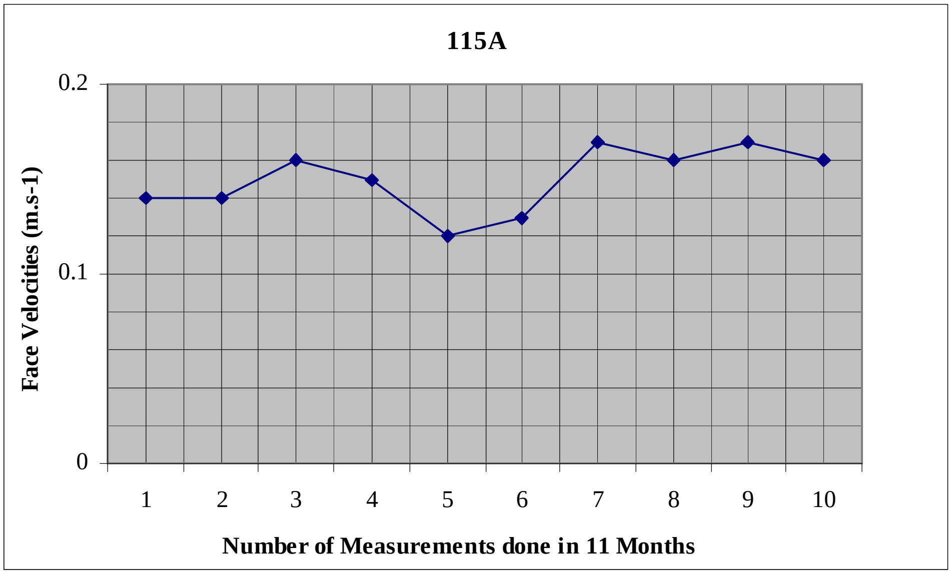


Figure 3.1 (a)

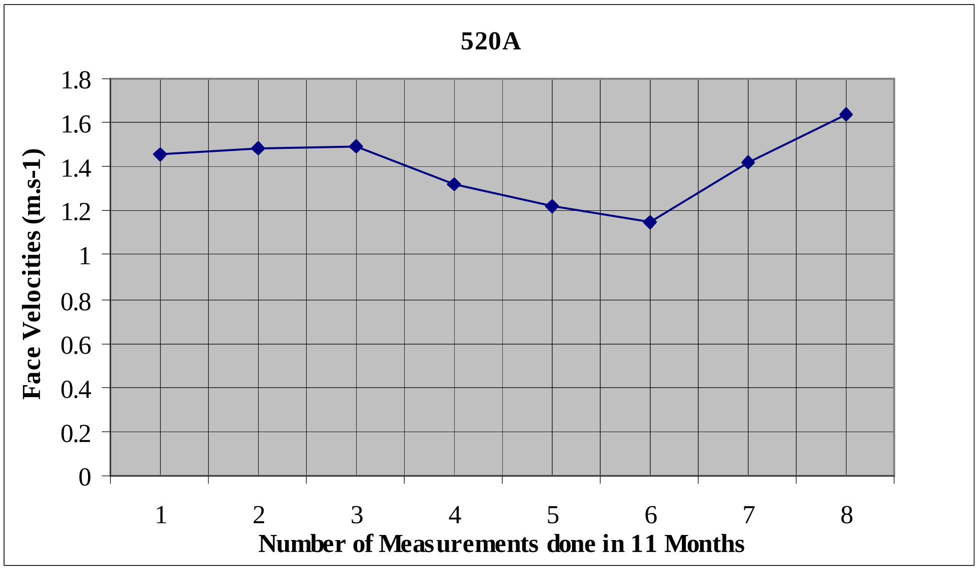


Figure 3.1 (b)

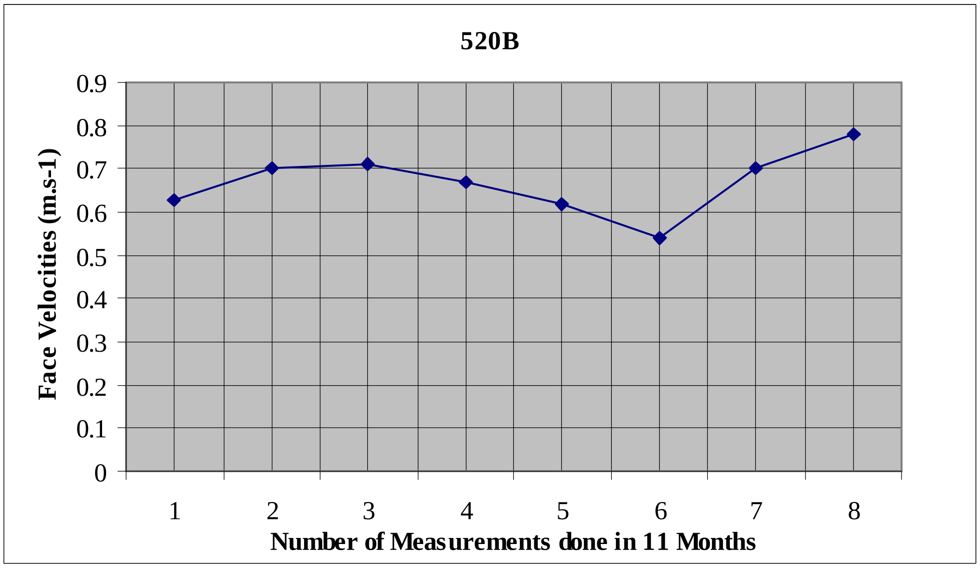


Figure 3.1 (c)

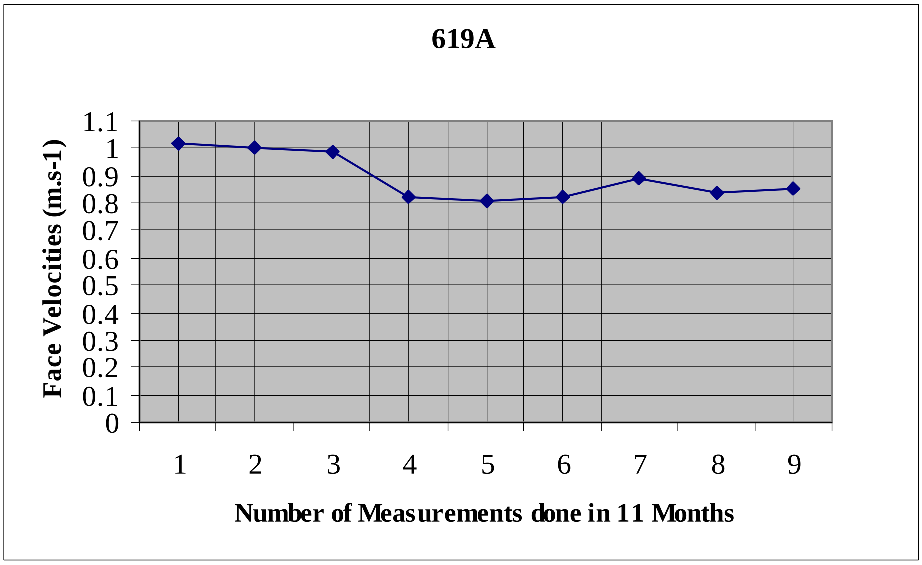


Figure 3.1 (d)

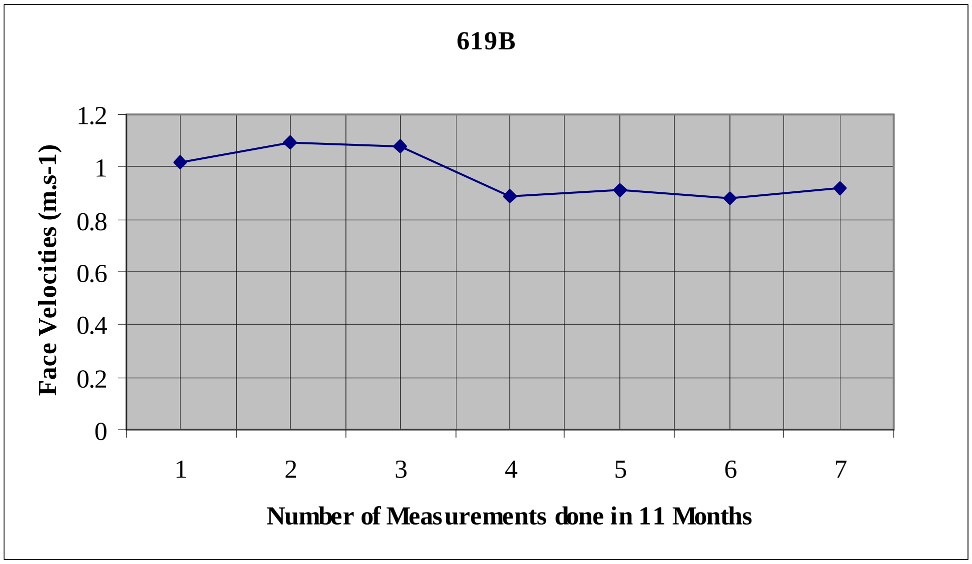
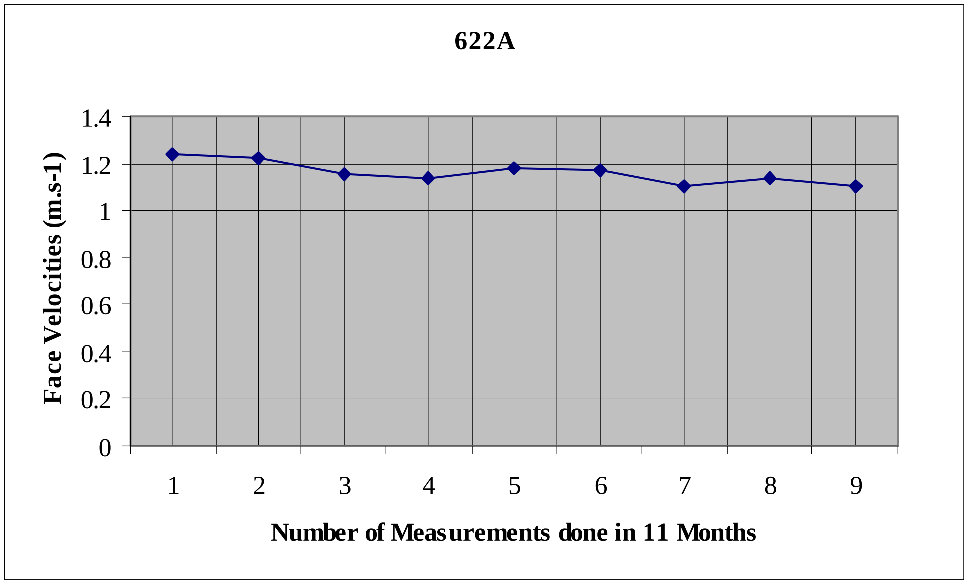


Figure 3.1 (e)



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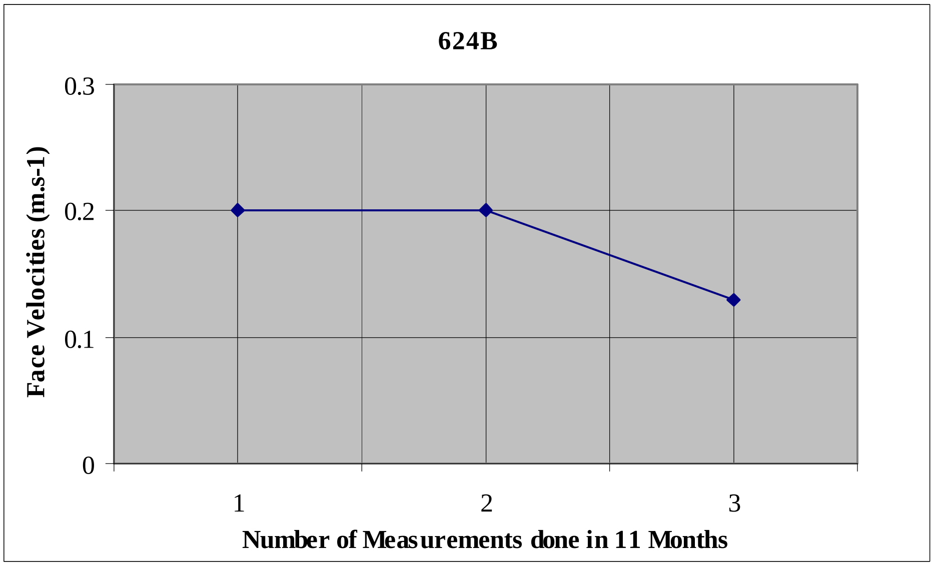

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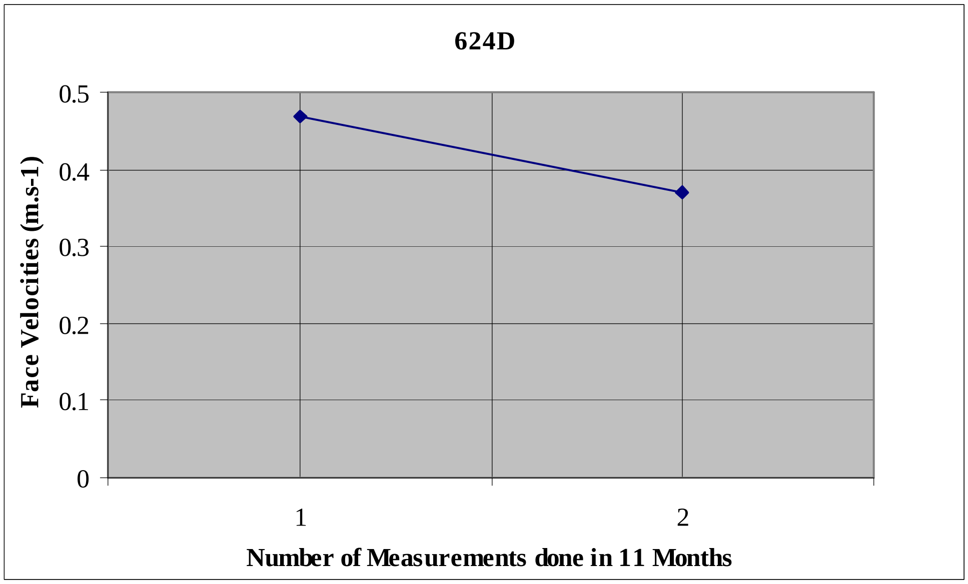
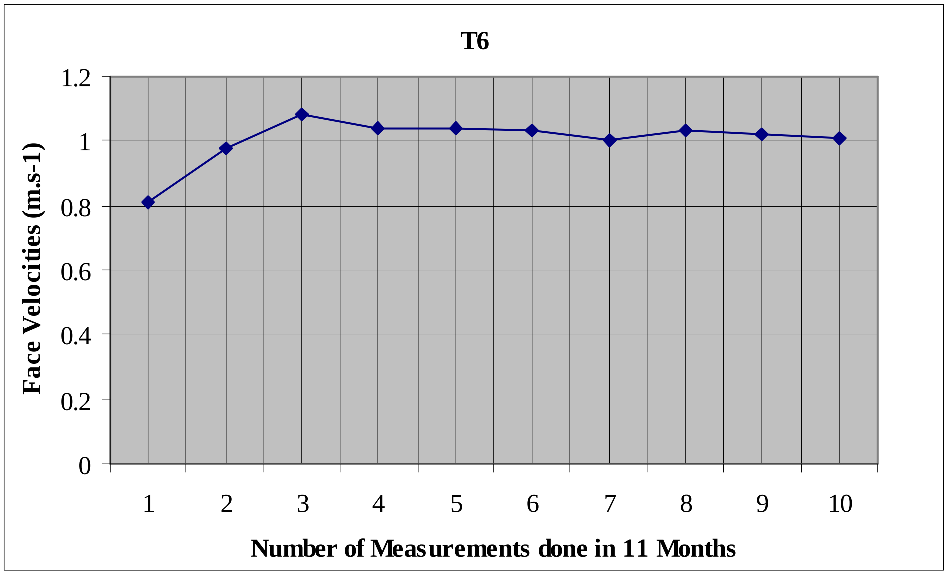


Figure 3.1 (h)

Figure 3.1 (a) to 3.1 (h) Eight fume hoods with the greatest deterioration in performance out of 47 fume hoods in a forensic science laboratory

Figures 3.2 (a) – 3.2 (h) show the mean face velocities over the study period with the biggest range of face velocities. Range is taken to be the difference between the highest and lowest mean.



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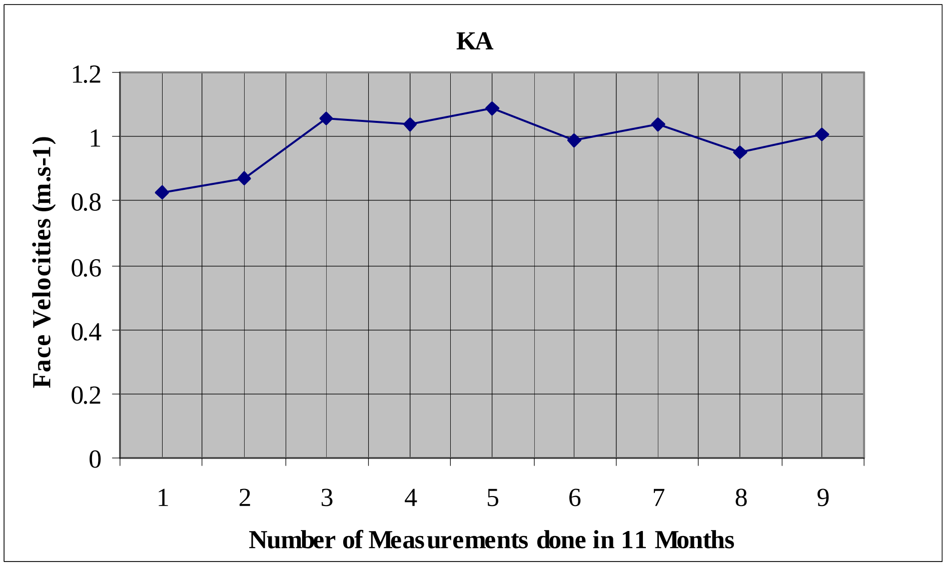

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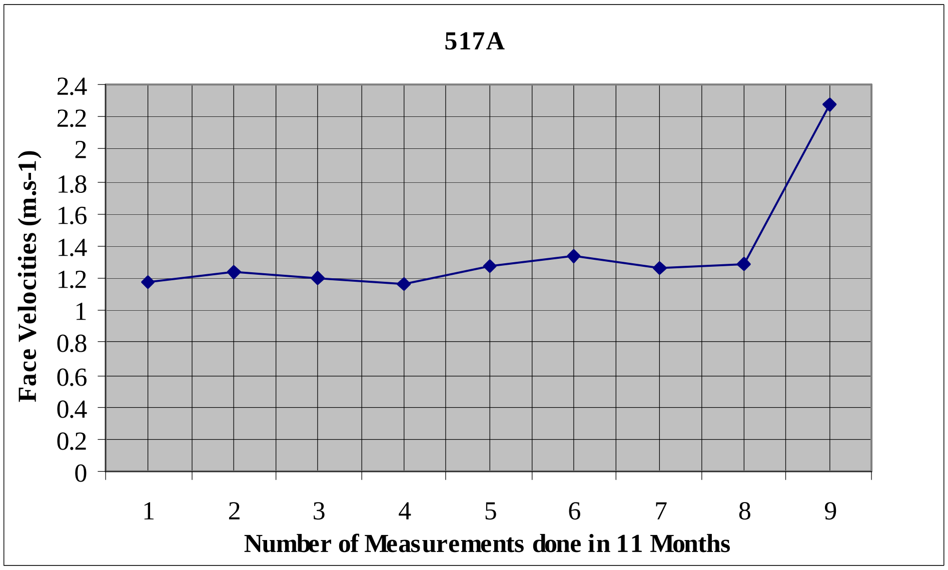

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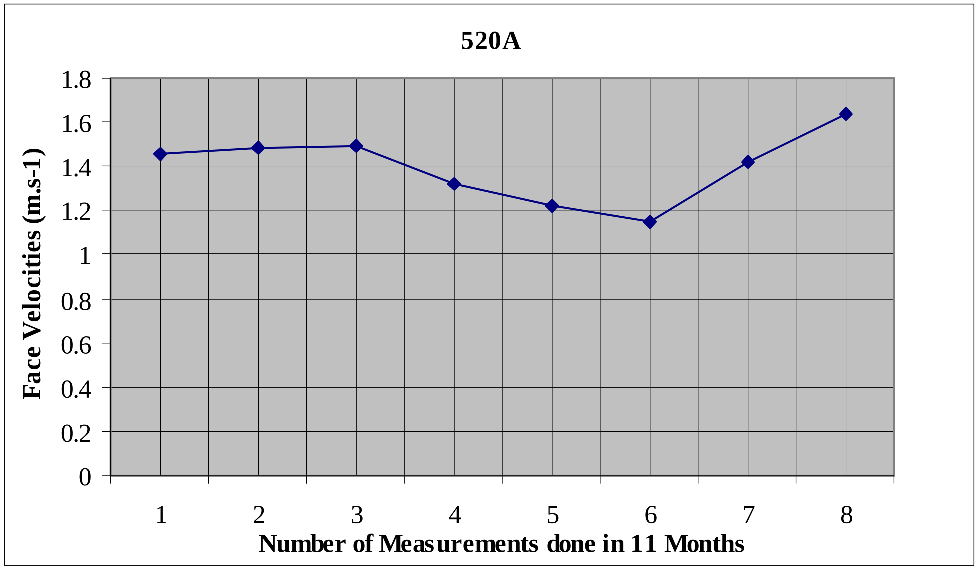

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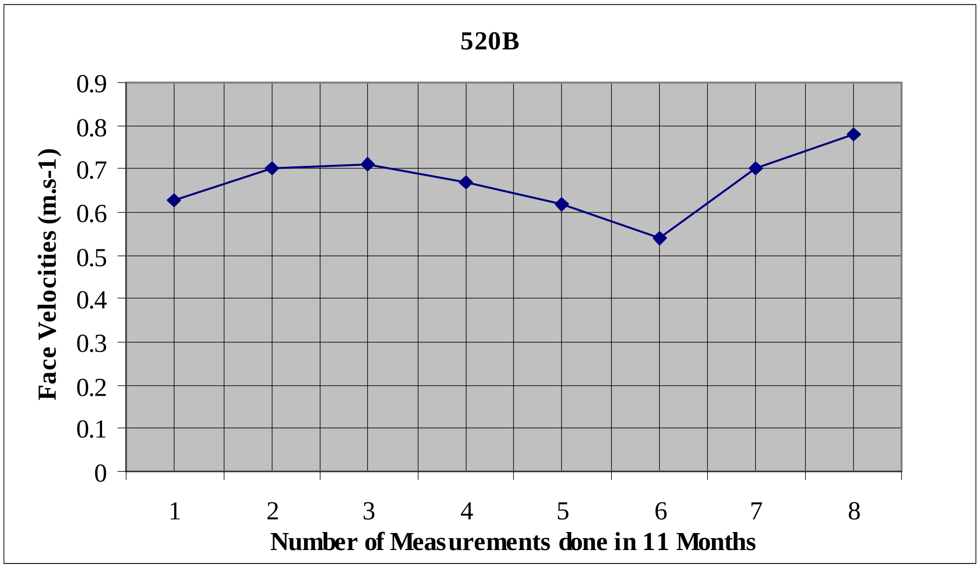

Figure 3.2 (e)

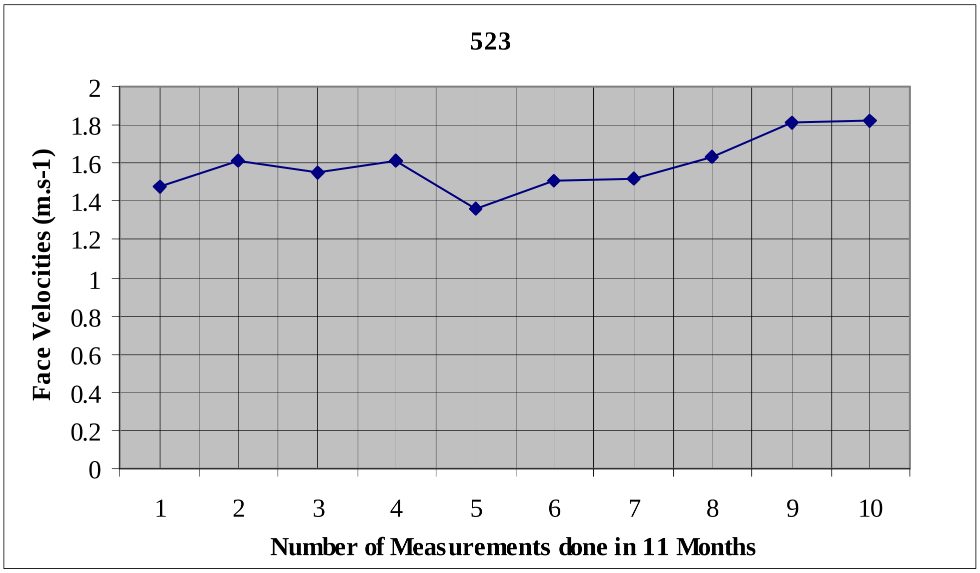

Figure 3.2 (f)

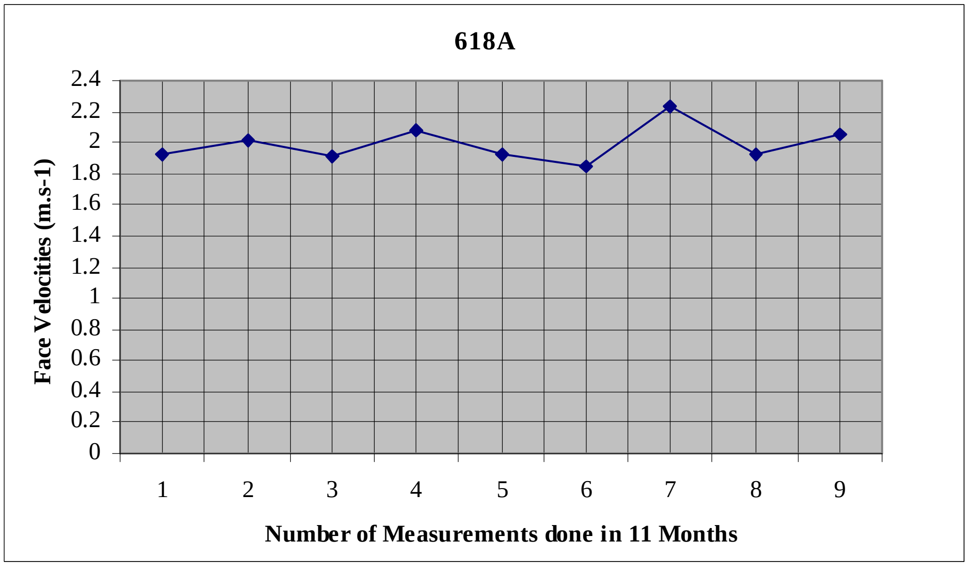

Figure 3.2 (g)

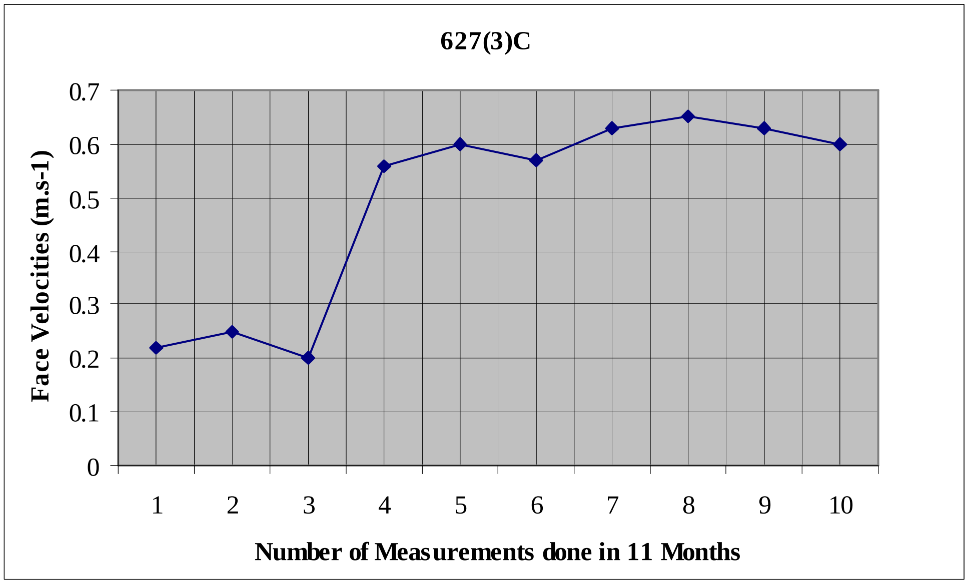

Figure 3.2 (h)

Figure 3.2 (a) to 3.2 (h) Eight fume hoods with the biggest range out of 47 fume hoods in a forensic science laboratory

3.4 Fume Hood Down Time

Every time velocity measurements were carried out on the fume hoods it would also be classified as an observation. Fume hoods were observed over the 10 test periods and those not working were identified and recorded as such. The 10 test periods were thus also classified as 10 observations. Figure 3.3 shows the 10 observation periods and the findings in relation to whether the fume hoods were operating or not.

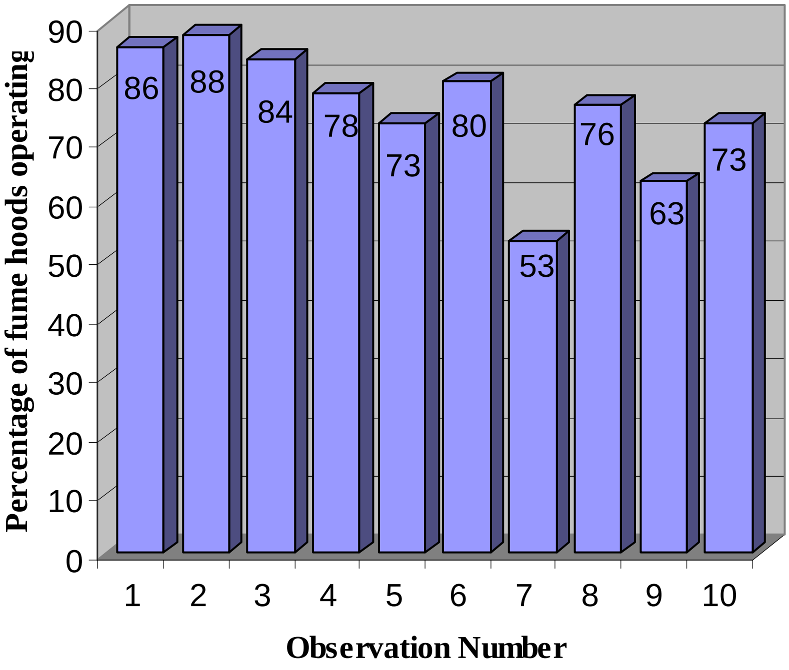

Figure 3.3 Down time of 49 fume hoods in a forensic science laboratory

3.5 Statistical Analysis

3.5.1 Time Effect on Mean Face Velocity

3.5.1.1 ANOVA

The results of the ANOVA test carried out to assess the effect of time on the total variability within the dataset can be seen in table 3.5. The results show that predicted variability (between month variability) is very low compared to the error variability (within month variability). The null hypothesis, that there is no significant difference between groups (months), can thus not be rejected (there was no significant difference between months). This result shows that significant increase or decrease in face velocities did not occur over time. The Kruskal-Wallis test presented with a P value of 0.896.

Table 3.5 ANOVA test to assess variability in mean face velocity over time

Source	**SS**	**df**	**MS**	**F**	**Prob › F**
Between Groups	.905597895	9	.100621988	0.53	0.8538
Within Groups	68.5425109	360	.190395864		
Total	69.4481088	369	.188206257		

3.5.1.2 Regression Analysis

It is possible that the mean face velocities of fume hoods drifted systematically up or down over the study period. To determine whether this occurred the mean face velocities at each month for the 47 hoods were regressed on month of measurement. No significant linear drift in face velocity was observed over the study period (figure 3.4).

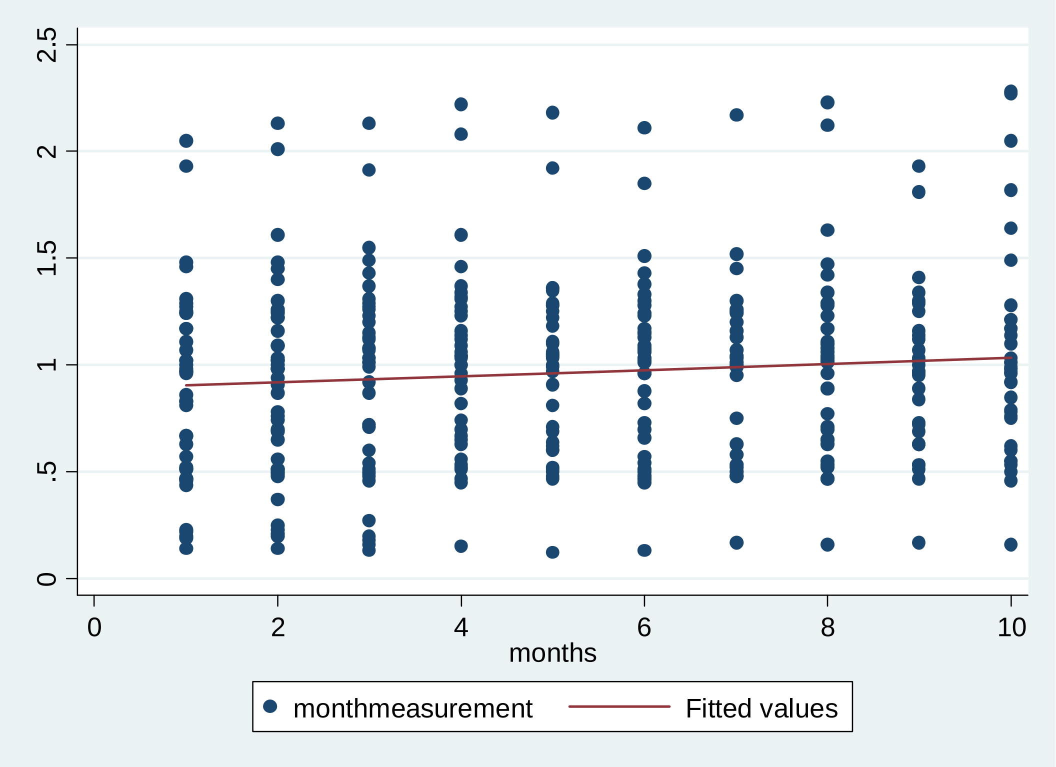

Figure 3.4 Regression analysis of velocity measurements

CHAPTER 4

4.0 DISCUSSION OF RESULTS

In chapter four, results set out in the previous chapter are discussed. The chapter starts with a brief summary of the study aims and the main finding of the study. It then moves on to the limitations of the study before discussing the main findings in detail under the headings of the research objectives as originally spelt out in chapter one.

4.1 Study Aims and Major Findings

The study aimed to evaluate the performance of laboratory fume hoods.

The main findings of this study are that fume hood performance relating to down time varied greatly over the study period (i.e. fan and sash operability fluctuated depending on repair status). Further, when assessed against the generally accepted standard, many fume hoods at many times during the study performed outside the standard. Performance over time for operating fume hoods, however, seemed to remain fairly constant (i.e. when operational, fume hoods performed within a fairly restricted range during the study period and significant drift did not occur).

4.2 Study Limitations

4.2.1 Performance Measurement

4.2.1.1 Face Velocity

This study measured the performance of fume hoods by measuring the speed at which air flows into the fume hood across its face. Based on this it was found that most fume hoods performed above the required standard of 0.51 $m.s^{-1}$.

It should be noted, though, that performance above the standard may not be a serious matter if the sash is partially closed, because the opening which can be influenced by external factors is reduced. As Saunders (2) has written, a fume hood that was designed to operate at 0.51 $m.s^{-1}$ was designed to do so with the sash fully open. When the sash is partially closed the measured velocity will be close to 0.86 $m.s^{-1}$. Saunders continues to write that some people say it is too high because they have read that face velocities above 0.76 $m.s^{-1}$ can in themselves be detrimental to hood performance. The hazardous 0.76 $m.s^{-1}$ that is being referred to is the velocity when the sash is fully opened. Saunders further says that these higher velocities become less and less of a disruptive factor, regarding operating performance, when the sash is moved to a smaller partially closed position. As the sash is lowered there is less area in the front place of the hood that can be influenced by cross drafts or traffic problems.

As previously stated in chapter two, performance standards generally make provision for a 20% variance around the set standard. Anything outside of this indicates that the fume hood is not performing properly. In comparing this to what Saunders says, a contradiction of statements seems to arise.

FSL fume hoods were originally designed to operate at 0.51 $m.s^{-1}$ with the sash fully open. The study took place with the sash placed in an as used position. In all instances this position required the sashes to be lowered into a partially closed position. This could influence the judgment of performance by condemning a fume hood for over performing whilst such over performance is not necessarily negatively influencing contaminant extraction capabilities.

Face velocity is just one of the three tests called for in the ASHRAE standard (14). Face velocity testing is referred to as qualitative whereas tracer gas testing is considered quantitative (2).

Studies have shown that a significant numbers of hoods that are able to meet face velocity tests are not able to pass containment tests such as the ASHRAE 110 standard (8).

4.2.1.2 Grid Sizing

Measurement grids were determined using the 30 cm x 30 cm standard as prescribed by ASHRAE (14). This yields an average flow rate with an accuracy of ± 20%. Accuracy could have been improved to approximately ± 10% if the number of grid points were increased by 50% (5).

4.2.1.3 Environmental Factors

Fume hoods were tested in an as used condition. This implies that environmental conditions were not identical during every set of measurements. In the winter months air-conditioners were turned off that were usually working during the summer months. In some instances windows and doors to laboratories were open during a measurement session whereas the same windows and doors were closed during a different session. It also happened that, in laboratories with more than one fume hood present, some were operating during testing whilst on a separate occasion all were off during testing. In the latter case, this allowed for each fume hood to be tested individually without interference from any other fume hood. Further, repairs carried out on fume hoods during the study may also have had an effect on their performance, with the possibility that readings may have been influenced after such repair work. Because fume hoods were evaluated in an "as used" condition this effect was not evaluated.

4.2.1.4 Standard and Actual Velocities

Upon evaluating ambient temperature measurements it was decided that they would not be incorporated into the report. This was because the difference between the actual ambient temperature and the standard temperature of 21˚C was not significant. The conversion of standard velocities to actual velocities would have brought about insignificant changes to recorded velocities. All measurements thus reflect standard velocities and were not corrected to actual velocities.

4.3 Major Findings

4.3.1 Research Objective 1 (Face Velocities)

The FSL had set a standard face velocity of 0.51 $m.s^{-1}$ averaged across the face of the fume hood. A deviation of 20% plus or minus was allowed around this standard. This implies that fume hoods operating between 0.41 to 0.61 $m.s^{-1}$ would comply with the standard.

Table 3.4 provides the distribution of face velocities measured during the study. Only nine or 18% complied with the standard. 12% were either not working or underperformed while the rest, 69%, over performed. More than half of those over performing done so at velocities of more than double the set standard.

Hitchings found in a cross-sectional study of 39 fume hoods that only 23 or 59% comply, upon initial testing, with a company’s set standard (25).

The fact that only 18% of the FSL’s fume hoods comply with the set standard is cause for concern. The increased velocities mean that energy is being wasted and the potential for turbulence inside the fume hoods increased.

4.3.2 Research Objective 2 (Performance over Time)

The study population comprised 49 fume hoods. Two fume hoods did not work throughout the study period thus no measurement of performance could be made on them. Of the 47 fume hoods tested, 27 showed a decline between the first mean and the lowest mean. These declines ranged from 35% (highest – “624B”) to 0.85% (lowest – “T11” and “517A”). The remaining 20 fume hoods showed no difference.

The biggest difference recorded between the highest and lowest means was 1.12 $m.s^{-1}$. This was for fume hood “517A”. This fume hood presented with consistent means except for the last mean. This phenomenon was probably caused by the fact that this fume hood ceased to operate at one point, was repaired, and then presented with excessive velocities. The significant differences in means as presented in figure 3.2 can be attributed to repairs effected during the study, poor work practices and/or unsuitable environmental conditions.

A performance comparison was done by taking the mean of the means. There were instances where large fluctuations between face velocity measurements as presented in table 3.1 occurred. These can probably be ascribed to environmental conditions including poor work practices relating to improper storage of material inside the fume hood. Comparing the eighth (2006-12-04) and ninth (2007-01-15) measurement data sets from table 3.1 with one another it can clearly be seen that the face velocity measurements differ significantly. The highest velocity in these two sets is 1.25 $m.s^{-1}$ with the lowest being 0.47 $m.s^{-1}$. Figures 4.1 and 4.2 visually explain the reason for this difference. Figure 4.1 shows the inside of the fume hood “T1” directly before the 8th set of measurements was taken. Figure 4.2 shows the inside immediately prior to the 9th set. The obstruction in the lower middle quadrant of the grid is responsible for the 0.47 $m.s^{-1}$ reading. The air entering the fume hood needed to find a way around this obstruction. This caused air to speed up resulting in the 1.25 $m.s^{-1}$ reading in the upper middle quadrant of the grid.

From the above it is clear that the decline in fume hood performance was not from one specific cause. Fume hoods “520A” and “520B” dipped in performance at one point where after performance improved. These fume hoods extract acid vapours. The acid vapours started corroding the duct work, diminishing performance peaking at mean six (figures 3.1 (b) and 3.1 (c)). Repairs were carried out and performance subsequently increased.

Figure 4.1 Photo showing the content of fume hood “T1” directly before the 8th set of measurements

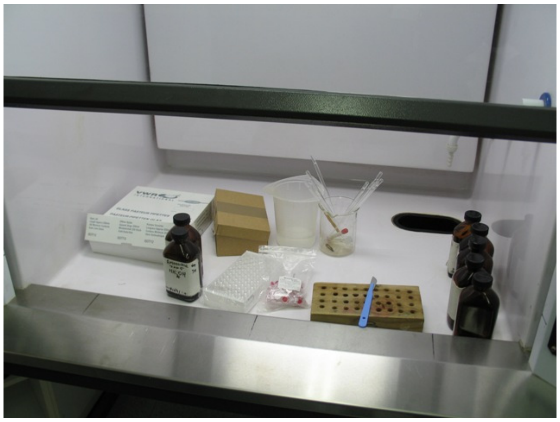

Figure 4.2 Photo showing the content of fume hood “T1” directly before the 9th set of measurements

4.3.2.1 Statistical Test Results

The ANOVA test indicated that month had no significant effect on velocity measurements (p-value = 0.8538) and that measurements remained fairly constant over time.

4.3.3 Study Objective 3 (Operability over Time)

Fume hood observations paint a bleaker picture of their performance. At the onset of the study 86% of the fume hoods worked. By the end of the study only 73% were working. At one point during the study 47% of fume hoods were not working.

An annual study of 598 fume hoods at Tufts University evaluating fume hoods for face velocity and visible signs of defects revealed that less than 10 fume hoods per year failed testing. This included reports from laboratory supervisors regarding fume hood malfunctioning (26).

It appears from the above that fans, when operating, seem to perform reasonably consistently over time, extracting the quantity of air that they were designed to do. The problem however is that fume hoods seemed to develop mechanical problems over the test period. These problems were either sashes that malfunctioned or fans that ceased to operate. The sash operating mechanism, a system of pulleys, were generally responsible for sash inoperability. No investigation was done into why fans malfunctioned. The fan malfunctioning may have been due to a number of reasons including electrical and mechanical failure of the fan motor. The amount of fume hoods that were inoperable during the study within the FSL is alarming. In comparison to the Tufts University study it is clear that a problem in this regard exists within the FSL and requires further attention.

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

Chapter five starts by summarising the test results, test method and the performance standard employed during the study period with recommendations pertaining to each of these. It then moves on to look at the test frequency for evaluating fume hoods. The chapter further makes a number of recommendations with regard to procurement and installation considerations, the work practices that operators need to employ and for the fitment of specific appurtenances to assist with the day to day evaluation of fume hoods. The chapter finally looks at the importance of considering costs when selecting and operating fume hoods.

5.1 Test Results

The test results highlighted in this report indicate that there is a problem in the FSL regarding fume hood performance. The problem relates to both excessive velocities and actual functioning. Too many fume hoods were overperforming and others not operating, over the study period. At no point was 100% functionality achieved. This in itself is cause for concern. The underlying causes for this warrants further investigation and remedying. No one factor can be pinpointed as the cause for poor performance. Rather, a combination of factors including improper maintenance, incorrect placement and work practices and unsuitable environmental conditions are to blame.

The FSL will have to launch a project whereby it addresses the procurement, installation, safe use and maintenance of all its fume hoods. The FSL will further have to compile detailed purchasing and operating specifications for fume hoods. It is further hoped that the regulating and standard setting authorities in South Africa can come up with standards for the method of testing fume hoods and the frequency with which such tests need to be conducted. This should level the playing field amongst manufacturers and users alike. It will further assist in preventing sub-standard fume hoods from entering the South African market.

5.2 Test Method

Face velocity measurements provide data regarding fume hood performance. The values obtained during the study indicated that most fume hoods, when working, were over-performing. The main question arose to the accuracy of these results given that only face velocity measurements were taken. It appears that face velocity testing should not be the only test method for determining fume hood performance. The results obtained in this study are probably reliable but to make a more informed decision regarding fume hood performance, additional test methods should be employed.

Some schools of thought argue that the ASHRAE test procedure should be used to verify containment of existing hoods and that once this is done less vigorous tests based on face velocity can be made. This, provided that no changes are made to the fume hood structure, laboratory airflow or other factors that influence fume hood performance (24). Others like Griffin (9) argue that face velocity measurements are inadequate. A research report by Dale

Hitchings states that 30% - 50% of hoods leaking excessive levels of contaminants pass the traditional face velocity tests (25).

Fume hoods need to be tested using an internationally recognized, scientifically proven test method. The ASHRAE 110 (14) provides for three types of tests to determine fume hood performance. This standard is widely used in the United States and is reviewed from time to time which implies continual improvement. The standard makes provision for the testing of fume hoods once manufactured, by the manufacturer, upon installation it needs to be tested again and then, in an “as used” condition periodically tested. Provision is thus made for testing of the fume hood from its inception. The possibility of using the method or adapting it at least to face velocity and containment testing, must be considered until a South African test method becomes available.

5.3 Performance Standards

Fume hood use has become ubiquitous in industry. The time has come for South Africa to set performance standards for fume hoods. Until this happens though, users need to adopt a standard in much the same way as the FSL has done. It is recommended that a universal standard of 0.51 $m.s^{-1}$ average face velocity ± 20% should be applied as an interim measure.

5.4 Test Frequency

The current requirement of once every 24 months seems inadequate. The observation results of the study show that 23 fume hoods were not working at one point. This is alarming. How do operators know that the fume hood is not working? Face velocity measurements are easy to perform and should be carried out once every six months. A trade off could perhaps be made between the frequency of testing and the fitting of air speed measurement devices and low flow alarms. The operator would then be in a position to check whether the hood is performing as intended both before and during use.

More comprehensive testing as specified in the ASHRAE standard (14) can be carried out once every 24 months. This should include tracer gas testing on a statistically significant number of fume hoods and containment and face velocity testing of all fume hoods.

5.5 Procurement and Installation

Persons responsible for procuring fume hoods for an organization need to do so with care. Proper specifications need to be compiled according to which fume hoods should be purchased. These specifications should include:

- The design of the fume hood;
- The type of material the fume hood needs to be constructed from, and;
- The type of testing the fume hood needs to undergo once construction is completed;

Fume hoods need to be installed and located in the following areas (5):

- Away from doorways, since a fire or explosion in the hood could block an exit from the room;
- Away from traffic patterns and doorways to minimize cross drafts caused by cross traffic;
- Away from corners, to minimize cross drafts from swirling air, and;
- Away from disruptive air discharge into the room from grills and diffusers;

It is a well known fact that fume hood placement within the FSL was never properly planned. Fume hoods were placed where space was available. It is not certain as to what influences the above had on the performance of the fume hoods in the study.

The ACGIH in their ventilation Manual (4) provide guidelines for laboratory fume hoods. Some of these are:

- Adjusting fume hood baffles so that velocities measured across the face vary by ≤ 10%, with the sash in the maximum open position;
- Locating the fume hood away from heavy traffic aisles and doorways. Hoods near doors are acceptable if:
    - an alternative safe means of exiting the room exists;
    - traffic past the hood is low, and;
    - the door is normally closed.
- Using corrosion-resistant material suitable for expected use;

- Providing proper air cleaning of contaminants exhausted and ensuring that exhaust stacks are high enough, and;
- Sharp corners should be avoided at the inlet to the fume hood. Tapered or round hood inlets are preferable.

Another problem is when facilities keep installing fume hoods beyond the original design parameter of a building's ventilation system. This implies that more air is extracted than supplied. This creates negative pressures throughout the building and can cause contaminants to be drawn from one laboratory to another.

Installing fume hoods needs to be done in conjunction with the adjustment and balancing of make-up air ventilation systems.

5.6 Work Practices

The study results show that the manner in which a laboratory fume hood is used has a definite influence on its performance. If material is stored incorrectly or in excess, then face velocities are negatively influenced. If one were to analyse poor fume hood performance, the first step would be to investigate the manner in which a fume hood is used. Improper storage of materials within fume hoods was visible during observations made throughout the study. Personnel required to use fume hoods must be comprehensively trained in the correct use thereof. Operating procedures need to be compiled and provided to such persons after they have been schooled therein.

SEFA (3) and the ACGIH (8) both provide a list of basic work practices that need to be followed around fume hoods. These include:

- Always locating equipment as deep in the hood as possible, at least 15 cm back. A line can be drawn at this distance as a reminder to users;
- Not putting ones head into the hood whilst contaminants are being generated;
- Elevating equipment by more than 5.10 cm to provide for airflow beneath equipment;
- By covering no more than 50% of the working surface inside the fume hood with equipment;
- Avoiding the use of electrically powered equipment inside the hood. If necessary power cords can be run to outside the hood and plugged in;
- Avoiding rapid movements near the face of the fume hood as the wake created by such can withdraw materials from inside the hood;
- Labeling the heights at which the sash may be operated;
- Keeping the sash closed as much as possible, and;
- Operating the fume hood with the sash in such a position that it forms a barrier between the operator and content of the hood thus providing physical protection in the event of a spill or explosion.

5.7 Appurtenances

Fume hoods should be fitted with devices that measure air speed. This will provide the operator with a visible tool to check whether the fume hood is actually working. An additional control measure is a low flow alarm. This alarm sounds when the air speed across the face drops below a velocity which is considered dangerous. This provides an audible alarm informing the operator that there is a fault with the hood.

5.8 Costing

A laboratory fume hood is a specialized piece of equipment. Initial purchasing costs are in excess of R20 000.00 per station. Installation costs can also be expensive. These include utilities fitted in the hood such as gas and water, drainage, electricity supply to the fan and ducting which may need to go through several floors in a multi-storey type building to get to the roof. Air filtering / cleaning devices may also need to be fitted which is also an added expense. A constant volume fume hood extracts a constant volume of air from a laboratory irrespective of the sash height. The air being extracted is in most instances air-conditioned. In summer cool air and in winter warm air. Replacement air has a cost to it, the cost to supply the air and then heat or cool it.

Fume hoods should only be installed if really necessary. The possibility of installing variable air volume (VAV) fume hoods need also be investigated. A VAV hood typically adjusts airflow according to the height of the sash opening. If the sash is lowered a pre-determined velocity is maintained. This is not the case with constant velocity fume hoods as seen in this study. The lower the sash height, the higher the velocity readings were. VAV hoods imply cost savings because less air is extracted when the sash is lowered thus requiring less make-up or supply air and fan power.

An option which can be considered with the FSL fume hoods is to have them designed using the sash height at which the operator will be working as the height at which they need to perform at the set standard. This implies a partially closed sash position around which fume hood performance is designed. Doing this will require a smaller fan to be used which in turn will consume less electricity and extract a smaller volume of air.

In this day and age of power shortages and fossil fuel depletion, reducing operating costs needs serious attention.

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APPENDIX A

EXAMPLE OF FORM USED TO RECORD MEASUREMENTS

FUME HOOD UNIQUE IDENTITY NUMBER	**:**	**T1**
DATE OF MEASUREMENT	:	2006-09-13
TIME OF MEASUREMENT	:	10:30
WIDTH OF FUME OPENING	:	90 cm
HEIGHT OF FUME OPENING	:	36 cm
WIDTH OF MEASURING GRID	:	30 cm
HEIGHT OF MEASURING GRID	:	18 cm
AVERAGE READING	:	0,97m/s
HIGHEST READING	:	1,24m/s
LOWEST READING	:	0,68m/s

Grid with Face Velocities

1,19	1,04	0,93
1,24	0,68	0,73

Visualization Challenge

SMOKE EXHAUSTED	
YES	**NO**
X	

TEMPERATURE MEASUREMENTS

Actual

WBGT IN	18.1°C
DRY BULB	25.5°C
WET BULB	16.1°C
GLOBE	26.6°C

Internal Calibration

WET BULB	70.6 °C
DRY BULB	46.9 °C
GLOBE	12.4 °C

APPENDIX B

CALIBRATION CERTIFICATES FOR THE “QUESTEMP 15”

Reg. No.1951/000234/07

ABB Powertech Transformers
(Pty) Ltd

SANAS
ACCREDITED LABORATORY

CERTIFICATE OF CALIBRATION

SANAS ACCREDITED LABORATORY
No. 115, 311, 824

CERTIFICATE NUMBER: T1732

Page 1 of 4 Pages

This certificate is issued in accordance with the conditions of the accreditation granted by SANAS. It is a correct record of the measurements made at the time of the calibration. Copyright of this certificate is owned jointly by SANAS and by ABB Powertech Transformers (Pty) Ltd. This certificate may not be reproduced other than in full except with prior written approval of SANAS and ABB Powertech Transformers (Pty) Ltd.

Type:	**Heat Stress Monitor**
Manufacturer:	**Quest Technologies**
Model:	**Questemp°15**
Serial no:	**KL9100003**
Instrument no:	**Not Marked**
Calibrated for:	**Forensics Laboratories** **Private Bag X254** **Pretoria** **0001**
Date of calibration:	**2006-02-20 till 2006-02-22**
Date of issue:	**2006-02-23**
Calibrated by:	Volschenk **Yvette Volschenk**
Checked by:	**Adam Ngobeni**

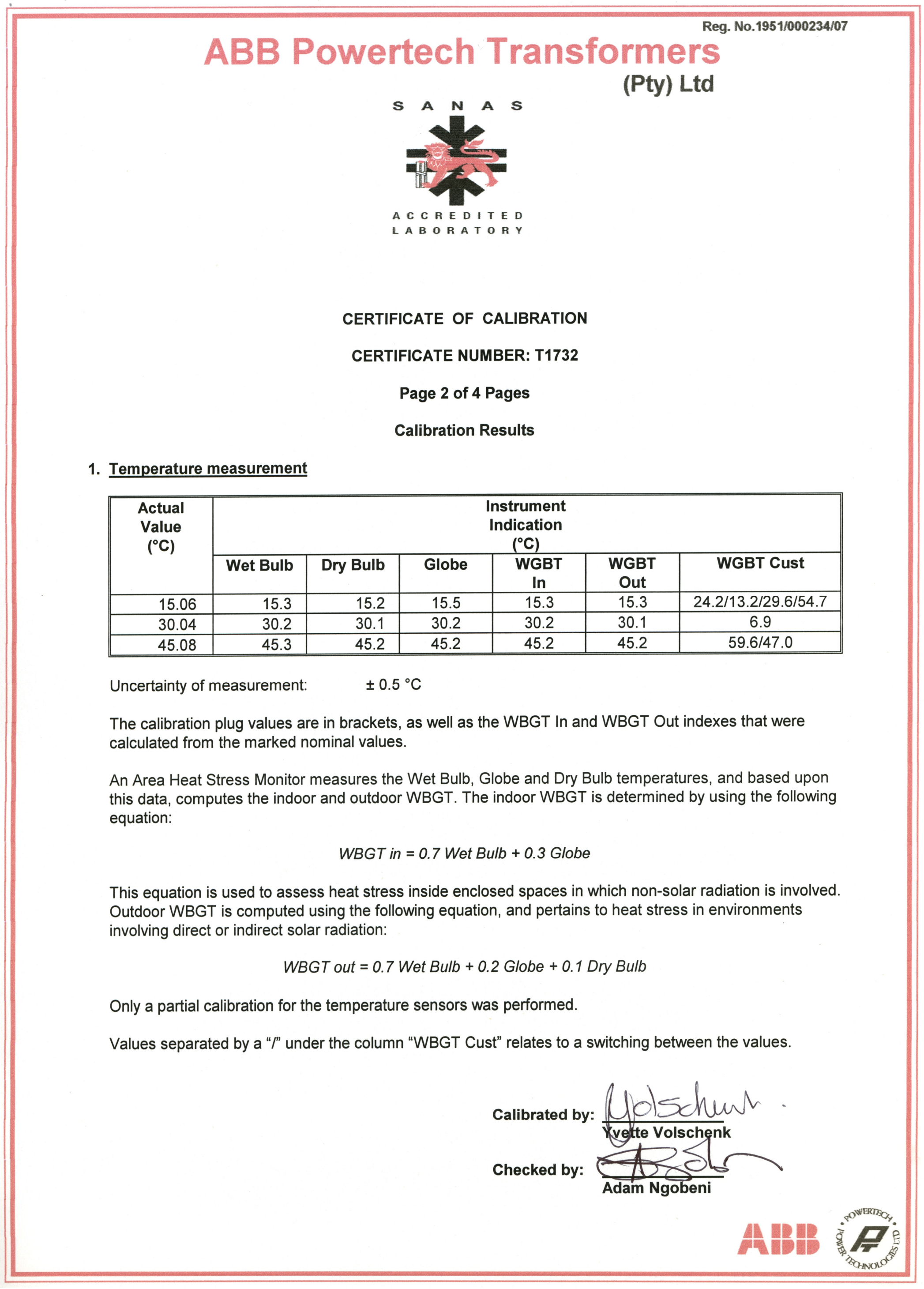
VALIDITY OF CALIBRATION

The values in this certificate are correct at the time of calibration. Subsequently the accuracy will depend on such factors as the care exercised in handling and use of the instrument and the frequency of use. Recalibration should be performed after a period which has been chosen to ensure that, under normal circumstances, the instrument's accuracy remains within the desired limits.

Approved signatories
P. le Roux (115, 311, 824) Y. Volschenk (311)

ABB Powertech Transformers (Pty) Ltd, PO Box 691, Pretoria, Gauteng 0001
1 Buitekant Street, Pretoria-West 0183
E-Mail: info@abbptt.co.za http://www.abbptt.co.za
Tel: +27 12 318-9911 Fax: +27 12 318-9995

ABB POWERTECH POWER TECHNOLOGIES LTD



Reg. No.1951/000234/07

ABB Powertech Transformers
(Pty) Ltd

SANAS
ACCREDITED
LABORATORY

CERTIFICATE OF CALIBRATION

CERTIFICATE NUMBER: T1732

Page 2 of 4 Pages

Calibration Results

1. Temperature measurement

Actual Value (°C)	Instrument Indication (°C)					
	Wet Bulb	Dry Bulb	Globe	WGBT In	WGBT Out	WGBT Cust
15.06	15.3	15.2	15.5	15.3	15.3	24.2/13.2/29.6/54.7
30.04	30.2	30.1	30.2	30.2	30.1	6.9
45.08	45.3	45.2	45.2	45.2	45.2	59.6/47.0

Uncertainty of measurement: ± 0.5 °C

The calibration plug values are in brackets, as well as the WBGT In and WBGT Out indexes that were calculated from the marked nominal values.

An Area Heat Stress Monitor measures the Wet Bulb, Globe and Dry Bulb temperatures, and based upon this data, computes the indoor and outdoor WBGT. The indoor WBGT is determined by using the following equation:

WBGT in = 0.7 Wet Bulb + 0.3 Globe

This equation is used to assess heat stress inside enclosed spaces in which non-solar radiation is involved. Outdoor WBGT is computed using the following equation, and pertains to heat stress in environments involving direct or indirect solar radiation:

WBGT out = 0.7 Wet Bulb + 0.2 Globe + 0.1 Dry Bulb

Only a partial calibration for the temperature sensors was performed.

Values separated by a "/" under the column "WBGT Cust" relates to a switching between the values.

Calibrated by: **Yvette Volschenk**

Checked by: **Adam Ngobeni**

ABB
POWERTECH POWER TECHNOLOGIES LTD

CSIR
NATIONAL METROLOGY
LABORATORY (NML)

Custodian of the
national measuring
standards of
South Africa

PO Box 395
Pretoria 0001 South Africa
Tel: +27 12 841-4623/2102
Fax: +27 12 841-4458
e-mail: nml@csir.co.za
http://www.nml.csir.co.za

CERTIFICATE OF CALIBRATION

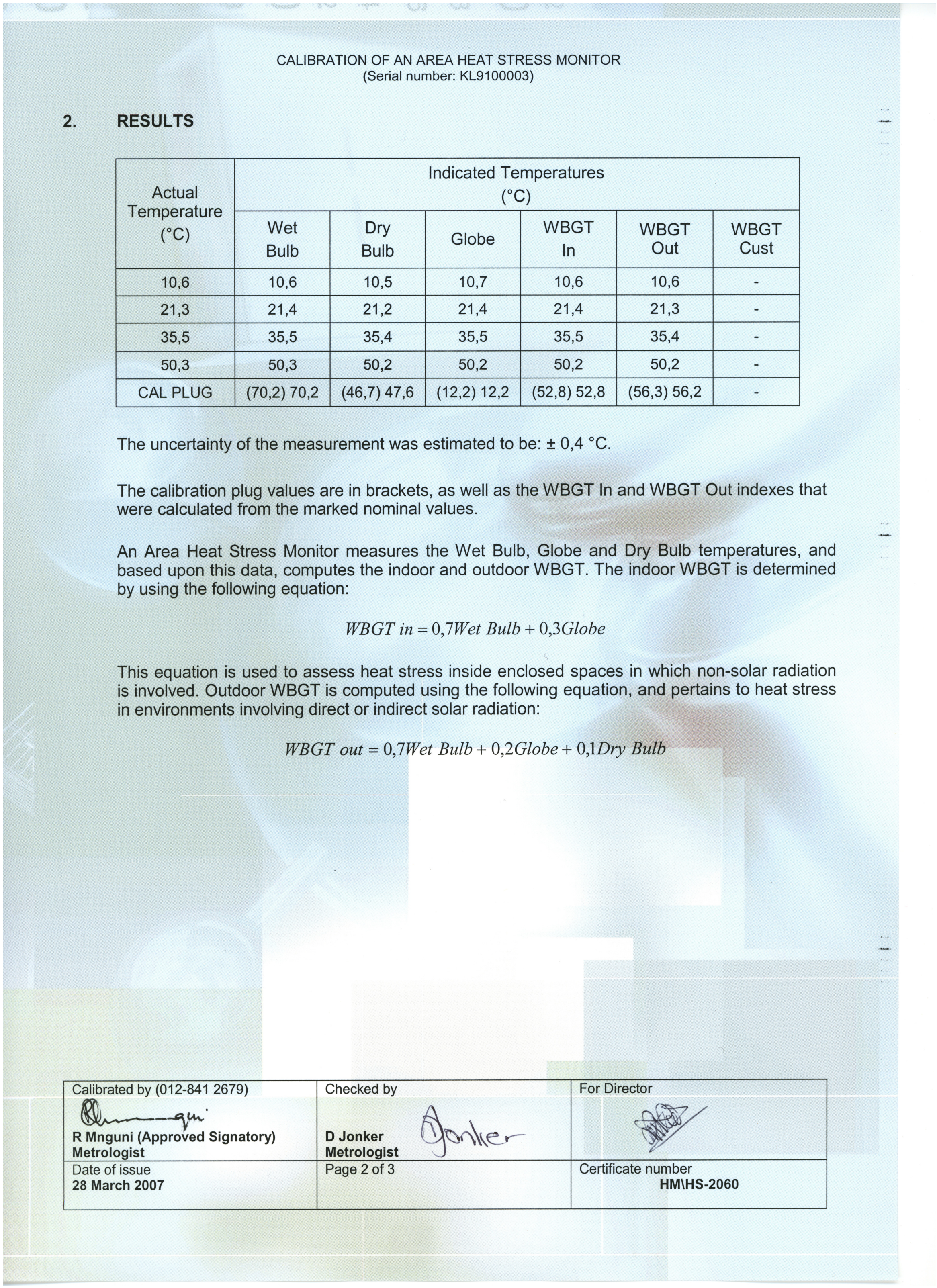
Calibration of:	An Area Heat Stress Monitor
Manufacturer:	Quest Technologies
Model number:	Questemp °15
Serial number:	KL9100003
Calibrated for:	SA Police – Forensics (Silverton), Pretoria
Calibration procedure:	NML-HM\HS-0002
Period of calibration:	26-27 March 2007

1. PROCEDURE

The sensors and the digital display unit were calibrated as a system against a digital thermometer with platinum resistance thermometer probes (S/N HMS-600). The measurements were done in a stirred water bath.

After water proofing the sensors, the temperature sensing thermometers were immersed in the water bath and allowed to stabilise. Measurement readings were then recorded at various temperatures once temperature stability had been achieved.

Calibrated by (012-841 2679) **R Mnguni (Approved Signatory)** **Metrologist**	Checked by **D Jonker** Jonker **Metrologist**	For Director
Date of issue **28 March 2007**	Page 1 of 3	Certificate number **HM\HS-2060**



CALIBRATION OF AN AREA HEAT STRESS MONITOR
(Serial number: KL9100003)

2. RESULTS

Actual Temperature (°C)	Indicated Temperatures (°C)					
	Wet Bulb	Dry Bulb	Globe	WBGT In	WBGT Out	WBGT Cust
10,6	10,6	10,5	10,7	10,6	10,6	-
21,3	21,4	21,2	21,4	21,4	21,3	-
35,5	35,5	35,4	35,5	35,5	35,4	-
50,3	50,3	50,2	50,2	50,2	50,2	-
CAL PLUG	(70,2) 70,2	(46,7) 47,6	(12,2) 12,2	(52,8) 52,8	(56,3) 56,2	-

The uncertainty of the measurement was estimated to be: ± 0,4 °C.

The calibration plug values are in brackets, as well as the WBGT In and WBGT Out indexes that were calculated from the marked nominal values.

An Area Heat Stress Monitor measures the Wet Bulb, Globe and Dry Bulb temperatures, and based upon this data, computes the indoor and outdoor WBGT. The indoor WBGT is determined by using the following equation:

$$WBGT\ in = 0{,}7Wet\ Bulb + 0{,}3Globe$$

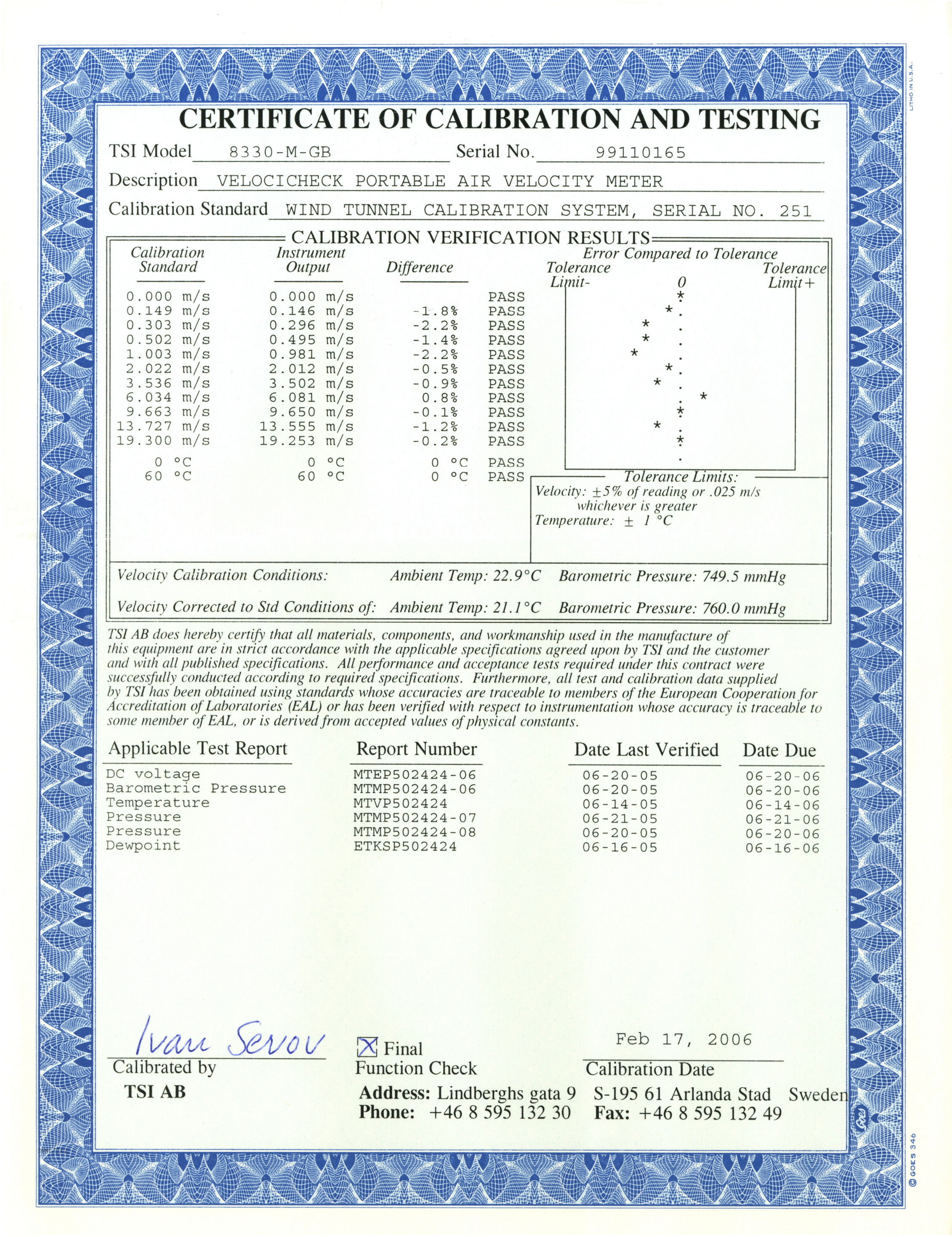
This equation is used to assess heat stress inside enclosed spaces in which non-solar radiation is involved. Outdoor WBGT is computed using the following equation, and pertains to heat stress in environments involving direct or indirect solar radiation:

$$WBGT\ out = 0{,}7Wet\ Bulb + 0{,}2Globe + 0{,}1Dry\ Bulb$$

Calibrated by (012-841 2679) **R Mnguni (Approved Signatory)** **Metrologist**	Checked by **D Jonker** **Metrologist** Jonker	For Director
Date of issue **28 March 2007**	Page 2 of 3	Certificate number **HM\HS-2060**

APPENDIX C

CALIBRATION CERTIFICATES FOR THE “VELOCICHECK”



CERTIFICATE OF CALIBRATION AND TESTING

TSI Model 8330-M-GB Serial No. 99110165

Description VELOCICHECK PORTABLE AIR VELOCITY METER

Calibration Standard WIND TUNNEL CALIBRATION SYSTEM, SERIAL NO. 251

CALIBRATION VERIFICATION RESULTS

Calibration Standard	*Instrument Output*	*Difference*	
0.000 m/s	0.000 m/s		PASS
0.149 m/s	0.146 m/s	-1.8%	PASS
0.303 m/s	0.296 m/s	-2.2%	PASS
0.502 m/s	0.495 m/s	-1.4%	PASS
1.003 m/s	0.981 m/s	-2.2%	PASS
2.022 m/s	2.012 m/s	-0.5%	PASS
3.536 m/s	3.502 m/s	-0.9%	PASS
6.034 m/s	6.081 m/s	0.8%	PASS
9.663 m/s	9.650 m/s	-0.1%	PASS
13.727 m/s	13.555 m/s	-1.2%	PASS
19.300 m/s	19.253 m/s	-0.2%	PASS
0 °C	0 °C	0 °C	PASS
60 °C	60 °C	0 °C	PASS

Tolerance Limits:
Velocity: ±5% of reading or .025 m/s whichever is greater
Temperature: ± 1 °C

Velocity Calibration Conditions: Ambient Temp: 22.9°C Barometric Pressure: 749.5 mmHg

Velocity Corrected to Std Conditions of: Ambient Temp: 21.1°C Barometric Pressure: 760.0 mmHg

TSI AB does hereby certify that all materials, components, and workmanship used in the manufacture of this equipment are in strict accordance with the applicable specifications agreed upon by TSI and the customer and with all published specifications. All performance and acceptance tests required under this contract were successfully conducted according to required specifications. Furthermore, all test and calibration data supplied by TSI has been obtained using standards whose accuracies are traceable to members of the European Cooperation for Accreditation of Laboratories (EAL) or has been verified with respect to instrumentation whose accuracy is traceable to some member of EAL, or is derived from accepted values of physical constants.

Applicable Test Report	Report Number	Date Last Verified	Date Due
DC voltage	MTEP502424-06	06-20-05	06-20-06
Barometric Pressure	MTMP502424-06	06-20-05	06-20-06
Temperature	MTVP502424	06-14-05	06-14-06
Pressure	MTMP502424-07	06-21-05	06-21-06
Pressure	MTMP502424-08	06-20-05	06-20-06
Dewpoint	ETKSP502424	06-16-05	06-16-06

Ivan Serov
Calibrated by
TSI AB

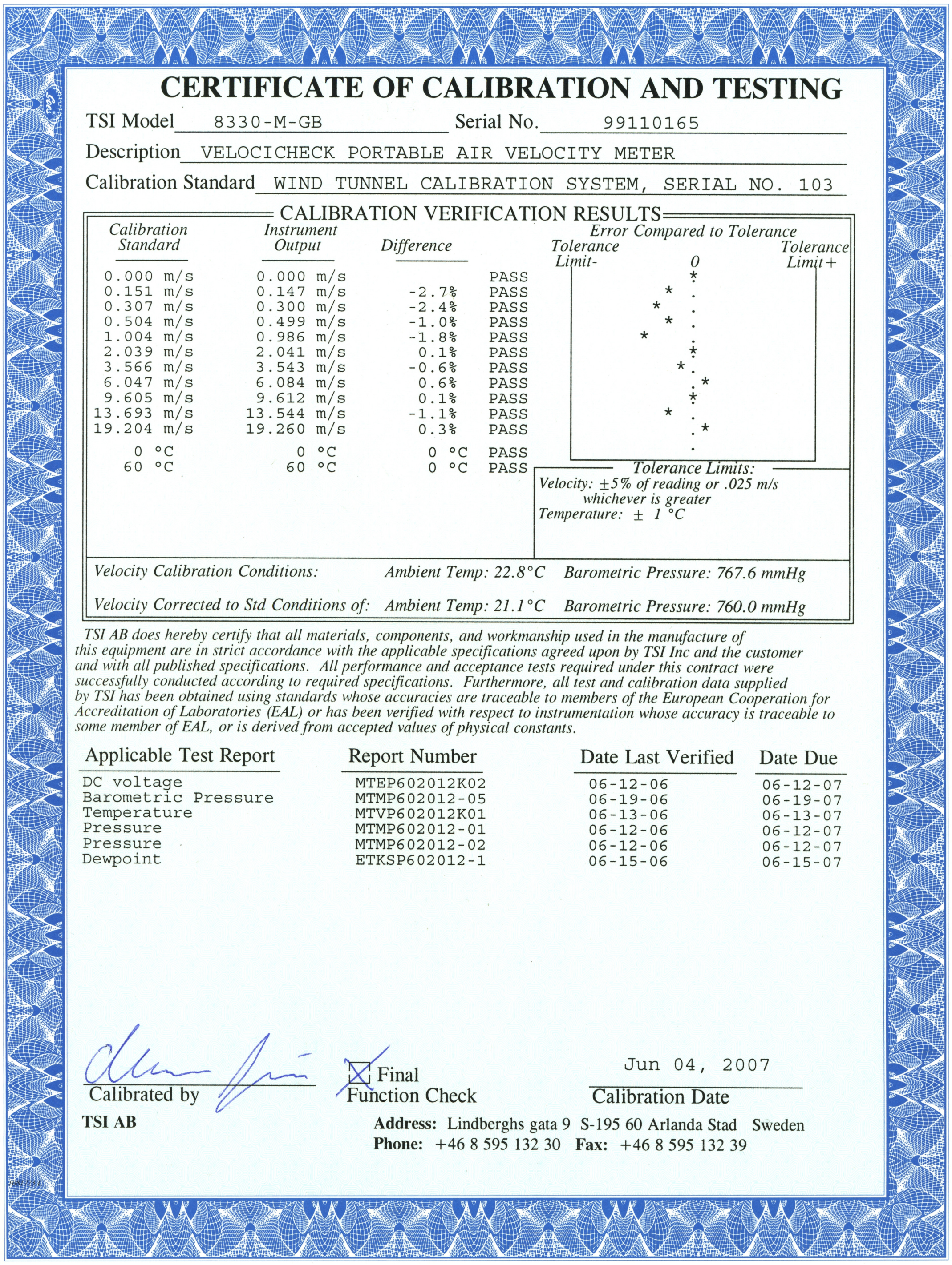
☒ Final
Function Check

Feb 17, 2006
Calibration Date

Address: Lindberghs gata 9 S-195 61 Arlanda Stad Sweden
Phone: +46 8 595 132 30 **Fax:** +46 8 595 132 49

LITHO IN U.S.A.

© GOES 346



CERTIFICATE OF CALIBRATION AND TESTING

TSI Model 8330-M-GB Serial No. 99110165

Description VELOCICHECK PORTABLE AIR VELOCITY METER

Calibration Standard WIND TUNNEL CALIBRATION SYSTEM, SERIAL NO. 103

CALIBRATION VERIFICATION RESULTS

Calibration Standard	*Instrument Output*	*Difference*	
0.000 m/s	0.000 m/s		PASS
0.151 m/s	0.147 m/s	-2.7%	PASS
0.307 m/s	0.300 m/s	-2.4%	PASS
0.504 m/s	0.499 m/s	-1.0%	PASS
1.004 m/s	0.986 m/s	-1.8%	PASS
2.039 m/s	2.041 m/s	0.1%	PASS
3.566 m/s	3.543 m/s	-0.6%	PASS
6.047 m/s	6.084 m/s	0.6%	PASS
9.605 m/s	9.612 m/s	0.1%	PASS
13.693 m/s	13.544 m/s	-1.1%	PASS
19.204 m/s	19.260 m/s	0.3%	PASS
0 °C	0 °C	0 °C	PASS
60 °C	60 °C	0 °C	PASS

Tolerance Limits:
Velocity: ±5% of reading or .025 m/s whichever is greater
Temperature: ± 1 °C

Velocity Calibration Conditions: *Ambient Temp: 22.8°C* *Barometric Pressure: 767.6 mmHg*

Velocity Corrected to Std Conditions of: *Ambient Temp: 21.1°C* *Barometric Pressure: 760.0 mmHg*

TSI AB does hereby certify that all materials, components, and workmanship used in the manufacture of this equipment are in strict accordance with the applicable specifications agreed upon by TSI Inc and the customer and with all published specifications. All performance and acceptance tests required under this contract were successfully conducted according to required specifications. Furthermore, all test and calibration data supplied by TSI has been obtained using standards whose accuracies are traceable to members of the European Cooperation for Accreditation of Laboratories (EAL) or has been verified with respect to instrumentation whose accuracy is traceable to some member of EAL, or is derived from accepted values of physical constants.

Applicable Test Report	Report Number	Date Last Verified	Date Due
DC voltage	MTEP602012K02	06-12-06	06-12-07
Barometric Pressure	MTMP602012-05	06-19-06	06-19-07
Temperature	MTVP602012K01	06-13-06	06-13-07
Pressure	MTMP602012-01	06-12-06	06-12-07
Pressure	MTMP602012-02	06-12-06	06-12-07
Dewpoint	ETKSP602012-1	06-15-06	06-15-07

Calibrated by

☒ Final Function Check

Jun 04, 2007
Calibration Date

TSI AB

Address: Lindberghs gata 9 S-195 60 Arlanda Stad Sweden
Phone: +46 8 595 132 30 **Fax:** +46 8 595 132 39

APPENDIX D

LETTER FROM THE HUMAN RESEARCH ETHICS COMMITTEE

University
of the Witwatersrand,
Johannesburg

Human Research Ethics Committee (Medical)
(formerly Committee for Research on Human Subjects (Medical)

Secretariat: Research Office, Room SH10005, 10th floor, Senate House • Telephone: +27 11 717-1234 • Fax: +27 11 339-5708
Private Bag 3, Wits 2050, South Africa

PC-J/466/dsk14es

5 August 2005

TO WHOM IT MAY CONCERN:

Name:	**Peter-John Jacobs**
re:	**The determination of fume hood performance in a South African police service forensic science laboratory**
Degree:	**Master of Public Health - Occupational Hygiene - Part Time**

This certifies that this project does not require clearance from the Human Research Ethics Committee (Medical).

The research involves the testing of laboratory fume hood performance; no human subjects will be involved.

Yours faithfully

Professor Peter Cleaton-Jones
Chair: Human Research Ethics Committee (Medical)

copy: Anisa Keshav, Research Office, Senate House, Wits

APPENDIX E

FACE VELOCITY DATA SETS SHOWING HIGHEST, LOWEST AND MEAN VALUES

Fume hood	Measurement Date	Mean face velocity (m.s^{-1})	Highest value (m.s^{-1})	Lowest value (m.s^{-1})
T1	2006-04-04	0.83	0.95	0.64
	2006-05-04	0.94	0.99	0.89
	2006-05-31	1.03	1.09	0.93
	2006-08-22	0.96	1.00	0.84
	2006-09-13	0.97	1.24	0.68
	2006-10-03	0.96	1.01	0.92
	2006-11-07	0.95	0.97	0.91
	2006-12-04	0.89	1.25	0.47
	2007-01-15	0.97	1.02	0.89
	2007-02-13	0.96	1.05	0.86
T2	2006-04-04	0.97	1.03	0.90
	2006-05-04	0.98	1.09	0.89
	2006-05-31	1.01	1.10	0.88
	2006-08-22	1.04	1.08	0.93
	2006-09-13	1.05	1.14	0.97
	2006-10-03	1.02	1.05	0.95
	2006-11-07	1.03	1.08	1.00
	2006-12-04	1.01	1.11	0.88
	2007-01-15	0.97	1.06	0.81
	2007-02-13	0.99	1.03	0.96
T3	2006-04-04	0.96	0.98	0.89
	2006-05-04	1.02	1.16	0.89
	2006-05-31	1.03	1.15	0.93
	2006-08-22	0.93	0.99	0.86
	2006-09-13	1.03	1.19	0.90
	2006-10-03	1.01	1.10	0.90
	2006-11-07	1.01	1.06	0.93
	2006-12-04	1.03	1.17	0.84
	2007-01-15	1.00	1.08	0.94
	2007-02-13	0.96	1.15	0.79

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
T4	2006-04-04	1.00	1.09	0.91
	2006-05-04	1.03	1.10	0.93
	2006-05-31	1.07	1.14	1.01
	2006-08-22	1.03	1.12	0.97
	2006-09-13	1.05	1.13	0.97
	2006-10-03	1.06	1.08	1.04
	2006-11-07	1.07	1.08	1.05
	2006-12-04	1.06	1.14	0.99
	2007-01-18	1.03	1.15	0.97
	2007-02-13	1.03	1.08	0.97
T5	2006-04-04	Fume hood not working		
	2006-05-04	Fume hood not working		
	2006-05-31	Fume hood not working		
	2006-08-22	Fume hood not working		
	2006-09-13	Fume hood not working		
	2006-10-03	1.13	1.20	1.04
	2006-11-07	1.16	1.32	1.04
	2006-12-04	1.08	1.22	0.70
	2007-01-18	1.12	1.31	0.90
	2007-02-13	0.98	1.27	0.56
T6	2006-04-04	0.81	1.07	0.63
	2006-05-04	0.98	1.06	0.93
	2006-05-31	1.08	1.12	1.05
	2006-08-22	1.04	1.09	0.98
	2006-09-13	1.04	1.10	1.02
	2006-10-03	1.03	1.08	0.94
	2006-11-07	1.00	1.06	0.82
	2006-12-04	1.03	1.22	0.75
	2007-01-18	1.02	1.22	0.81
	2007-02-13	1.01	1.11	0.91
T7	2006-04-04	Fume hood not working		
	2006-05-04	Fume hood not working		
	2006-05-31	Fume hood not working		
	2006-08-22	Fume hood not working		
	2006-09-13	Fume hood not working		
	2006-10-03	Fume hood not working		
	2006-11-07	Fume hood not working		
	2006-12-04	Fume hood not working		
	2007-01-18	Fume hood not working		
	2007-02-13	Fume hood not working		

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
T8	2006-04-04	0.97	1.11	0.84
	2006-05-04	1.02	1.11	0.87
	2006-05-31	1.13	1.31	1.01
	2006-08-22	1.04	1.35	0.27
	2006-09-13	1.06	1.15	1.01
	2006-10-03	1.07	1.15	0.97
	2006-11-07	1.04	1.14	0.93
	2006-12-04	1.11	1.20	1.06
	2007-01-18	1.02	1.35	0.55
	2007-02-13	0.98	1.22	0.53
T9	2006-04-04	Fume hood not working		
	2006-05-04	Fume hood not working		
	2006-05-31	Fume hood not working		
	2006-08-22	1.09	1.21	0.97
	2006-09-13	Fume hood not working		
	2006-10-03	Fume hood not working		
	2006-11-07	Fume hood not working		
	2006-12-04	Fume hood not working		
	2007-01-18	Fume hood not working		
	2007-02-13	Fume hood not working		
T10	2006-04-04	1.24	1.35	1.13
	2006-05-04	1.25	1.32	1.12
	2006-05-31	1.31	1.59	1.17
	2006-08-22	1.34	1.42	1.23
	2006-09-13	1.25	1.34	1.19
	2006-10-03	1.30	1.37	1.24
	2006-11-07	1.30	1.36	1.24
	2006-12-04	1.23	1.44	0.75
	2007-01-18	1.25	1.49	0.94
	2007-02-13	1.17	1.41	0.92
T11	2006-04-04	1.17	1.27	1.01
	2006-05-04	1.16	1.25	1.06
	2006-05-31	1.26	1.35	1.17
	2006-08-22	1.25	1.43	0.84
	2006-09-13	Fume hood not working		
	2006-10-03	1.23	1.38	1.13
	2006-11-07	1.20	1.32	1.11
	2006-12-04	1.17	1.43	0.89
	2007-01-18	Fume hood not working		
	2007-02-13	Fume hood not working		

Fume hood	Measurement Date	Mean face velocity (m.s^{-1})	Highest value (m.s^{-1})	Lowest value (m.s^{-1})
KA	2006-04-04	0.83	0.90	0.73
	2006-05-04	0.87	0.90	0.82
	2006-06-01	Fume hood not working		
	2006-08-22	1.06	1.13	0.99
	2006-09-13	1.04	1.09	1.00
	2006-10-03	1.09	1.22	1.00
	2006-11-07	0.99	1.10	0.93
	2006-12-05	1.04	1.10	0.99
	2007-01-17	0.95	1.02	0.88
	2007-02-13	1.01	1.06	0.89
K03	2006-04-04	0.44	0.67	0.27
	2006-05-04	0.48	0.76	0.19
	2006-06-01	0.46	0.58	0.30
	2006-08-22	0.45	0.54	0.14
	2006-09-13	0.51	0.61	0.41
	2006-10-03	0.48	0.68	0.23
	2006-11-07	0.48	0.54	0.33
	2006-12-04	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-13	Fume hood not working		
115A	2006-04-05	0.14	0.20	0.04
	2006-05-04	0.14	0.17	0.08
	2006-05-31	0.16	0.18	0.14
	2006-08-22	0.15	0.24	0.01
	2006-09-13	0.12	0.19	0.00
	2006-10-03	0.13	0.19	0.03
	2006-11-07	0.17	0.21	0.12
	2006-12-04	0.16	0.18	0.14
	2007-01-16	0.17	0.20	0.13
	2007-02-13	0.16	0.22	0.02
130	2006-04-05	1.27	1.57	1.04
	2006-05-04	1.45	1.63	1.17
	2006-05-31	1.43	1.71	1.20
	2006-08-22	1.37	1.71	0.88
	2006-09-13	1.35	1.54	1.11
	2006-10-03	1.38	1.65	1.11
	2006-11-07	Fume hood not working		
	2006-12-04	1.34	1.54	1.04
	2007-01-16	1.34	1.61	1.03
	2007-02-13	1.21	1.79	0.72

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
202	2006-04-05	0.52	0.66	0.37
	2006-05-04	0.56	0.59	0.52
	2006-05-31	0.60	0.72	0.55
	2006-08-23	0.63	0.73	0.53
	2006-09-13	0.60	0.73	0.46
	2006-10-03	0.51	0.60	0.17
	2006-11-07	0.58	0.69	0.50
	2006-12-04	0.63	0.69	0.59
	2007-01-16	0.63	0.77	0.47
	2007-02-13	0.62	0.75	0.54
211A	2006-04-05	0.51	0.54	0.46
	2006-05-04	0.51	0.56	0.47
	2006-05-31	0.49	0.57	0.45
	2006-08-23	0.47	0.53	0.38
	2006-09-13	0.47	0.54	0.33
	2006-10-03	0.47	0.53	0.34
	2006-11-07	0.50	0.54	0.43
	2006-12-04	0.47	0.53	0.38
	2007-01-16	0.47	0.55	0.29
	2007-02-13	0.46	0.51	0.37
211B	2006-04-05	0.47	0.50	0.40
	2006-05-04	0.49	0.55	0.43
	2006-05-31	0.50	0.56	0.38
	2006-08-23	0.53	0.61	0.41
	2006-09-13	0.52	0.60	0.41
	2006-10-03	0.50	0.58	0.42
	2006-11-07	0.52	0.55	0.47
	2006-12-04	0.47	0.52	0.36
	2007-01-16	0.51	0.56	0.43
	2007-02-13	0.50	0.53	0.45
310(1)	2006-04-05	1.29	1.32	1.23
	2006-05-04	1.40	1.42	1.38
	2006-05-31	1.37	1.43	1.29
	2006-08-23	1.46	1.47	1.44
	2006-09-14	1.36	1.38	1.33
	2006-10-03	1.43	1.47	1.40
	2006-11-07	1.45	1.50	1.43
	2006-12-05	1.47	1.48	1.46
	2007-01-18	1.41	1.47	1.38
	2007-02-14	1.49	1.55	1.43

Fume hood	Measurement Date	Mean face velocity (m.s^{-1})	Highest value (m.s^{-1})	Lowest value (m.s^{-1})
311	2006-04-05	0.67	0.75	0.57
	2006-05-04	0.78	0.84	0.70
	2006-05-31	0.71	0.75	0.68
	2006-08-22	Fume hood not working		
	2006-09-14	Fume hood not working		
	2006-10-03	Fume hood not working		
	2006-11-07	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-18	Fume hood not working		
	2007-02-14	Fume hood not working		
318	2006-04-05	2.05	2.15	1.99
	2006-05-04	2.13	2.20	2.10
	2006-05-31	2.13	2.20	2.10
	2006-08-23	2.22	2.25	2.15
	2006-09-14	2.18	2.25	2.15
	2006-10-03	2.11	2.25	1.99
	2006-11-07	2.17	2.25	2.10
	2006-12-04	2.12	2.15	2.05
	2007-01-16	Fume hood not working		
	2007-02-14	2.27	2.30	2.25
400A	2006-04-05	Fume hood not working		
	2006-05-05	Fume hood not working		
	2006-05-31	Fume hood not working		
	2006-08-23	0.70	0.75	0.66
	2006-09-14	0.69	0.73	0.54
	2006-10-04	0.73	0.77	0.68
	2006-11-07	Fume hood not working		
	2006-12-04	0.77	0.86	0.70
	2007-01-16	0.73	0.80	0.63
	2007-02-14	0.76	0.86	0.67
400B	2006-04-05	0.67	0.74	0.60
	2006-05-05	0.76	0.81	0.71
	2006-05-31	0.72	0.79	0.67
	2006-08-23	0.74	0.85	0.66
	2006-09-14	0.71	0.78	0.64
	2006-10-04	0.70	0.73	0.65
	2006-11-07	0.75	0.82	0.68
	2006-12-04	0.71	0.77	0.64
	2007-01-16	0.72	0.91	0.40
	2007-02-14	0.75	0.82	0.68

Fume hood	**Measurement Date**	**Mean face velocity ($m.s^{-1}$)**	**Highest value ($m.s^{-1}$)**	**Lowest value ($m.s^{-1}$)**
413	2006-04-05	Fume hood not working		
	2006-05-05	0.74	0.86	0.55
	2006-05-31	0.72	0.84	0.49
	2006-08-23	Fume hood not working		
	2006-09-14	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-07	Fume hood not working		
	2006-12-04	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-14	Fume hood not working		
425A	2006-04-05	Fume hood not working		
	2006-05-05	Fume hood not working		
	2006-05-31	Fume hood not working		
	2006-08-23	Fume hood not working		
	2006-09-14	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-07	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-14	Fume hood not working		
425B	2006-04-05	0.57	0.75	0.45
	2006-05-05	0.69	0.87	0.47
	2006-05-31	0.87	1.33	0.30
	2006-08-23	0.65	0.70	0.61
	2006-09-14	0.64	0.68	0.60
	2006-10-03\4	0.66	0.70	0.64
	2006-11-08	Fume hood not working		
	2006-12-05	0.65	0.79	0.57
	2007-01-17	0.69	0.85	0.55
	2007-02-14	Fume hood not working		
511	2006-04-05	0.51	0.60	0.43
	2006-05-05	0.65	0.88	0.48
	2006-06-01	0.54	0.62	0.45
	2006-08-24	0.51	0.61	0.44
	2006-09-14	0.48	0.55	0.44
	2006-10-04	0.48	0.55	0.41
	2006-11-08	0.53	0.69	0.38
	2006-12-05	0.55	0.74	0.35
	2007-01-17	Fume hood not working		
	2007-02-14	0.55	0.64	0.40

Fume hood	Measurement Date	Mean face velocity (m.s^{-1})	Highest value (m.s^{-1})	Lowest value (m.s^{-1})
517A	2006-04-05	1.17	1.35	1.05
	2006-05-05	1.24	1.46	1.06
	2006-06-01	1.20	1.37	1.09
	2006-08-24	1.16	1.43	0.90
	2006-09-14	1.28	1.34	1.18
	2006-10-04	1.33	1.52	1.20
	2006-11-08	1.26	1.38	1.16
	2006-12-05	1.29	1.40	1.19
	2007-01-17	Fume hood not working		
	2007-02-14	2.28	2.40	2.10
520A	2006-04-05	1.46	1.68	1.29
	2006-05-05	1.48	1.66	1.33
	2006-06-01	1.49	1.74	1.28
	2006-08-24	1.32	1.55	1.14
	2006-09-14	1.22	1.40	1.06
	2006-10-04	1.15	1.24	0.98
	2006-11-08	Fume hood not working		
	2006-12-05	1.42	1.66	1.13
	2007-01-17	Fume hood not working		
	2007-02-14	1.64	1.86	1.49
520B	2006-04-05	0.63	0.73	0.50
	2006-05-05	0.70	0.78	0.64
	2006-06-01	0.71	0.82	0.50
	2006-08-24	0.67	0.76	0.51
	2006-09-14	0.62	0.72	0.47
	2006-10-04	0.54	0.66	0.42
	2006-11-08	Fume hood not working		
	2006-12-05	0.70	0.75	0.61
	2007-01-17	Fume hood not working		
	2007-02-14	0.78	0.89	0.63
520C	2006-04-05	Fume hood not working		
	2006-05-05	Fume hood not working		
	2006-06-01	Fume hood not working		
	2006-08-24	Fume hood not working		
	2006-09-14	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-08	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-14	0.79	1.08	0.56

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
522B	2006-04-05	0.47	0.61	0.25
	2006-05-05	0.51	0.62	0.44
	2006-06-01	0.48	0.60	0.29
	2006-08-24	0.52	0.65	0.41
	2006-09-14	0.50	0.60	0.28
	2006-10-04	0.47	0.58	0.35
	2006-11-08	Fume hood not working		
	2006-12-05	0.53	0.74	0.27
	2007-01-17	0.53	0.69	0.28
	2007-02-14	0.55	0.85	0.22
523	2006-04-05	1.48	1.75	1.28
	2006-05-05	1.61	1.74	1.34
	2006-06-01	1.55	1.75	1.40
	2006-08-24	1.61	1.88	1.19
	2006-09-14	1.36	1.56	1.23
	2006-10-04	1.51	1.62	1.37
	2006-11-08	1.52	1.62	1.45
	2006-12-05	1.63	2.30	1.24
	2007-01-17	1.81	2.70	1.35
	2007-02-14	1.82	2.45	1.39
601	2006-04-10	1.11	1.25	1.01
	2006-05-08	1.22	1.45	1.00
	2006-06-01	1.23	1.36	1.13
	2006-08-24	1.23	1.45	1.12
	2006-09-15	1.11	1.30	0.59
	2006-10-04	1.15	1.23	0.96
	2006-11-08	1.13	1.25	0.92
	2006-12-05	1.17	1.24	1.11
	2007-01-17	1.16	1.28	1.06
	2007-02-14	1.17	1.30	1.00
603	2006-04-10	0.46	0.70	0.19
	2006-05-05	0.50	0.76	0.21
	2006-06-01	0.51	0.76	0.20
	2006-08-24	Fume hood not working		
	2006-09-15	Fume hood not working		
	2006-10-04	0.45	0.72	0.15
	2006-11-08	0.48	0.72	0.21
	2006-12-05	0.52	0.58	0.45
	2007-01-17	0.53	0.64	0.45
	2007-02-14	0.53	0.61	0.45

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
612A	2006-04-05	1.25	1.39	1.13
	2006-05-08	1.26	1.37	1.17
	2006-06-01	1.27	1.40	1.12
	2006-08-24	1.27	1.46	1.15
	2006-09-15	1.28	1.47	1.14
	2006-10-04	1.28	1.45	1.13
	2006-11-09	1.24	1.30	1.19
	2006-12-05	1.28	1.37	1.09
	2007-01-17	1.30	1.41	1.23
	2007-02-14	1.21	1.35	1.00
612B	2006-04-05	1.31	1.47	1.21
	2006-05-08	1.30	1.54	1.15
	2006-06-01	1.29	1.46	1.12
	2006-08-24	1.31	1.46	1.15
	2006-09-15	1.29	1.45	1.15
	2006-10-04	1.24	1.37	1.07
	2006-11-09	1.25	1.41	1.05
	2006-12-05	1.29	1.51	1.07
	2007-01-17	1.29	1.45	1.11
	2007-02-14	1.28	1.43	1.13
618A	2006-04-10	1.93	2.40	1.53
	2006-05-08	2.01	2.40	1.66
	2006-06-01	1.91	2.40	1.45
	2006-08-24	2.08	2.50	1.74
	2006-09-15	1.92	2.45	1.57
	2006-10-04	1.85	2.20	1.46
	2006-11-09	Fume hood not working		
	2006-12-05	2.23	2.55	1.60
	2007-01-17	1.93	2.40	1.44
	2007-02-15	2.05	2.20	1.87
619A	2006-04-05	1.02	1.19	0.83
	2006-05-05	1.00	1.18	0.76
	2006-06-01	0.99	1.17	0.65
	2006-08-24	0.82	1.07	0.42
	2006-09-15	0.81	1.04	0.60
	2006-10-04	0.82	0.98	0.58
	2006-11-09	Fume hood not working		
	2006-12-05	0.89	1.08	0.65
	2007-01-17	0.84	0.94	0.58
	2007-02-15	0.85	0.90	0.77

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
619B	2006-04-05	1.02	1.19	0.75
	2006-05-05	1.09	1.28	0.89
	2006-06-01	1.08	1.18	0.90
	2006-08-24	0.89	1.00	0.73
	2006-09-15	0.91	1.00	0.81
	2006-10-04	0.88	0.99	0.75
	2006-11-09	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-15	0.92	1.05	0.79
622A	2006-04-10	1.24	1.38	0.92
	2006-05-05	1.22	1.41	0.90
	2006-06-01	1.15	1.34	0.76
	2006-08-24	1.14	1.22	0.88
	2006-09-15	1.18	1.35	0.82
	2006-10-04	1.17	1.32	0.91
	2006-11-09	Fume hood not working		
	2006-12-05	1.10	1.36	0.92
	2007-01-17	1.14	1.40	0.85
	2007-02-15	1.10	1.33	0.83
622B	2006-04-10	1.07	1.19	0.88
	2006-05-05	1.09	1.30	0.85
	2006-06-01	1.12	1.30	0.94
	2006-08-24	1.12	1.25	0.88
	2006-09-15	1.10	1.33	0.76
	2006-10-04	1.08	1.19	0.81
	2006-11-09	Fume hood not working		
	2006-12-05	1.10	1.27	0.88
	2007-01-17	1.07	1.22	0.84
	2007-02-15	1.14	1.31	0.87
622C	2006-04-10	0.86	1.01	0.69
	2006-05-05	0.91	1.05	0.69
	2006-06-01	0.92	1.10	0.71
	2006-08-24	1.00	1.09	0.91
	2006-09-15	0.99	1.05	0.89
	2006-10-04	0.96	1.05	0.87
	2006-11-09	Fume hood not working		
	2006-12-05	0.96	1.07	0.92
	2007-01-17	0.89	1.02	0.82
	2007-02-15	0.92	0.98	0.81

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
624A	2006-04-10	0.23	0.36	0.17
	2006-05-05	0.23	0.33	0.15
	2006-06-01	0.27	0.39	0.17
	2006-08-24	Fume hood not working		
	2006-09-15	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-09	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-15	Fume hood not working		
624B	2006-04-10	0.20	0.25	0.12
	2006-05-05	0.20	0.32	0.14
	2006-06-01	0.13	0.23	0.04
	2006-08-24	Fume hood not working		
	2006-09-15	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-09	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-15	Fume hood not working		
624C	2006-04-10	0.19	0.22	0.16
	2006-05-05	0.21	0.25	0.15
	2006-06-01	0.18	0.27	0.08
	2006-08-24	Fume hood not working		
	2006-09-15	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-09	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-15	Fume hood not working		
624D	2006-04-10	0.47	0.82	0.23
	2006-05-05	0.37	0.62	0.19
	2006-06-01	Fume hood not working		
	2006-08-24	Fume hood not working		
	2006-09-15	Fume hood not working		
	2006-10-04	Fume hood not working		
	2006-11-09	Fume hood not working		
	2006-12-05	Fume hood not working		
	2007-01-17	Fume hood not working		
	2007-02-15	Fume hood not working		

Fume hood	**Measurement Date**	**Mean face velocity (m.s^{-1})**	**Highest value (m.s^{-1})**	**Lowest value (m.s^{-1})**
627(2)B	2006-04-10	0.98	1.10	0.83
	2006-05-05	0.98	1.21	0.57
	2006-06-01	1.01	1.08	0.91
	2006-08-24	1.00	1.14	0.87
	2006-09-15	1.00	1.11	0.90
	2006-10-04	0.96	1.09	0.75
	2006-11-09	Fume hood not working		
	2006-12-05	1.02	1.14	0.71
	2007-01-17	0.96	1.10	0.71
	2007-02-15	0.97	1.13	0.64
627(3)C	2006-04-10	0.22	0.30	0.06
	2006-05-05	0.25	0.36	0.03
	2006-06-01	0.20	0.27	0.11
	2006-08-24	0.56	0.62	0.50
	2006-09-15	0.60	0.67	0.47
	2006-10-04	0.57	0.65	0.44
	2006-11-09	0.63	0.70	0.55
	2006-12-05	0.65	0.70	0.61
	2007-01-17	0.63	0.69	0.51
	2007-02-15	0.60	0.70	0.44