THE EFFECT OF GAS EXPOSURE ON WELDERS AT A LARGE ENGINEERING PLANT IN BLOEMFONTEIN, SOUTH AFRICA

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DECLARATION OF INDEPENDENT WORK

I, Catharina Elizabeth Barnard, do hereby declare that this research project submitted for the degree Magister Technologiae: Environmental Health, is my own independent work that has not been submitted before to any institution by me or anyone else as part of any qualification.

SIGNATURE DATE

A wise man changes his mind: a fool never will. - Spanish proverb

to mom and dad

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LIST OF IMPORTANT ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
ASHRAE	American Society for Heating, Refrigeration, and Air Conditioning
AWS	American Welding Society
USEPA	United States Environmental Protection Agency
MIG	Metal Arc Welding
NIOSH	National Institute of Occupational Safety and Health
OSHA	United States Department of Labour
PMR	Proportional Mortality Ratio
RADS	Reactive Airway Dysfunction Syndrome
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
TLV	Threshold Limit Value
TLV-C	Threshold Limit Value Ceiling
TLV-STEL	Threshold Limit Value Short Term Exposure Limit
TLV-TWA	Threshold Limit Value-Time Weighted Average
VOC	Volatile Organic Compounds
WHO	World Health Organisation

SUMMARY

Not much data are available on low-level chronic exposure to gases present in the ambient air of welding workshops. This is especially true with regard to South African welding conditions. A study was conducted to determine the ambient gas exposure of welders in a large engineering plant in Bloemfontein, South Africa. The aim of the study was the characterisation of gas exposure during the summer and winter months for the determination of possible health risks after chronic exposure to air inside a welding shop.

Gases were sampled by means of a direct reading instrument called the Processes Monitoring System (PMS-64). The system was installed at a stationary sample base in the centre of the workshop. Data were collected during one week of each month, extending from February 1997 to July 1997, so as to include both summer and winter months in the experiment.

The data were retrieved from the system by means of a computer printer. It was then processed and divided into eight-hour TWA concentrations and weekly TWA concentrations. The PMS-64 was equipped to sample the following gases: NH_3, CO, Cl_2, ClO_2, C_2H_4O, H_2, HCl, HCN, H_2S, NO, NO_2, O_2, O_3, PH_3 and SO_2.

The concentrations found in the welding shop were compared to the environmental Threshold Limit Values (TLV) or occupational TLV recommended by global authoritative organisations. In the absence of such specific TLV's, a calculated environmental TLV, consisting of one fortieth of the occupational TLV, was used.

High C_2H_4O concentrations were found in the welding shop as a result of the oxy-ethylene welding process. Hydrogen chloride emissions continuously showed low-level concentrations. It is expected that welders could experience

chronic irritation as a result of this exposure. The gases, PH_3, CO, O_3, and SO_2, were sporadically present in low concentrations, but this occurred only during the winter months. The H_2 concentrations measured were high, but the indicator O_2 concentrations never dropped to hazardous low levels.

It is concluded that the welders exposed to the ambient air in the workshop will experience health problems after chronic exposure as found during the study. The results emphasise the importance of exposure characterisation studies in order to provide for the identification of pollutants and to implement engineering control of emission sources.

OPSOMMING

Min data is beskikbaar rakende lae chroniese blootstellingsvlakke van gasse in die omringende lug van 'n sweiswerkswinkel. Sodanige tekort aan data is veral van toepassing op Suid-Afrikaanse sweistoestande. 'n Ondersoek is uitgevoer om die gasblootstelling in die omgewing van sweisers in 'n groot ingenieursaanleg in Bloemfontein, Suid-Afrika, te bepaal. Die doel van die ondersoek was om die gasblootstellings gedurende die somer- en wintermaande vas te stel, ten einde die moontlike gesondheidsrisiko's ná kroniese blootstelling aan lug binne die sweiswinkel te bepaal.

'n Direkte leesinstrument, die "Process Monitoring System" (PMS-64), is gebruik om die gasse te toets. Die stelsel is in die middel van die werkswinkel by 'n vaste monsterbasis geïnstalleer. Data is versamel gedurende een week van elke maand, vanaf Februarie 1997 tot Julie 1997, om sodoende lesings gedurende die somer- sowel as wintermaande te bekom.

Die data is van die stelsel deur middel van 'n rekenaardrukker onttrek. Dit is daarna verwerk en in agt-uur Tyd Beswaarde Gemiddelde drempelwaarde (TBG) konsentrasies en weeklikse TBG-konsentrasies ingedeel. Die PMS-64 was toegerus om die volgende gasse te toets: NH_3, CO, Cl_2, ClO_2, C_2H_4O, H_2, HCl, HCN, H_2S, NO, NO_2, O_2, O_3, PH_3 en SO_2.

Die gaskonsentrasies wat binne die werkswinkel gevind is, is hierna met omgewings Drempelwaardes (DLW's) of beroeps-DLW's vergelyk wat deur wêreldwye kundige organisasies op hierdie gebied aanbeveel word. By die afwesigheid van sulke spesifieke DLW's, is 'n omgewings-DLW bereken gebruik wat bestaan uit 'n veertigste gedeelte van die beroeps-DLW.

Hoë C_2H_4O konsentrasies is in die werkswinkel as gevolg van die oksie-etileen sweisproses gevind. Die vrystelling van HCl het deurentyd 'n lae konsentrasievlak getoon. Dit word verwag dat werkers moontlik kroniese irritasie weens blootstellling kan ondervind. Die gasse, PH_3, CO, O_3 en SO_2, was sporadies in lae konsentrasies teenwoordig, maar het slegs tydens die wintermaande voorgekom. Die gemete H_2 konsentrasies was hoog, maar die indikator O_2-konsentrasies het nooit tot gevaarlike lae vlakke gedaal nie.

Die gevolgtrekking kan gemaak word dat werkers wat aan die omgewingslug binne die werkswinkel blootgestel word, gesondheidsprobleme ná kroniese blootstelling kan ervaar. Die resultate beklemtoon die belangrikheid van blootstellingskarakterisering in ondersoeke met die doel om vir die identifikasie van besoedelende stowwe voorsiening te maak en om vrystellingsbronne te beheer en effektief te bestuur.

1. INTRODUCTION

It is only during the last few years that the world has become aware of the environment as something which is of direct concern to man. Man is slowly learning that his own activities could interfere with the natural environmental processes, the most important of these interferences being atmospheric pollution.

Air quality is an issue of sustainability, as we strive to create an environment in which individuals and communities can thrive. Essential to that process is the continued improvement of the conditions which affect human health. There is an increasing understanding of what those risks to health entail, and the kind of benefits to be gained from cleaning the air. While great progress has been made, and is still being made regarding the improvement of air quality, important medium- and long-term goals remain. The latter will lead to a significant, further reduction in the number and extent of episodes of poor air quality, both in summer and in winter. Business and industry have a key role to play in meeting the objectives of programmes such as the reconstruction and development programme (RDP) which *inter alia* include that the majority of South Africans must have access to land, water and clean air (African National Congress (ANC), 1994). Industrial processes cause emissions of some air pollutants in significant proportions country-wide, and, in some cases, there are also objectives to be achieved regarding the local pollution of air (National Air Quality Strategy, 1996).

South Africa has many diverse industries such as welding, foundries and metal processing. After the Second World War, welding became the principal means of joining metal throughout the manufacturing, shipbuilding and construction industries (World Health Organisation (WHO), 1990).

Welding is a general occupation in South Africa. Welding includes those processes involving the joining or cutting of pieces of metal by using heat, pressure, or both these methods. These processes differ in the way that heat is created and applied to the parts being joined. It involves a number of processes referred to as welding, brazing, and thermal cutting.

The environment surrounding many welding processes contains fumes (particles of material) that may be either harmful (toxic) or relatively harmless, as well as gases which could have pulmonary or non-pulmonary effects. The presence of fumes and gases in the welding environment is a matter of concern to those responsible for the well-being of welding personnel (American Welding Society (AWS), 1987).

The possible long-term detrimental effect on lung function of short-term exposure to irritant inhalation is well recognised, but the actual risk of such an adverse outcome is difficult to quantify. The frequency and underlying causes of persistent respiratory symptoms associated with increased airway responsiveness after acute irritant inhalation, are not known (Blanc *et al.*, 1993a).

Fumes, gases and high-intensity ultraviolet light are given off during the welding process. Some welding fumes and gases could irritate the eyes, nose and respiratory system, while others could cause permanent damage to internal organs such as the brain, liver and kidneys (Rekus, 1991).

Specific welding processes entail potential exposure to diverse chemical agents known to cause specific occupation-related adverse health effects. The contribution of population-based studies among workers exposed to hazardous inhalants is widely recognised. The results from studies on workers in the cotton textile, asbestos, coal, and many other industries have been used to set standards in the workplace and have substantially mitigated the adverse respiratory effects of these exposures (Weill, 1993).

The inhalation of irritant chemicals at home, on the job or in the community is a common cause of illness due to unintentional toxic exposures. Based on national poison control reports, more than 60 000 such cases occur annually in the United States, although the actual number of illnesses may be ten times as many (Blanc *et al.*, 1993b). A previous proportional mortality ratio (PMR) study among workers at a metal components manufacturing facility, showed a greater proportion of lung cancer deaths than a prediction based on US rates envisaged (29 observed, PMR = 212, 95% confidence interval [CI] 152-298) (Acquavella and Leet, 1991). In South Africa such data are non-existent, mainly as a result of underreporting and the absence of exposure characterisation programmes.

A general exposure characterisation for environmental welding gas emissions cannot be established, because the composition of welding emissions change for different welding processes, and the various components of a welding emission could interact to cause adverse health effects. The type of welding process used on steel can affect gas generation rates. Flux-cored arc and shielded metal arc welding generate much more fumes than gas metal arc and gas tungsten arc welding (National Institute of Occupational Safety and Health (NIOSH), 1988a).

The aim of this project is to identify and characterise all health-related agents regarding gases to which welders of a large engineering plant are potentially exposed. A further aim is the identification of exposure patterns and possible health risks to which the workers inside the plant are exposed.

1.1 Occupational epidemiology

Epidemiology is a study of the distribution and determinants of disease frequency. Researchers in this study field aim to identify factors which promote health and reduce the burden of disease in human populations. When applied to occupational health, epidemiology thus has the dual task of describing the distribution of deaths, accidents, illnesses, and their precursors in the various sections of the occupationally active population, and of searching for the determinants of health, injury and disease in the occupational environment (WHO, 1986).

Epidemiological studies are also concerned with the raw materials and intermediates of a manufacturing process, their physical and chemical properties, and their possible transformations in the surrounding media.

In health professions, human life is high on the hierarchical list of priorities. The general public also considers health as a major determinant of the quality of life. In some countries, epidemiology has in recent years already been introduced into the training and practice of at least some categories of occupational health personnel. Mostly, however, epidemiology has not contributed its full potential to occupational health (WHO, 1986).

Working conditions are frequently characterised by a considerable variability in the concentrations of dust, vapours and gases. The proper quantitative estimation of exposure to a given chemical substance is the basis for the corresponding estimation of the response of the organism and the determination of correlations between the quantity indicators of the effects of chemical agents and the changes in the workers' health (WHO, 1986).

1.2 Exposure characterisation

Measurement of gases is usually difficult, expensive and comprises of a very long procedure. However, detecting gases with a direct reading instrument is easier and much more accurate. Unfortunately, such instrumentation is heavy and thus complicates individual sampling and the detection of personal exposures. It is generally used to characterise the surrounding air in the workplace, with a stationed sample base.

In practice it is found that the concentration of gases could vary substantially during the day. This is as a result of the continuous diffusion of gases. If the emission process stops completely, the concentrations could fall well below the detection limit as a result of the diffusion process.

It must be taken into account that molecular weight plays an important role in diffusion therein that lighter molecules diffuse faster than heavier ones. This relationship was stated by Graham's universal law as follows: "The rate of the diffusion of gases is inversely proportional to the square roots of the molecular weights" (or inversely proportional to the square roots of the densities) (Sackheim and Lehman, 1990).

When data are collected during a period of one week with a sampling interval of 30 minutes, the characteristics of exposure are indicated substantially for the identification of specific processes or sources of exposure. In this study, a sampling base was set up in the centre of the welding activities to obtain emissions representative of the working environment. The sampling was conducted during summer and winter months to obtain the contrast between the different type of emissions and the exposure concentrations. During the winter months, doors and windows are closed and fires are made inside the workplace to heat the surrounding environment. Incomplete combustion of the fires causes gases to be emitted and it is anticipated that exposure should be more severe than during the hot summer months.

No data exist for time distributions with weekly interval exposures of welders, and the concentrations, which vary temporally and particularly due to atmospheric changes (e.g. temperature) in such workplaces, are not characterised. Due to the lack of such exposure data, the emissions from processes are generally controlled or not controlled at all. A general ignorance or unawareness of gas emissions therefore exists, causing emissions not to be controlled.

Every hazardous gas likely to be encountered, can be classified according to the danger it poses and a "safe" concentration can usually be quoted in terms of a Threshold Limit Value (TLV). These concentrations may also be quoted in terms of Time Weighted Averages (TWA).

Time Weighted Averages can be calculated by using the average concentration for an 8-hour shift, or alternatively the time of exposure to polluted air. The TWA concentration is then compared to the Time Weighted Average Threshold Limit Value (TWA.TLV). The limits are specified in the Hazardous Chemical Substances Regulation, 1995 (South Africa, 1995), and are expressed in terms of one part pollutant to one million parts of air (ppm) or milligrams of contaminant per cubic metre of air (mg/m^3).

Time Weighted Average Threshold Limit Values (TWA.TLV) may be exceeded for short periods of time (15 minutes in an hour with a maximum of 4 excursions per day), provided that the average concentration for the 8-hour shift does not exceed the TWA and that no ceiling concentration (C.TLV) has been set (Schröder and Schoeman, 1994).

Schröder and Schoeman (1994) stated that the amount by which a TWA may be exceeded without injury to health, depends on factors such as:

- the nature of the contaminant;
- whether high concentrations, even for short periods, will cause acute poisoning;
- whether the effects are cumulative;
- the frequency with which high concentrations occur; and
- the duration of such periods.

1.3 Welding

Welding refers to any process of joining pieces of metal at joint faces that have been made soft or have been liquefied by means of heat and/or pressure. In electric arc welding, which has been in commercial use since 1882 and is the most commonly used of the approximately 80 different types of welding and allied processes, the heat produced when electricity flows through a gas-filled gap from one electrical conductor to another, is utilised. The arc between the two conductors has an average temperature of 2204 °C in most processes, and in certain processes it may be as high as 22204 °C, which is a temperature above the boiling point of most elements contained in welding rods. The high temperature of the process causes liquefiction of both the "base metal" pieces to be joined and the "filler metal" of a consumable electrode or wire, which is fed into the weld (Radaj, 1992).

Consumable electrodes are designed to generate an oxygen-free shielding gas, and to protect the weld from immediate weakening by oxidation of the welded metal when heated. Molten fluxes from the consumable electrodes help carry away impurities from the weld in a liquid steam. Fluxes may be integral components of the consumable welding electrode or may be added separately.

Shielding gases may also be added to minimise oxidation and other reactions that occur when arc welding is performed in air. In some instances, the shielding gas intensifies ultraviolet radiation, leading to increased photochemical production of gases, which are toxic to the respiratory system. Wavelengths below 200 nm (UV-C) are most important in the formation of ozone (O_3) during welding. Carbon dioxide (CO_2) in the shielding gas produces carbon monoxide (CO) through reduction (Sferlazza and Beckett, 1991).

This occupation may involve inhalation exposure to a number of agents, depending on the specific welding process. The adverse health effect of welding is due to chemical, physical and radiation hazards. Common chemical hazards include gases such as CO, nitrogen oxides, and O_3. The gases generated in welding processes are considered to be among the more harmful of the agents to which many welders are exposed. Exposure, as measured during working conditions, depends on the composition of the welding technique, the process being used, the ventilation of the area and the presence of respiratory protection. Welders may also experience respiratory illness as a result of the interaction between welding inhalation exposures and cigarette smoking (Karlsen *et al.*, 1992).

More common, and less easily discerned, is an overall increase in the general level of sickness in a population exposed to toxic chemicals. Most chemicals do not only cause a single abnormality, but some organ systems may be affected more often than others (Sherman, 1994).

1.4 Metal degreasing

All surface treatments of metals such as galvanising, nickel-plating, plastic-coating, painting, et cetera, require surfaces to be free from grease, dirt or any other kind of contaminant before the actual treatment is carried out. In the welding workshop a process called degreasing is performed.

The biggest bulk of degreasing (if dirt, as well as oil or grease, has to be removed) is carried out by immersing the metal or metal component in a boiling liquid solvent. The basic principle of degreasing is that the contaminated component is suspended in the vapour rising from boiling chlorinated hydrocarbon solvents such as trichloroethylene (Smith, 1993) or methyl chloride (Davies, 1994) in the degreasing system. The vapour immediately condenses on contact with the relatively cold metal surfaces, dissolves the contaminant (usually oil or grease) and the condensate flows back into the degreasing system. Within a short period of time the component reaches the temperature at which vaporisation commences, and then condensation ceases. Degreasing is now complete and the component is slowly withdrawn from the plant in a perfectly clean condition. The basis of all degreasing systems is the solvent, of which trichloroethylene is the most powerful grease solvent known. Its low boiling point, low specific heat and low latent heat of vaporisation make only moderate demands on fuel and cooling water (Smith, 1993).

1.5 Gas exposure

In this study, the following gases were selected for the identification of health effects and the possibility of the presence of each gas:

1.5.1 Ammonia (NH_3)

Ammonia is present during a variety of processes such as chemical synthesis, the manufacturing of explosives, petroleum and pharmaceuticals, to name but a few (Plunkett, 1987). Ammonia concentrations as low as 50 ppm are moderately irritating, but workers generally become accustomed to these levels. Other than sensory effects - either irritation or annoyance of the respiratory tract - there is no evidence of acute or chronic adverse effects caused by exposure to NH_3. Accidental exposures to extremely high (10 000 ppm) concentrations, however, could be fatal (Calabrese and Kenyon, 1991).

1.5.2 Carbon monoxide (CO)

Carbon monoxide is a colourless, tasteless gas that can be formed when CO_2 shielding gas is used in gas metal arc welding. A toxic concentration of 50 ppm is set as maximum allowable exposure by the Hazardous Chemical Substances Regulations, 1995 (South Africa, 1995). Low level exposures may result in pounding of the heart, ringing in the ears and a throbbing headache (Rekus, 1991).

1.5.3 Chlorine gas (Cl_2)

The main use of Cl_2 is to kill micro-organisms in water (Krimsley, 1994). Chronic lung disease, electrocardiograph changes, and death have occurred in humans exposed to high concentrations of Cl_2 as a consequence of industrial accidents. Studies involving both humans and laboratory animals have shown that Cl_2 is a potent primary irritant to the eyes, as well as to both the upper respiratory tract and the deeper structures of the lung (Calabrese and Kenyon, 1991).

1.5.4 Chlorine dioxide (ClO_2)

Chlorine dioxide is used in bleaching textiles, paper pulp and flour, as oxidising agent, for the purification of water, as well as for the taste and odour control of water (ACGIH, 1991a). Smith and Willhite (1990) reviewed the genotoxicity of ClO_2 and concluded that ClO_2 has a weak mutagenic potential. However, it is still highly toxic and corrosive in nature. Severe conjunctivitis, rhinorrhea, coughing, headache, vomiting and pulmonary oedema could occur (Plunkett, 1987).

1.5.5 Ethylene oxide (C_2H_4O)

Acetylene (C_2H_2) and oxygen (O_2) are two fuel gases used for welding and can result in emissions of C_2H_4O. Cases of acute exposure have been relatively rare. Chronic exposure to relatively high levels has been observed to cause reversible peripheral neuropathy. Chronic exposure to low levels may cause numbing of the sense of smell, slight eye irritation, and adverse effects on a number of organs, including the liver, kidneys and central nervous system (Stacey, 1993).

1.5.6 Hydrogen (H_2)

Hydrogen is amongst the gases and vapours that, when present in high concentrations in air, act primarily as simple asphyxiates without other significant physiologic effects. A TLV is not recommended for H_2, because the limiting factor is the available O_2. If the percentage of O_2 in the ambient air is below the minimum level, the asphyxiant characteristics of H_2 will be more severe and suffocation can result. The minimum amount of O_2 should be 18% per volume under normal atmospheric pressure (Stacey, 1993).

1.5.7 Hydrogen chloride (HCl)

Hydrogen chloride is used in the manufacturing of chemicals and food, metal-processing and the acid treatment of oil wells to increase crude oil flow (Manahan, 1992). There is very little information available on the respiratory effects of low concentrations and no ambient standards for HCl exist in the

United States and South Africa. Hydrogen chloride vapour tends to dehydrate the tissue of the eyes and the respiratory tract, because of its high affinity for water (Stevens *et al.*, 1992).

1.5.8 Hydrogen cyanide (HCN)

Hydrogen cyanide is extremely poisonous and acts very rapidly, with death occurring within a few minutes due to respiratory failure. The early symptoms of toxic reactions to lower levels of exposure to HCN could include weakness, headache, confusion and occasionally, nausea and vomiting; the rate and depth of respiration increase, and respiration later becomes slow and gasping. High concentrations of HCN could cause almost instantaneous collapse, cessation of respiration and death (Haley and Berndt, 1987).

1.5.9 Hydrogen sulphide (H_2S)

Hydrogen sulphide is a flammable, poisonous gas with the characteristic odour of rotten eggs. It is detectable in air at a concentration of 0.008 ppm (Amoore and Hautala, 1983). According to the National Institute of Occupational Safety and Health (NIOSH, 1977), H_2S is extremely hazardous and is the leading cause of sudden death in the workplace. Collapse, oedema, and death from respiratory failure may occur within a few seconds of one or two inhalations (The Merk Index, 1983).

1.5.10 Nitric oxide (NO)

Nitric oxide is formed by the combination of nitrogen (N) and O_2 in the air at elevated temperatures, as encountered in electric arc welding and especially in oxyacetylene gas welding processes (Norwood *et al.*, 1966). The affinity of NO for ferrous haemoglobin is 1400 times that of CO (where CO binds ferrous haemoglobin with an affinity 245 times that of O_2). Immediately on contact with air, nitric oxide (NO) is converted into the highly poisonous nitrogen dioxide (NO_2) and nitrogen trioxide (NO_3) (The Merk Index, 1983).

1.5.11 Nitrogen dioxide (NO_2)

Low-level concentrations have been observed during oxyacetylene welding. No long-term effects are associated with exposure to NO_2, although low levels could irritate the eyes and respiratory tract (Rekus, 1991).

1.5.12 Oxygen (O_2)

Oxygen is continuously present in the atmosphere in a concentration of approximately 21%. No health effects will occur with a small increase or decrease in O_2. It can be dangerous, however, if the concentration drops to below 18%. It is also used as an indicator for dangerous H_2 concentrations (Stacey, 1993).

1.5.13 Ozone (O_3)

Occupational exposure to O_3 occurs during arc and inert gas welding. The route of entry is inhalation and it acts as an irritant. During exposure, symptoms such as irritation of the eyes, headaches, dizziness, weakness and decreased visual acuity could occur (Plunkett, 1987).

1.5.14 Phosphine (PH_3)

Phosphine is a by-product of such processes as the pickling of metals, and is often found in the semiconductor industries. A TLV of 0.3 ppm is recommended by the Hazardous Chemical Substances Regulations, 1995 (South Africa, 1995).

It is known to be an irritant and can cause pulmonary and cerebral oedema, as well as liver and kidney damage (Plunkett, 1987).

1.5.15 Sulphur dioxide (SO_2)

Sulphur dioxide is a corrosive gas and forms sulphurous and sulphuric acids on contact with moisture. The signs and symptoms accompanying acute exposure are conjunctivas and irritation with rhinorrhea, dyspnea, laryngeal spasms and suffocation. On chronic exposure, epistaxis and ulcers of the nasal septum, burning and obstructive pulmonary disease could occur (Plunkett, 1987).

1.6 Gas characteristics

The molecules of a gas do not experience the strong mutual attraction forces characteristic of the molecules of a solid or liquid. There are small attractive forces in very dense gases and in gases which are near the temperature at which they condense into liquids, but otherwise these forces are often so small that they are negligible. Many gaseous phenomena can be explained by assuming that gases consist of hard, sphere-like molecules which move randomly at very high speeds and interact with each other only by collision (Nave and Nave, 1985).

Various properties of gases can be explained in terms of gas laws. Boyle's law states that: "The volume occupied by a gas is inversely proportional to the pressure if the temperature remains constant" (Krimsley, 1994). When gases are heated, they expand; when gases are cooled, they contract. The relationship between volume and temperature is expressed by Charles's law: "The volume of a fixed quantity of a gas is directly proportional to its absolute temperature if the pressure remains constant" (Sackheim and Lehman, 1990).

Dalton's law refers to a mixture of gases rather than to a pure gas. He states that: "In a mixture of gases, each gas exerts a partial pressure proportional to its concentration" (Andrew and Rispoli, 1991).

In view of the above-mentioned universal laws and densities, it can be determined whether a specific gas will ascend or descend in a so-called "normal" atmosphere. The working height, the toxicity of gases, the chemical classification thereof, and the signs and symptoms thereof, play an important role in the assessment of exposure to gases.

1.7 Hypothesis

Given the nature of gases, the industrial process and the chemical agents, as well as the likelihood of toxic human exposures presently or in the past, this study considers the plausible adverse health effects (acute, sub-acute and chronic) to which employees may be exposed. A null hypothesis regarding the presence of gaseous toxicants in the mentioned workplace is formulated as follows:

> **H_0:** The workers in the welding shop are exposed to concentrations of air toxicants which will affect their health after chronic exposure.

The alternate hypothesis is:

> **H_a:** The workers of the welding shop are exposed to concentrations of air contaminants which will not affect their health after chronic exposure. The H_o can be accepted if it falls within the 95% confidence interval.

2. METHODS

2.1 Experimental Set-up

2.1.1 Welding shop

The welding shop where sampling was performed, houses a construction line for train trucks. The specific site was chosen as it is considered to be a large welding process in the province and is representative of similar welding situations in South Africa. The welding shop has been in operation for the past 30 years. Operation proceeds during one 8-hour shift a day for 5 days a week, and in special cases, also on Saturdays and Sundays. At the plant all train trucks for the national railway company are assembled. Metal sheets are cut, moulded and prepared for assembly in the workshop. The sheets are placed in jigs (frames) and then welded.

A few engineering processes are used in this welding shop. Plasma arc cutting is used to cut metal to the correct size. It is an arc-cutting process used to separate metal by melting a localised area with a constricted arc and removing the molten material with a high-velocity jet of hot, ionised gas directed through an orifice (NIOSH, 1988a).

Different types of welding are also used during the process. Gas metal arc welding, which is mostly used, is an arc-welding process for the coalescence of metal by heating it with an arc between a continuous filler metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture. Some variations of this process are called gas metal arc welding (MIG) or CO_2 welding (Sferlazza and Beckett, 1991).

Oxyacetylene welding is an oxyfuel gas-welding process that causes the coalescence of metals by heating the steel with a gas flame obtained from the combustion of acetylene with O_2. The process may be used with or without the application of pressure and with or without the use of filler metal (Sferlazza and Beckett, 1991).

The third method in use is plasma arc welding whereby an arc-welding process causes produces coalescence of metals by heating steel with a constricted arc between an electrode and the work piece (transferred arc) or between the electrode and the constricting nozzle (non-transferred arc). Shielding is obtained from the hot ionised gas flowing from the orifice, which may be supplemented by an inert gas or a mixture of gases. Pressure may or may not be applied, and filler metal may or may not be supplied (Sferlazza and Beckett, 1991).

2.1.2 Preliminary sampling and analysis

2.1.2.1 Instrumentation

A direct reading instrument known as a Process Monitoring System (PMS-64), manufactured by Spero Technology cc, Johannesburg, was used for sampling purposes (Figure 1).

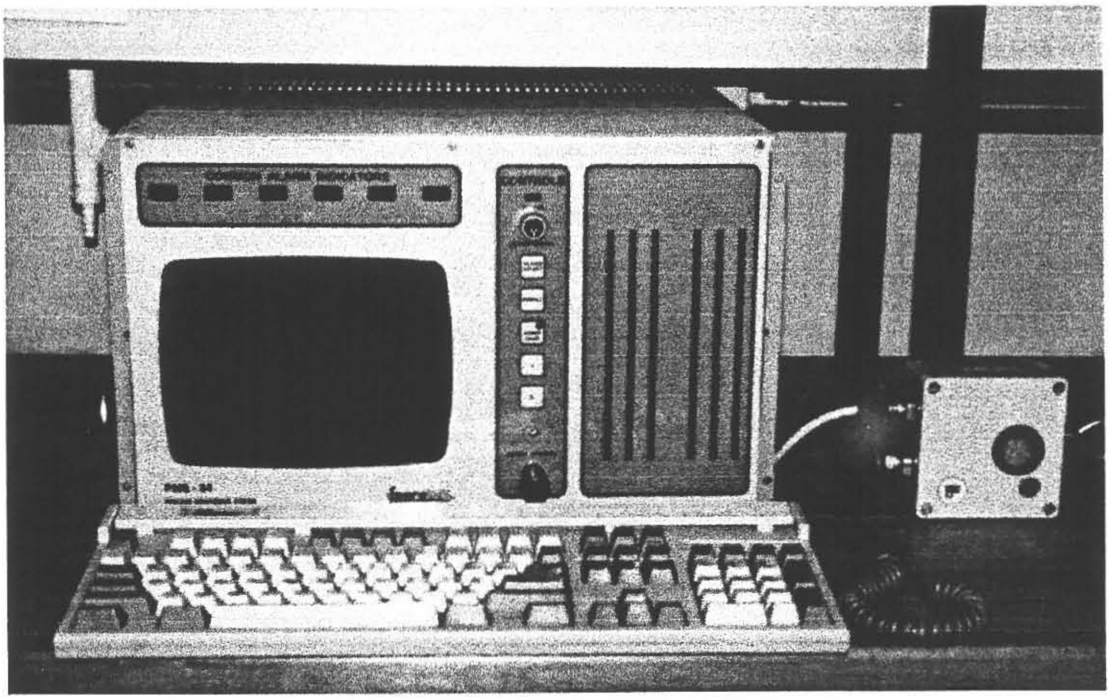

FIGURE 1: Process Monitoring System (PMS-64)

The PMS-64 is a multi-purpose data acquisition and control system. It is particularly suitable for process and / or environmental monitoring and control, as well as for a wide range of related applications in the measurement of gases and the control thereof. The PMS-64 is linked to an 80386 microcomputer with a built-in VGA monitor. A standard IBM-PC keyboard can be connected to the system to gain access to its advanced features. The built-in signal processing circuits make provision for all popular types of sensors with voltage or current outputs to be used with the PMS-64. Every analogue input channel is capable of handling one sample every second. The system provides a maximum of 16 digital input channels to monitor the status of electrochemical cells. Internal signal processing allows for input voltage signals of 5V, 12V or 24V (Sperotec, 1993).

2.1.2.2 Calibration

Depending on the nature of the physical input devices connected to the PMS-64, it is required to check and correct the calibration of the input channels of the system from time to time. A typical gas detector for toxic gases based on a fuel cell sensor, such as CO, needs to be calibrated at specified intervals to compensate for saturation of the fuel cell due to prolonged exposure to the specific gas.

The PMS-64 provides a method for calibrating an entire input channel in-situ, from the detector to the sampled value in the system memory, without having to disconnect the sensor or interrupt the operation of the rest of the system. This method of calibration typically requires a calibrated input in the form of a known gas which is applied to the detector. The operator of the PMS-64 then monitors the response of the input channel to the calibration source and makes adjustments to the cells if the reading from the instrument differs from the known concentration of the calibration gas.

Calibration data for each analogue channel are stored in the system memory in the form of gain and offset values. These values are used by the system to convert every raw, sampled value of the channel into engineering units, using the following equation:

(Engineering unit value) = (raw value) x (channel gain) + (channel offset),

where the raw value is simply a number between -2048 and 2047, the result of converting the analogue electrical signal from the detector into a digital quantity in the system memory. These values are never specified in the system when an analogue channel is set-up. A zero voltage and full-scale value (in engineering units) which are expected from the channel, are supplied by the software. The gain and offset values are calculated automatically, based on the programmed information. It is then stored as the "master" gain and offset for that particular channel. In-situ calibration, which is the process of modifying the nominal values of gain and offset in order to compensate for deviations from the "master" in the behaviour of the channel, can also be done.

For this study the PMS-64 was fitted with 15 different "smart" sensors. These sensors are called smart sensors, because each sensor is equipped with a microchip containing all the necessary calibration and detection-limit data. The sensors are equipped with automatic altitude adjustment and therefore the altitude has no influence on the calibration of the sensors.

The O_3 sensor, which is based on a high output Cl_2 sensor, has been tested to respond well to O_3. Due to the difficulty in obtaining an accurate and pure calibration gas for the specific sensor, it was not possible to establish the exact sensitivity of the O_3 sensor to O_3. It is known that the response of the sensor to O_3 will be between 100 % and 200 % in relation to its response to Cl_2. The response is more or less consistent with a figure of approximately 120 % (Sperotec, 1993).

Lower and higher detection limits were calculated for each sensor with regard to the milliamperes input and the detection-limit. These values are stored in the memory of the instrument, and the ranges of the individual sensors are taken into consideration.

The PMS-64 store channel data and alarm events on a circular set of files on a RAM (Random Access Memory) disk. The number of files and the size of each file are configured in the factory prior to delivery. Separate sets of files are maintained for data and alarm events. When the current file in the set is full, a new file is created by the programme software. When the last file in the set is full, the first file is deleted and a new file is created. Logging characteristics for individual channels in the system can be specified, by specifying whether data and / or alarm events for the channel should be logged, as well as the time interval at which data for that channel must be logged. The size of a database record (channel instantaneous value or alarm event) is 10 bytes, and the following fields are included in the record:

- channel number (1 byte);
- date and time (4 bytes);
- channel instantaneous value (4 bytes); and
- the type of alarm that occurred (1 byte) (This field is undefined for logged data and applies only to logged alarm events.)

The PMS-64 uses a non-volatile internal mass storage device to log data and alarm events. Specifying the logging set-up for individual channels is done by using a computer keyboard and the on-line menu system. Logged data and alarm events could be viewed on a screen or printed by a standard printer.

The system keeps track of the current logging configuration and is therefore able to predict when the logged data will overflow. At the end of each sampling period, the instrument is removed and the data is retrieved by using a computer printer.

2.1.2.3 Operation of sensors

The fuel cell is an electrolytic cell with three electrodes which operate under conditions of controlled diffusion. Gas molecules pass through a membrane and are absorbed by an electrocatalytic electrode. The molecules are then either electrochemically oxidised or deposited on the measurement electrode. The catalyst of the electrode is specific to the detection gas and a current of a few microamperes, which is directly proportional to the concentration of the gas, is produced within the limits of diffusion. The electrolyte never needs topping up, but lasts for a period of between 2 and 5 years, depending on working conditions such as temperature, humidity, etc. (Sperotec 1993).

2.2 Gas concentrations

2.2.1 Sampling

Static sampling was conducted in the welding shop of a railway truck factory in Bloemfontein by using a Process Monitoring System (PMS-64) as described in section 2.1.2.1

The PMS-64 was placed in the centre of the welding shop, at a stationed sampling base. Sensors were plugged into the instrument and enabled to start the sampling process. The sensors were placed at a height of approximately 1.8 m above floor-level.

The different gas detection sensors were selected on the basis of the toxicity of the gases, the possibility of occurrence, the different processes in operation and the envisaged concentrations which could result.

2.2.2 Gas characteristics

The density of each gas determines the movement thereof, and determines whether the specific gas will ascend or descend under normal atmospheric pressure (1 atmosphere) at a temperature of 25°C, if not otherwise specified. The properties of the gases in this study, are listed in Table 1 to indicate the expected movement (Sackheim and Lehman, 1990).

TABLE 1: Gas characteristics of the measured gases (ACGIH, 1991 a,b and c).

Common gas name	Chemical symbol	Density	Movement
Ammonia	NH_3	0.60	Ascend
Carbon monoxide	CO	0.97	Ascend
Chlorine gas	Cl_2	3.21	Descend
Chlorine dioxide	ClO_2	3.09	Descend
Ethylene oxide	C_2H_4O	0.89	Ascend
Hydrogen	H_2	0.07	Ascend
Hydrogen chloride	HCl	1.27	Descend
Hydrogen cyanide	HCN	0.94	Ascend
Hydrogen sulphide	H_2S	1.19	Descend
Nitric oxide	NO	1.04	Descend
Nitrogen dioxide	NO_2	1.58	Descend
Oxygen	O_2	1.43 (0°C)	Descend
Ozone	O_3	2.14 (0°C)	Descend
Sulphur dioxide	SO_2	2.30	Descend
Phosphine	PH_3	1.18	Descend

2.2.3 Sampling period

The PMS-64 was set up in such a way that sampled air was representative of the indoor air quality to which workers are exposed during normal working conditions.

Sampling was done for one week during each month starting from February 1997 and lasting until July 1997 (Table 2). The specific period was selected to characterise the differences in concentrations during seasonal changes. The sampling intervals were set to log data every 30 minutes, thus obtaining 240 samples per week (Monday to Friday).

TABLE 2: Representative sampling intervals during the period February 1997 to July 1997

Seasons	Months	Date sampled
Summer	February	10 - 14
	March	10 - 14
	April	14 - 18
Winter	May	12 - 16
	June	9 - 13
	July	21 - 25

2.2.4 Weather data

Weather data were obtained from the local weather station of the Department of Environmental Affairs, Bloemfontein. The weather station is approximately 5 km north-east of the sampling base. The weather data play an important role in the study, because the activities and behaviour of the workers are influenced by it.

3. RESULTS

3.1 Summer concentrations 1997

3.1.1 February

During the month of February, O_2, C_2H_4O, H_2 and HCl concentrations were detected. The 8-hour work shift TWA concentrations for February are shown in Table 3.

TABLE 3: Work shift 8-hour TWA concentrations measured during February 1997 (10/02/97 - 14/02/97)

SUBSTANCE	SAMPLING DAYS				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
C_2H_4O (ppm)	0.56 ± 0.11	0.65 ± 0.29	0.63 ± 0.17	0.46 ± 0.11	0.34 ± 0.10
H_2 (ppm)	97.63 ± 1.96	85.69 ± 1.92	81.63 ± 6.40	59.06 ± 4.61	43.69 ± 2.60
HCl (ppm)	0.68 ± 0.34	1.12 ± 0.42	0.99 ± 0.39	1.19 ± 0.60	0.58 ± 0.17
O_2 (%)	20.67 ± 0.08	20.61 ± 0.10	20.68 ± 0.12	20.48 ± 0.16	20.66 ± 0.13

Ethylene oxide: The measured C_2H_4O concentration with a TWA concentration of 0.45 ± 0.21 ppm (for the full week) is shown in Figure 2A. The maximum concentration was 1.4 ppm and the minimum concentration 0.1 ppm.

Hydrogen: Hydrogen showed a TWA concentration of 65.06 ± 20.41 ppm with a range from 36 ppm to 100 ppm. The H_2 concentration is depicted in Figure 3A.

Hydrogen chloride: The HCl concentration is shown in Figure 4A. It ranged from 0.1 ppm to 2.2 ppm with a mean concentration of 0.73 ± 0.51 ppm was calculated.

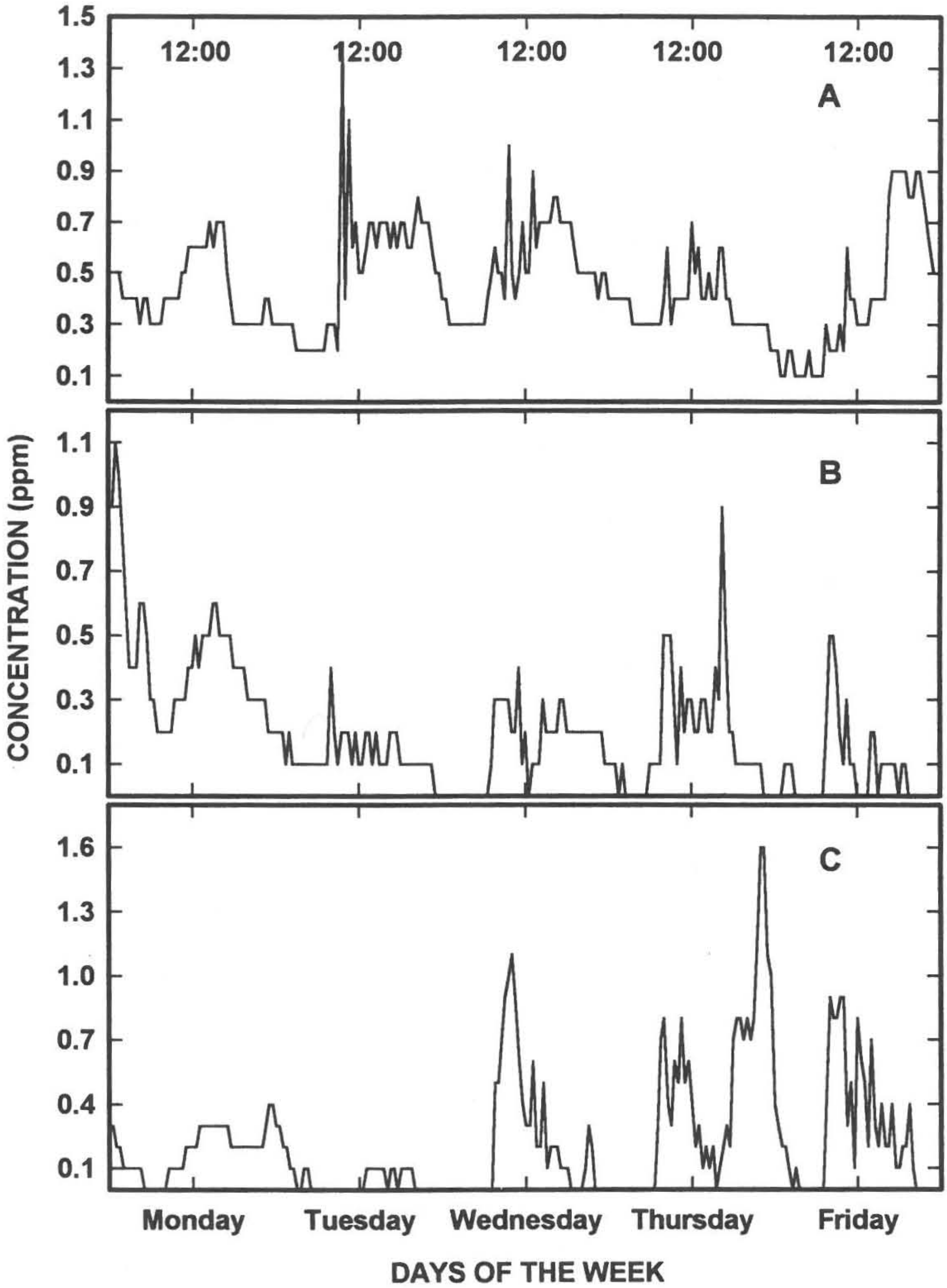

FIGURE 2: A: C_2H_4O concentrations (ppm) measured in welding shop air during February 1997
B: C_2H_4O concentrations (ppm) measured in welding shop air during March 1997
C: C_2H_4O concentrations (ppm) measured in welding shop air during April 1997

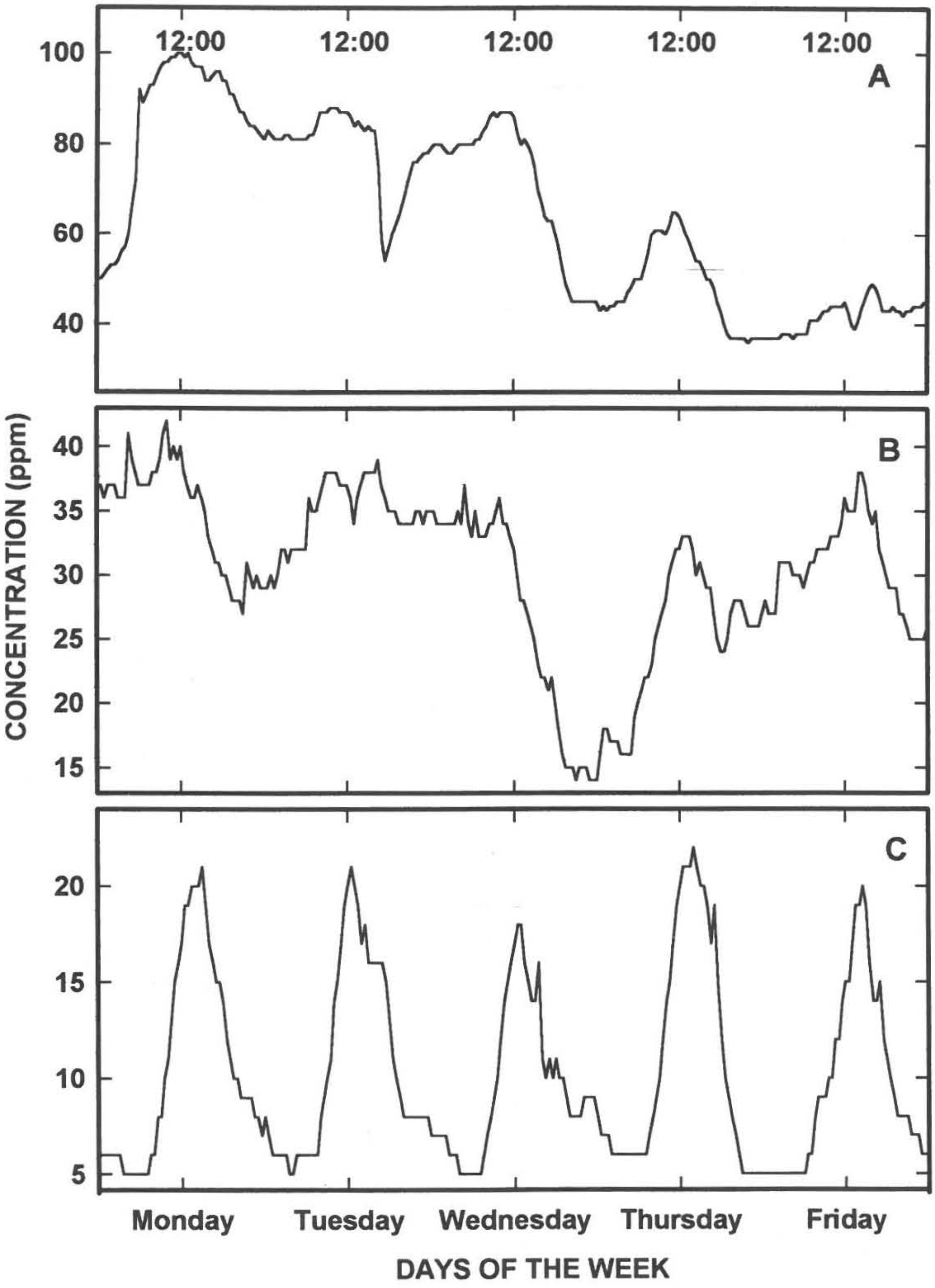

FIGURE 3: A: H_2 concentrations (ppm) measured in welding shop air during February 1997
B: H_2 concentrations (ppm) measured in welding shop air during March 1997
C: H_2 concentrations (ppm) measured in welding shop air during April 1997

Oxygen: Oxygen concentrations varied between 20.4 % and 20.8 % with a TWA concentration of 20.58 ± 0.12 %. The O_2 concentration is shown in Figure 5A.

Ammonia: The concentrations for NH_3 were below the detection limit (1-100) of the PMS-64.

Carbon monoxide: The CO concentration was below the detection limit (0-1 000 ppm) of the CO sensor used.

Chlorine gas: No Cl_2 concentrations were found during the sampling period of February 1997.

Chlorine dioxide: The measured ClO_2 concentrations were below the detection limit (0-3 ppm) of the instrument and considered as negligibly low.

Hydrogen cyanide: No HCN concentrations were found during the sampling period.

Hydrogen sulphide: The measured H_2S concentrations were very low and below the detection limit (0-100 ppm) of the instrument.

Nitric oxide: No NO concentrations were detected during the specified sampling period.

Nitrogen dioxide: Concentrations of NO_2 were not detected and therefore considered to be below the detection limit (0-30 ppm) of the instrument.

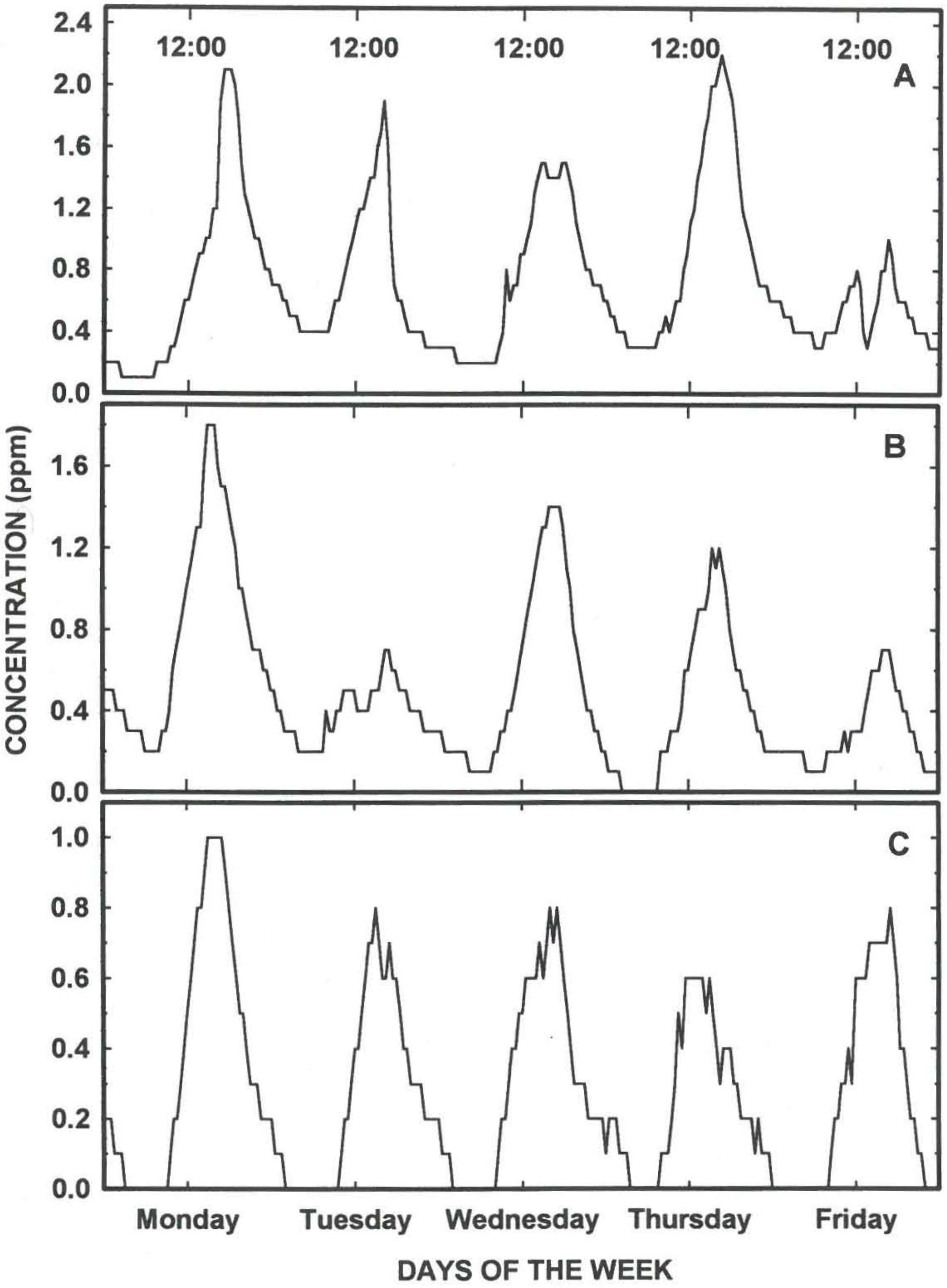

FIGURE 4: A: HCl concentrations (ppm) measured in welding shop air during February 1997
B: HCl concentrations (ppm) measured in welding shop air during March 1997
C: HCl concentrations (ppm) measured in welding shop air during April 1997

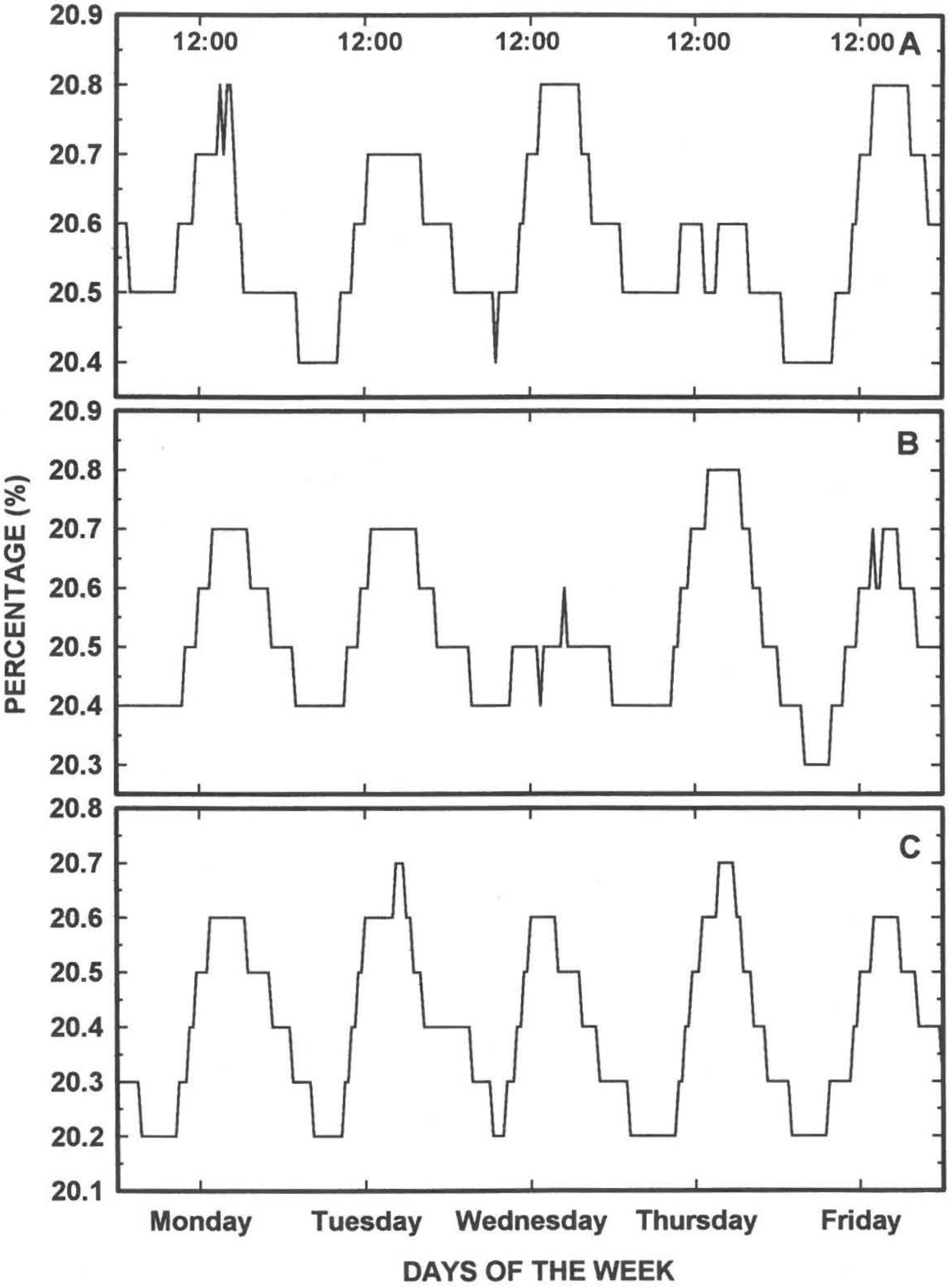

FIGURE 5: A: Percentage O_2 measured in welding shop air during February 1997
B: Percentage O_2 measured in welding shop air during March 1997
C: Percentage O_2 measured in welding shop air during April 1997

Ozone: The measured concentrations of O_3 were below the detection limit (0-1 ppm) of the PMS-64.

Sulphur dioxide: No SO_2 concentrations were detected during February 1997.

Phosphine: Phosphine concentrations were below the detection limit (0-30 ppm) of the instrument.

Weather data: The maximum and minimum temperatures, obtained from the weather station, for the February 1997 sampling period are depicted in Table 4. The percentage humidity detected and obtained from the weather station during February 1997 is recorded in Table 5.

TABLE 4: Maximum and minimum temperatures (°C) during the February 1997 sampling period

TEMPERATURE (°C)	SAMPLING DATE				
	10/02/97	11/02/97	12/02/97	13/02/97	14/02/97
Maximum	29.9	29.4	33.5	26.1	26.9
Minimum	14.5	16.1	17.6	14.1	6.3

TABLE 5: Percentage (%) humidity detected during the February 1997 sampling period (10/02/97 - 14/02/97)

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HIGH	TIME	LOW	TIME
10/02/97	95	97	100	100	100	100	96	82	85	72	63	57	54	50	46	49	47	46	50	66	76	80	78	80	100	02:26	44	17:37
11/02/97	79	78	83	89	92	92	81	76	69	62	51	44	37	34	24	27	25	27	41	49	53	66	70	73	94	06:20	17	14:32
12/02/97	74	69	69	71	74	78	73	70	63	57	55	65	83	81	62	65	53	65	74	81	86	89	90	92	92	23:59	50	11:37
13/02/97	94	94	96	97	97	97	90	80	66	59	49	36	26	21	19	21	20	20	25	31	38	44	52	60	97	03:34	16	14:51
14/02/97	64	71	77	76	70	70	66	59	59	55	53	48	41	38	34	31	32	31	36	52	62	68	71	64	78	03:43	29	16:03

3.1.2 March

The gases O_2, H_2, C_2H_4O and HCl were detected during March. Work shift 8-hour TWA concentrations are depicted in Table 6.

TABLE 6: Work shift 8-hour TWA concentrations measured during March 1997 (10/03/97 - 14/03/97)

SUBSTANCE	SAMPLING DAYS				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
C_2H_4O (ppm)	0.41 ± 0.13	0.16 ± 0.05	0.21 ± 0.11	0.31 ± 0.12	0.14 ± 0.15
H_2 (ppm)	37.88 ± 2.36	37.19 ± 1.11	30.06 ± 4.54	30.13 ± 2.53	34.50 ± 2.00
HCl (ppm)	1.06 ± 0.52	0.44 ± 0.08	0.78 ± 0.41	0.65 ± 0.33	0.37 ± 0.17
O_2 (%)	20.57 ± 0.11	20.59 ± 0.11	20.48 ± 0.04	20.67 ± 0.13	20.56 ± 0.10

Ethylene oxide: Ethylene oxide concentrations were measured with a TWA concentration of 0.19 ± 0.19 ppm. It showed a maximum concentration of 1.1 ppm with a minimum value of 0 ppm. The C_2H_4O exposure is depicted in Figure 2B.

Hydrogen: The H_2 concentrations ranged from 14.0 ppm to 42.0 ppm with a TWA concentration of 30.46 ± 6.53 ppm. Hydrogen concentrations during March 1997 are shown in Figure 3B.

Hydrogen chloride: The HCl concentration, with a maximum concentration of 1.8 ppm and a minimum concentration of 0 ppm, is depicted in Figure 4B. A TWA concentration of 0.49 ± 0.40 ppm was calculated.

Oxygen: Oxygen concentrations are shown in Figure 5B. A TWA concentration of 20.52 ± 0.13 % and a maximum concentration of 20.8 % were obtained. The concentration dropped to 20.3 % at times.

Ammonia: Ammonia concentrations present in the welding environment were below the detection limit (0-100 ppm) of the instrument.

Carbon monoxide: No detectable concentrations of CO were present in the welding environment.

Chlorine gas: No Cl_2 concentrations were detected during the sampling period.

Chlorine dioxide: Chlorine dioxide concentrations present were below the detection limit (0-3 ppm) of the ClO_2 sensor used in this study.

Hydrogen cyanide: No HCN concentrations were detected during the March 1997 sampling period.

Hydrogen sulphide: No concentrations of H_2S were detected in the studied environment.

Nitric oxide: No meaningful values of NO were detected with the instrument used in this study.

Nitrogen dioxide: All the sampled values for NO_2 were below the detection limit (0-30 ppm) of the instrument.

Ozone: Ozone concentrations were below the detection limit (0-1 ppm) of the PMS-64.

Sulphur dioxide: No values for SO_2 were detected for the duration of March 1997.

Phosphine: Phosphine concentrations were below the detection limit (0-1 ppm) of the instrument.

Weather data: The maximum and minimum temperatures, obtained from the weather station, for the March 1997 sampling period are depicted in Table 7. The percentage humidity obtained from the weather station during March 1997 is shown in Table 8.

TABLE 7: Maximum and minimum temperatures (°C) during the March 1997 sampling period

TEMPERATURE (°C)	SAMPLING DATE				
	10/03/97	11/03/97	12/03/97	13/03/97	14/03/97
Maximum	30.0	25.3	26.7	27.4	24.5
Minimum	16.5	13.6	6.5	15.3	7.7

TABLE 8: Percentage (%) humidity detected during the March 1997 sampling period (10/03/97 - 14/03/97)

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HIGH	TIME	LOW	TIME
10/03/97	78	84	87	89	90	91	88	79	68	65	66	66	84	68	68	63	64	66	67	70	64	66	77	79	91	05:35	62	15:16
11/03/97	87	88	91	91	89	87	91	60	30	24	11	12	17	9	13	13	14	19	32	37	53	66	69	70	93	07:15	8	13:24
12/03/97	72	74	80	85	94	94	92	88	73	65	59	54	48	43	43	39	42	56	63	70	74	72	76	78	96	05:06	38	16:10
13/03/97	83	86	84	84	86	86	84	83	81	76	74	67	65	57	58	59	52	57	57	69	72	75	78	81	86	01:51	49	16:46
14/03/97	84	84	89	89	89	91	96	80	67	61	53	47	40	38	37	38	35	40	47	62	71	77	73	80	97	07:20	34	15:41

3.1.3 April

During April 1997 C_2H_4O, O_2, H_2 and HCl were once again, emitted from the welding process. In Table 9, the work shift 8-hour TWA concentration for each day of the week is shown.

TABLE 9: Work shift 8-hour TWA concentrations measured during April 1997 (14/04/97 - 18/04/97)

SUBSTANCE	SAMPLING DAYS				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
C_2H_4O (ppm)	0.21 ± 0.09	0.04 ± 0.05	0.51 ± 0.33	0.33 ± 0.22	0.51 ± 0.28
H_2 (ppm)	15.81 ± 4.48	16.13 ± 3.61	13.94 ± 3.11	17.56 ± 4.24	14.38 ± 3.77
HCl (ppm)	0.53 ± 0.37	0.39 ± 0.28	0.49 ± 0.20	0.45 ± 0.18	0.48 ± 0.22
O_2 (%)	20.47 ± 0.14	20.50 ± 0.14	20.50 ± 0.12	20.48 ± 0.16	20.46 ± 0.13

Ethylene oxide: The weekly exposure to C_2H_4O is shown in Figure 2C. The concentration ranged from 0 ppm to 1.60 ppm with a TWA concentration of 0.22 ± 0.30 ppm.

Hydrogen: The H_2 exposure showed a TWA concentration of 10.30 ± 4.99 ppm with a maximum value of 22 ppm and a minimum value of 5 ppm. The H_2 concentrations are depicted in Figure 3C.

Hydrogen chloride: Hydrogen chloride concentrations varied between 0 ppm and 1 ppm with a TWA concentration of 0.28 ± 0.28 ppm. The HCl concentrations are shown in Figure 4C.

Oxygen: Oxygen concentrations ranged from 20.2 % to 20.7 % with a TWA concentration of 20.40 ± 0.15 %. Oxygen concentrations are shown in Figure 5C.

Ammonia: Ammonia concentrations were below the detection limit (0-100 ppm) of the PMS-64.

Carbon monoxide: During the sampling period of April 1997, no CO concentrations were detected.

Chlorine gas: No Cl_2 concentrations were detected with the PMS-64.

Chlorine dioxide: Chlorine dioxide concentrations were below the detection limit (0-3 ppm) of the instrument.

Hydrogen cyanide: No HCN concentrations were found during the sampling period.

Hydrogen sulphide: No H_2S concentrations were detected.

Nitric oxide: Nitric oxide concentrations detected were below the detection limit (0-100 ppm) of the instrument.

Nitrogen dioxide: During the April 1997 sampling period NO_2 concentrations were not detected.

Ozone: No O_3 concentrations were found during this sampling period.

Sulphur dioxide: The detection limit (0-30 ppm) of the PMS-64 was above the SO_2 concentration of the air.

Phosphine: No PH_3 concentrations were detected during April 1997.

Weather data: The maximum and minimum temperatures, obtained from the weather station, for the April 1997 sampling period are depicted in Table 10. The percentage humidity obtained from the weather station during April 1997 is shown in Table 11.

TABLE 10: Maximum and minimum temperatures (°C) during the April 1997 sampling period

TEMPERATURE (°C)	SAMPLING DATE				
	14/04/97	15/04/97	16/04/97	17/04/97	18/04/97
Maximum	24.3	23.9	23.3	23.4	24.1
Minimum	5.7	5.9	4.1	5.3	6.3

TABLE 11: Percentage (%) humidity detected during the April 1997 sampling period (14/04/97 - 18/04/97)

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HIGH	TIME	LOW	TIME
14/04/97	82	86	86	87	88	88	91	92	69	56	39	33	28	30	33	26	33	45	51	65	70	71	79	81	93	07:57	26	13:08
15/04/97	83	83	83	87	89	91	92	86	68	54	46	35	35	36	40	60	59	63	77	80	86	87	84	88	94	07:19	34	12:57
16/04/97	88	89	90	91	93	91	93	91	74	59	43	37	33	30	30	25	30	40	55	69	73	77	82	84	95	07:21	25	15:01
17/04/97	86	88	89	89	90	91	88	89	77	66	53	49	37	34	36	38	40	51	60	59	67	84	86	88	91	05:44	31	13:42
18/04/97	91	94	96	97	98	98	98	95	78	61	58	52	47	42	35	32	33	41	56	71	76	81	82	85	98	04:18	30	16:20

3.2 Winter concentrations 1997

3.2.1 May

During the sampling period in May, the welding process emitted detectable concentrations of the following 8 gases: C_2H_4O, O_2, H_2, HCl, CO, O_3, PH_3 and SO_2. In Table 12, the work shift 8-hour TWA concentration for each day of the week is depicted.

TABLE 12: Work shift 8-hour TWA concentrations measured during May 1997 (12/05/97 - 16/05/97)

SUBSTANCE	SAMPLING DAYS				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
CO (ppm)	0.13 ± 0.50	1.76 ± 1.87	2.26 ± 2.12	1.90 ± 2.96	0.02 ± 0.08
C_2H_4O (ppm)	0.19 ± 0.09	0.01 ± 0.03	1.35 ± 0.65	1.39 ± 0.67	1.01 ± 1.23
H_2 (ppm)	3.25 ± 1.88	3.94 ± 2.21	5.13 ± 1.78	3.81 ± 1.47	3.66 ± 0.62
HCl (ppm)	0.27 ± 0.24	0.17 ± 0.17	0.47 ± 0.16	0.54 ± 0.16	0.51 ± 0.14
O_2 (%)	20.36 ± 0.18	20.39 ± 0.20	20.42 ± 0.20	20.46 ± 0.17	20.47 ± 0.15
O_3 (ppm)	0.000 ± 0.00	0.001 ± 0.00	0.009 ± 0.01	0.004 ± 0.01	0.00 ± 0.00
PH_3 (ppm)	0.004 ± 0.01	0.007 ± 0.01	0.013 ± 0.01	0.006 ± 0.01	0.00 ± 0.01
SO_2 (ppm)	n/d	n/d	0.02 ± 0.04	n/d	n/d

n/d = not detected during sampling.

Carbon monoxide: A maximum CO concentration of 7.7 ppm with a TWA concentration of 0.45 ± 1.34 ppm were detected. Carbon monoxide concentrations are shown in Figure 6A.

Ethylene oxide: Ethylene oxide concentrations are shown in Figure 7A. This gas showed a TWA concentration of 0.17 ± 0.23 ppm. A maximum concentration of 3.0 ppm and a minimum concentration of 0 ppm were detected respectively.

Hydrogen: The H_2 concentrations with a maximum concentration of 7 ppm are shown in Figure 8A. A TWA concentration of 1.92 ± 2.13 ppm were calculated.

Hydrogen chloride: Hydrogen chloride concentrations are shown in Figure 9A. The HCl concentrations ranged between 0 ppm and 0.8 ppm with a TWA concentration of 0.20 ± 0.24 ppm.

Oxygen: Oxygen concentrations ranged from 20.1 % to 20.7 % with a TWA concentration of 20.35 ± 0.18 %. The O_2 exposure is depicted in Figure 10A.

Ozone: Ozone concentrations, depicted in Figure 11, were the lowest detected exposure with a maximum concentration of 0.03 ppm and a TWA concentration of 0.001 ± 0.004 ppm.

Phosphine: Phosphine exposure exhibited a maximum concentration of 0.02 ppm and a TWA concentration of 0.003 ± 0.005 ppm. Phosphine concentrations are shown in Figure 12.

Sulphur dioxide: Sulphur dioxide was detected only for one day of the week. A maximum concentration of 0.1 ppm was found and a TWA concentration of 0.001 ± 0.01 ppm was calculated. Sulphur dioxide concentrations are depicted in Figure 13.

Ammonia: Ammonia was never detected during sampling in the month of May 1997.

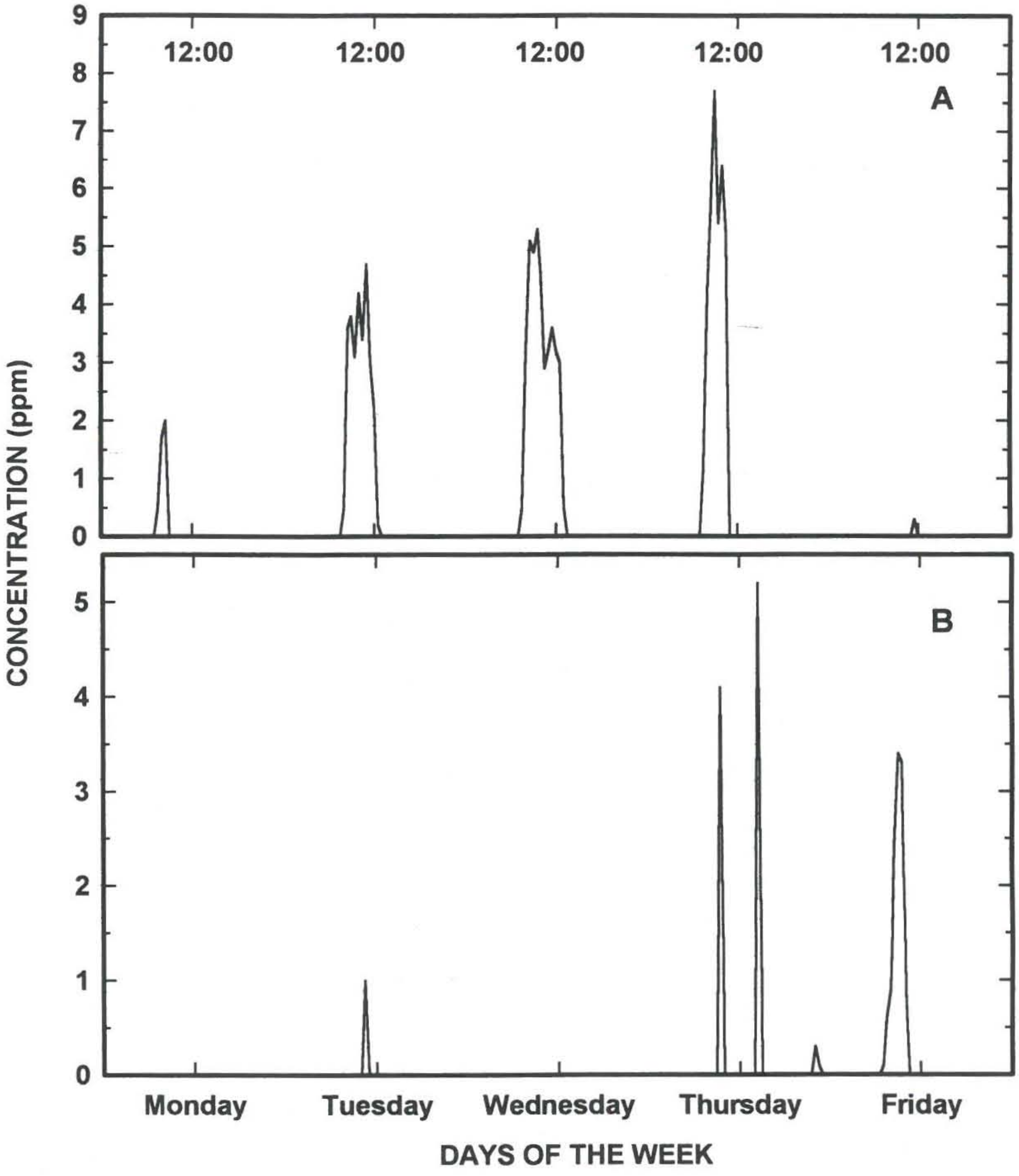

FIGURE 6: A: CO concentrations (ppm) measured in welding shop air during May 1997
B: CO concentrations (ppm) measured in welding shop air during July 1997

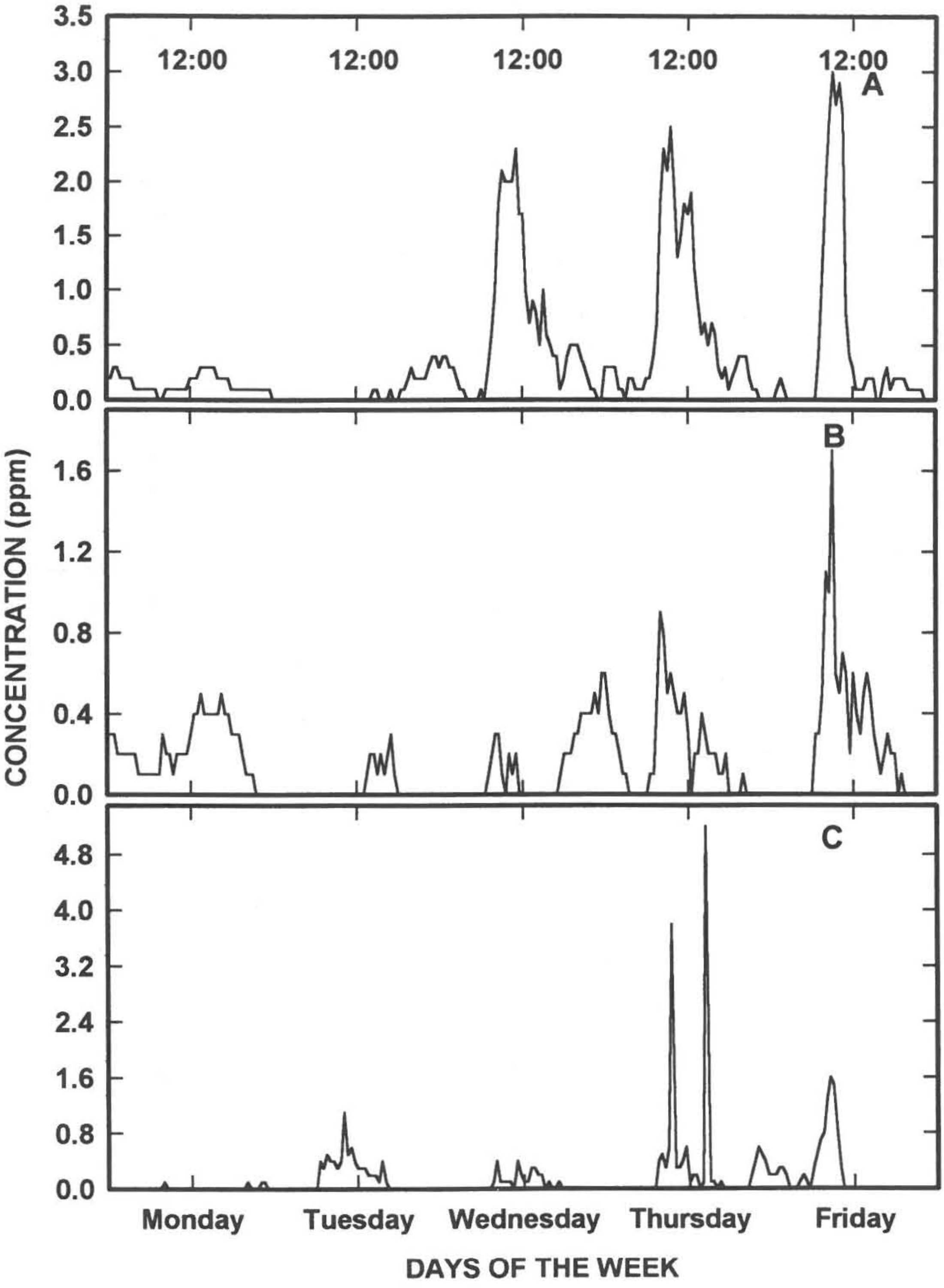

FIGURE 7: A: C_2H_4O concentrations (ppm) measured in welding shop air during May 1997
B: C_2H_4O concentrations (ppm) measured in welding shop air during June 1997
C: C_2H_4O concentrations (ppm) measured in welding shop air during July 1997

Chlorine gas: The concentrations of Cl_2 in the ambient air were below the detection limit (0-10 ppm).

Chlorine dioxide: No ClO_2 was present during this sampling period. Concentrations were below the detection limit (0-3 ppm) of the sensor used.

Hydrogen cyanide: Hydrogen cyanide concentrations present were below the detection limit of the HCN sensor (0-10 ppm).

Hydrogen sulphide: No H_2S concentrations were detected with the PMS-64.

Nitric oxide: Concentrations of NO were below the detection limit (0-100 ppm) of the instrument.

Nitrogen dioxide: Nitrogen dioxide concentrations were too low for the instrument to detect.

Weather data: The maximum and minimum temperatures, obtained from the weather station, for the May 1997 sampling period are depicted in Table 13. The percentage humidity obtained from the weather station during May 1997 is shown in Table 14.

TABLE 13: Maximum and minimum temperatures (°C) during the May 1997 sampling period

TEMPERATURE (°C)	SAMPLING DATE				
	12/05/97	13/05/97	14/05/97	15/05/97	16/05/97
Maximum	20.8	21.7	23.1	22.8	21.5
Minimum	-0.7	-3.0	-2.1	-2.3	-1.7

TABLE 14: Percentage (%) humidity detected during the May 1997 sampling period (12/05/97 - 16/05/97)

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HIGH	TIME	LOW	TIME
12/05/97	88	87	90	88	90	92	91	92	75	56	39	35	28	26	25	22	24	38	51	67	50	69	74	79	93	05:21	21	15:53
13/05/97	81	87	85	86	88	88	89	87	65	42	34	25	18	12	10	11	20	29	32	51	60	65	69	69	90	07:05	10	14:50
14/05/97	76	79	82	84	84	85	86	82	59	41	30	24	20	19	17	20	25	36	41	43	48	53	68	75	87	06:11	17	14:29
15/05/97	74	78	81	84	81	87	89	88	62	45	32	23	21	17	21	24	31	42	50	60	68	68	75	79	90	06:53	15	14:11
16/05/97	80	84	83	85	91	90	91	95	73	56	44	35	32	29	26	24	28	41	57	67	72	78	81	84	95	07:41	24	15:20

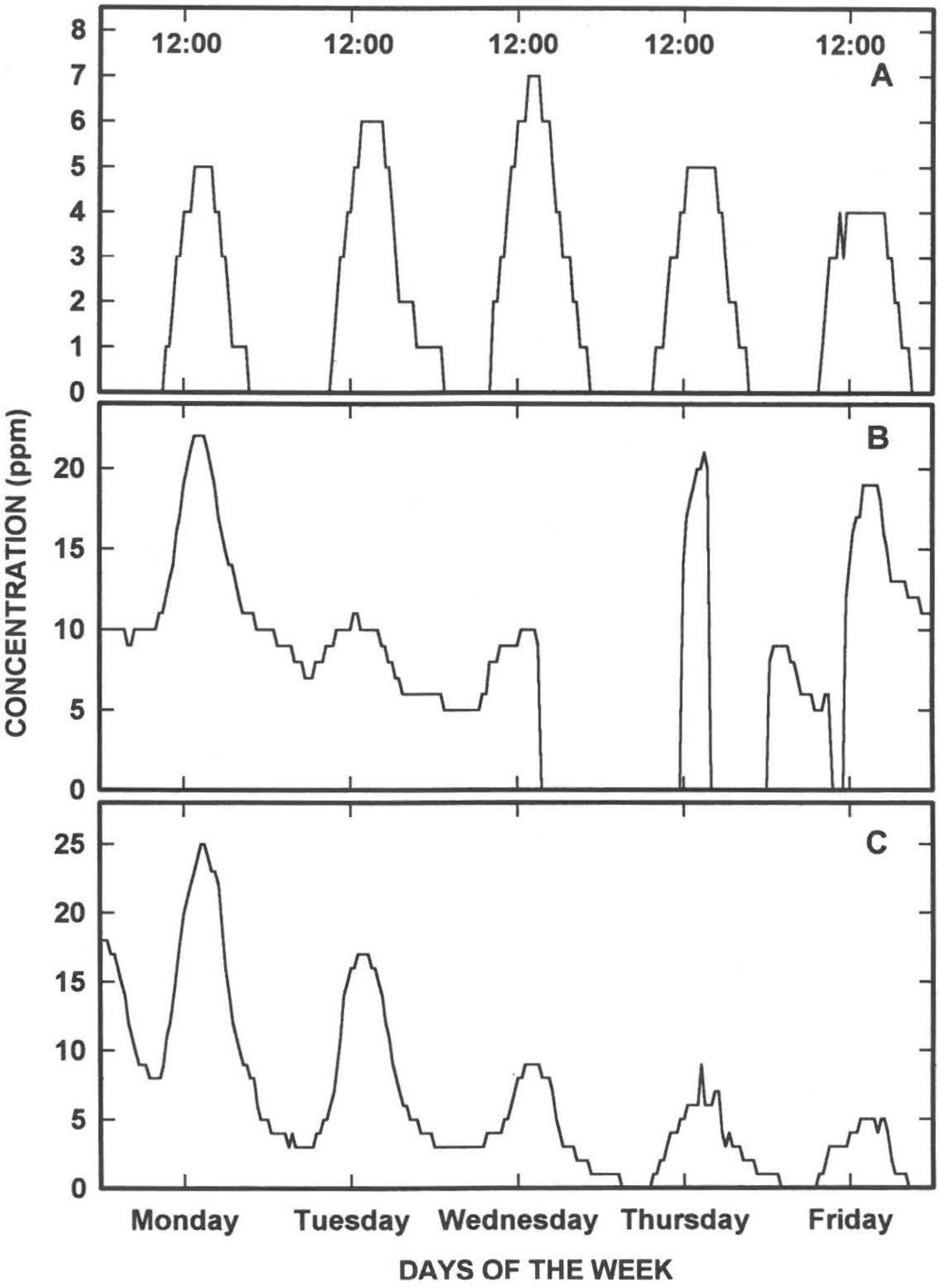

FIGURE 8: A: H_2 concentrations (ppm) measured in welding shop air during May 1997
B: H_2 concentrations (ppm) measured in welding shop air during June 1997
C: H_2 concentrations (ppm) measured in welding shop air during July 1997

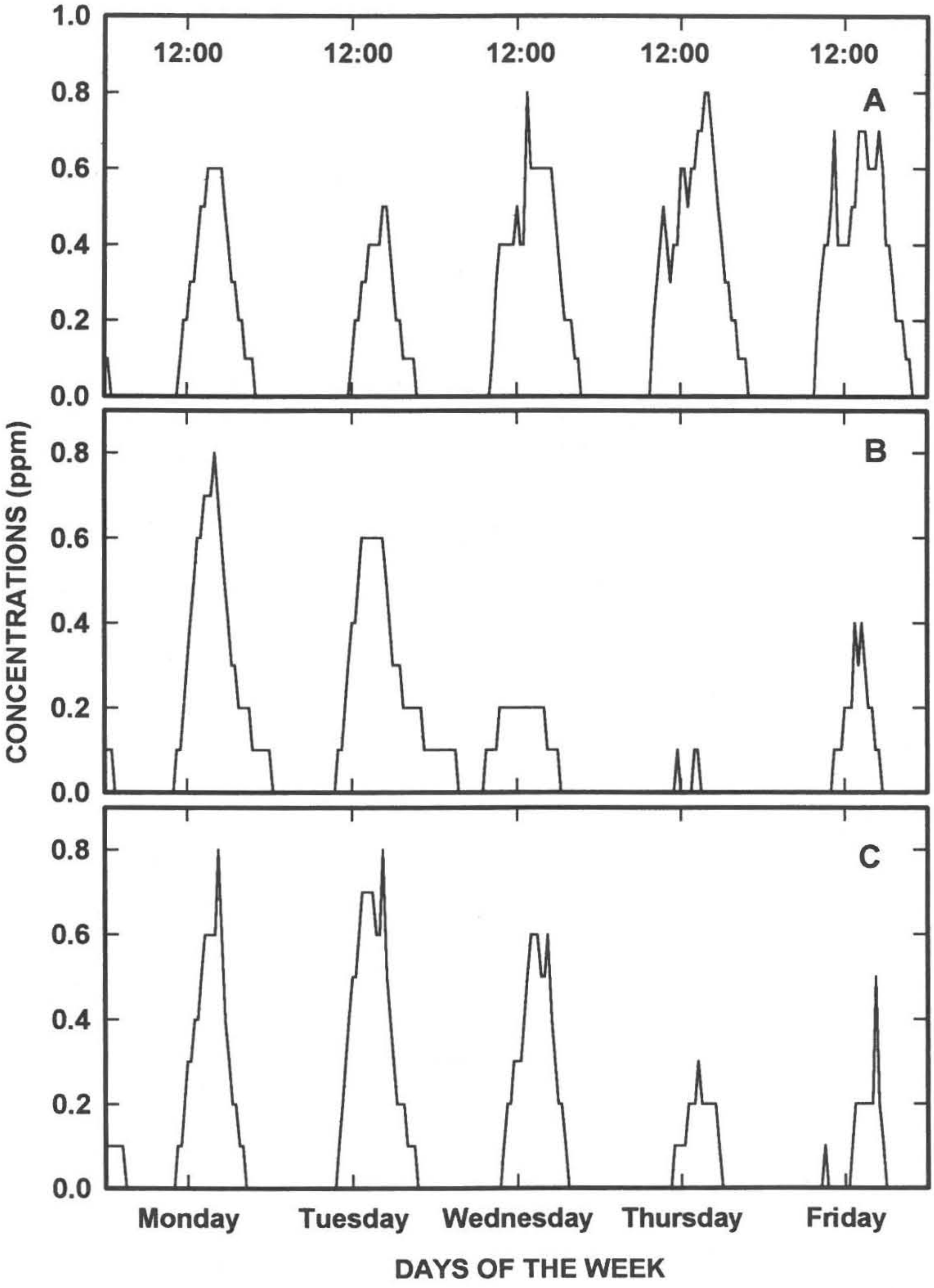

FIGURE 9: A: HCl concentrations (ppm) measured in welding shop air during May 1997
B: HCl concentrations (ppm) measured in welding shop air during June 1997
C: HCl concentrations (ppm) measured in welding shop air during July 1997

3.2.2 June

During the month of June, C_2H_4O, O_2, H_2 and HCl were detected. In Table 15, the work shift 8-hour TWA concentrations for each day during the sampling week are depicted.

TABLE 15: Work shift 8-hour TWA concentrations measured during June 1997 (09/06/97 - 13/06/97)

SUBSTANCE	SAMPLING DAYS				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
C_2H_4O (ppm)	0.31 ± 0.12	0.06 ± 0.08	0.06 ± 0.10	0.36 ± 0.20	0.55 ± 0.38
H_2 (ppm)	17.69 ± 4.24	9.94 ± 0.57	8.06 ± 3.21	9.31 ± 9.74	11.44 ± 7.99
HCl (ppm)	0.36 ± 0.30	0.35 ± 0.25	0.19 ± 0.03	0.02 ± 0.04	0.17 ± 0.14
O_2 (%)	20.46 ± 0.12	20.38 ± 0.04	20.28 ± 0.04	20.33 ± 0.11	20.26 ± 0.05

Ethylene oxide: Ethylene oxide concentrations are depicted in Figure 7B. A TWA concentration of 0.17 ± 0.23 ppm was calculated and a minimum concentration of 0 ppm with a maximum concentration of 1.7 ppm were detected respectively.

Hydrogen: Hydrogen concentrations present in the ambient air are shown in Figure 8B. A maximum concentration of 22 ppm was reached. A TWA concentration of 7.98 ± 6.09 ppm was calculated.

Hydrogen chloride: Hydrogen chloride concentrations showed a TWA concentration of 0.11 ± 0.18 ppm. A maximum concentration of 0.8 ppm was detected. Hydrogen chloride concentrations are depicted in Figure 9B.

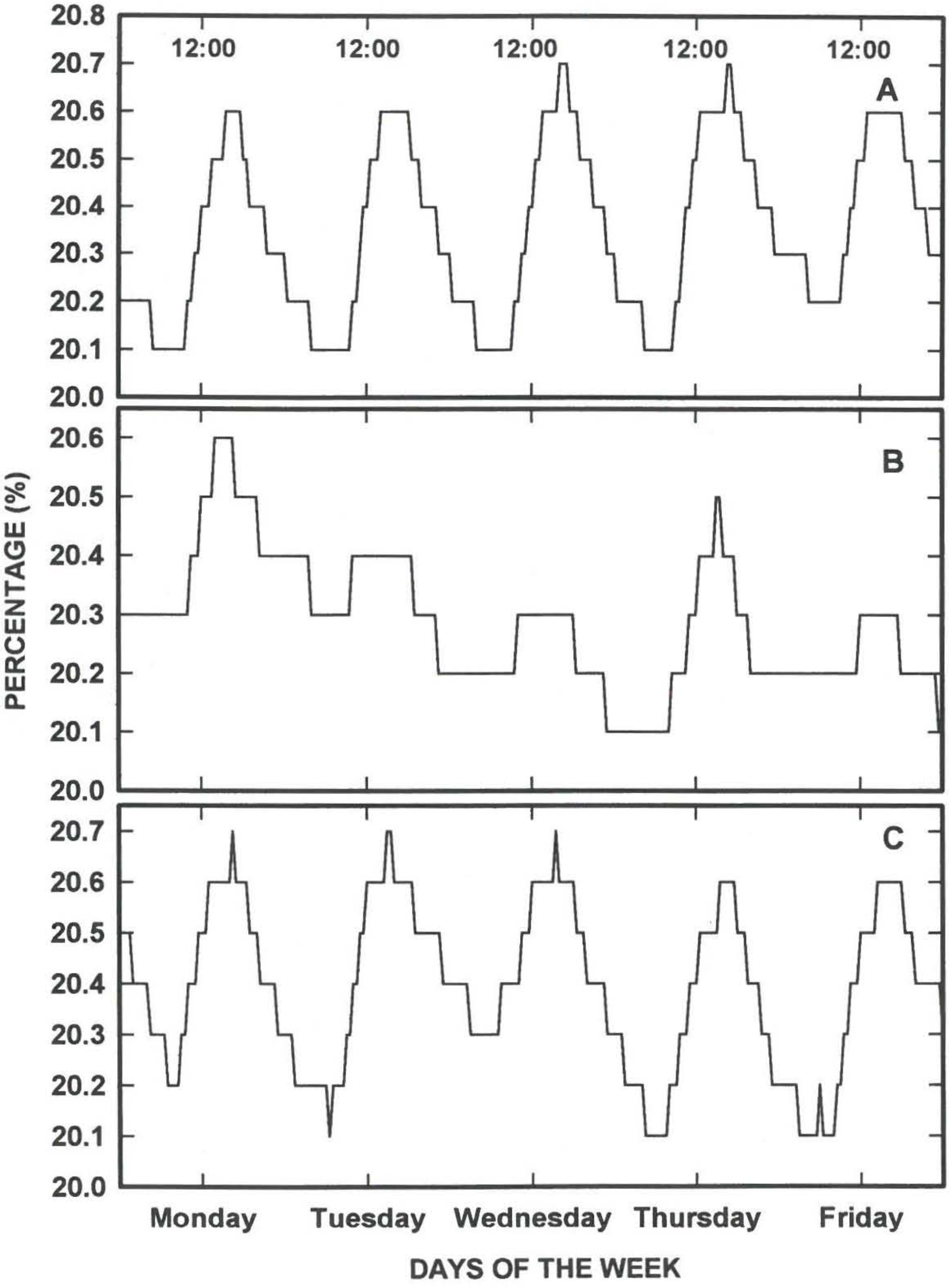

FIGURE 10: A: Percentage O_2 measured in welding shop air during May 1997
B: Percentage O_2 measured in welding shop air during June 1997
C: Percentage O_2 measured in welding shop air during July 1997

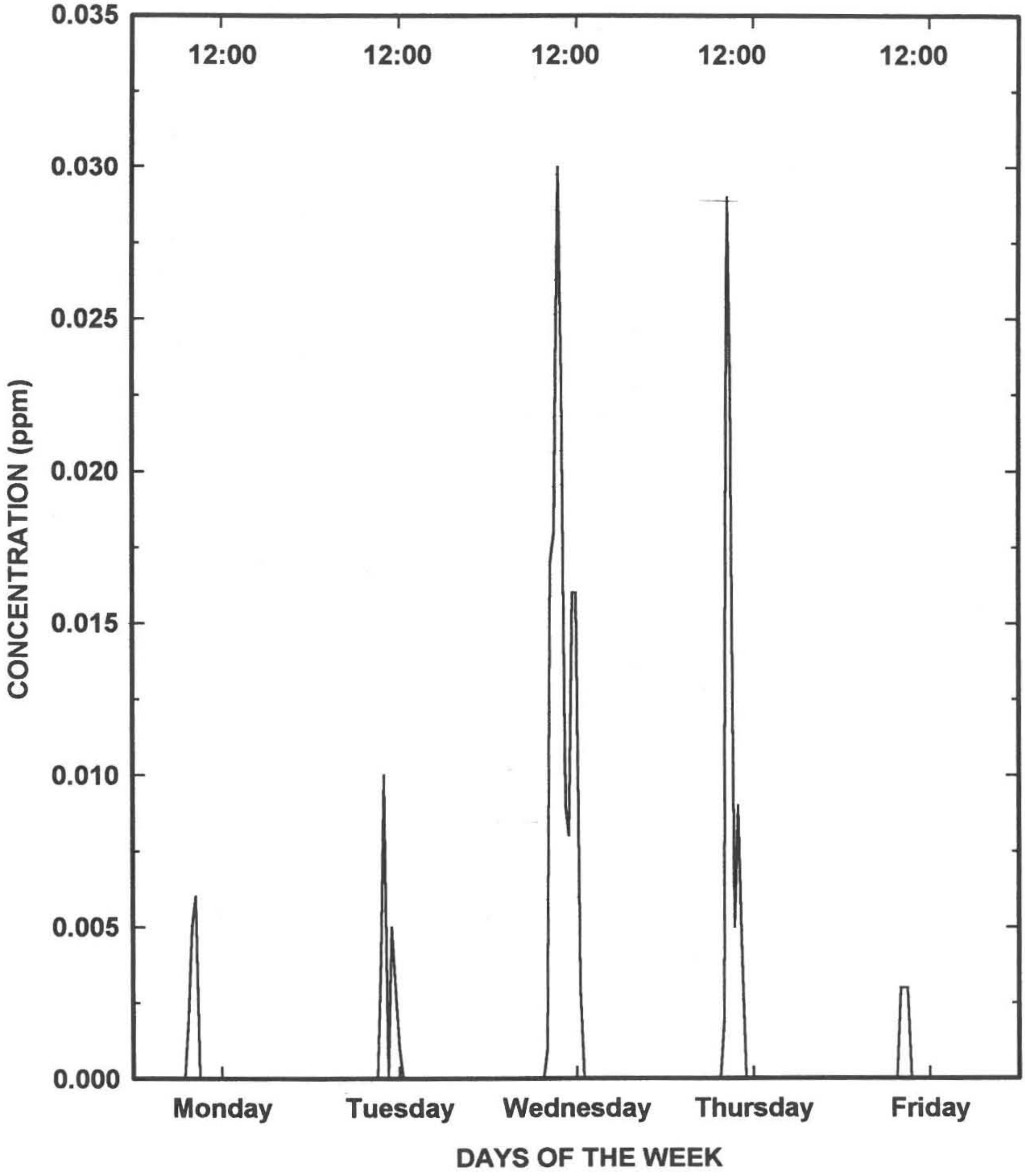

FIGURE 11: O_3 concentrations (ppm) measured in welding shop air during May 1997

Oxygen: Oxygen measured, showed a TWA concentration of 20.29 ± 0.11 %. Concentrations reached a maximum of 20.6 % and a minimum of 20.1 %. These concentrations are depicted in Figure 10B.

Ammonia: Ambient NH_3 concentrations were below the detection limit (0-100 ppm) of the PMS-64.

Carbon monoxide: All CO concentrations were below the detection limit (0-1000 ppm).

Chlorine gas: No Cl_2 concentrations were detected during this sampling period.

Chlorine dioxide: The measured concentrations of ClO_2 were below the detection limit (0-3 ppm) of the instrument.

Hydrogen cyanide: No concentrations for HCN were found during the sampling period in June 1997.

Hydrogen sulphide: No meaningful H_2S concentrations were detected during the sampling period.

Nitric oxide: Nitric oxide concentrations were below the detection limit (0-100 ppm) of the instrument.

Nitrogen dioxide: During the sampling period of June 1997, no NO_2 concentrations were detected.

Ozone: No O_3 concentrations were found in the ambient air during the sampling period.

Sulphur dioxide: The detection limit (0-30 ppm) of the PMS-64 was above the SO_2 concentration in the air.

Phosphine: No meaningful values of PH_3 in the ambient air were detected during June 1997.

Weather data: The maximum and minimum temperatures, obtained from the weather station, for the June 1997 are depicted in Table 16. The percentage humidity during June 1997 is shown in Table 17.

TABLE 16: Maximum and minimum temperatures (°C) during the June 1997 sampling period

TEMPERATURE (°C)	SAMPLING DATE				
	09/06/97	10/06/97	11/06/97	12/06/97	13/06/97
Maximum	22.7	13.2	11.3	17.5	10.1
Minimum	-6.4	-3.1	-1.1	0.0	-2.1

TABLE 17: Percentage (%) humidity detected during the June 1997 sampling period (09/06/97 - 13/06/97)

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HIGH	TIME	LOW	TIME
09/06/97	51	54	55	53	54	63	66	66	62	58	55	53	53	48	46	45	50	57	67	74	78	79	77	79	80	21:45	44	12:20
10/06/97	83	86	86	89	87	88	88	88	85	78	73	69	64	75	86	84	87	89	88	87	89	93	93	95	96	23:37	64	12:45
11/06/97	95	94	94	95	96	95	95	95	95	93	77	62	60	54	54	57	67	73	82	90	90	91	93	94	96	00:03	48	14:32
12/06/97	94	95	95	95	95	95	95	96	96	95	95	82	86	75	65	66	69	74	72	76	76	75	77	81	98	10:38	64	16:18
13/06/97	86	86	87	87	88	87	87	84	74	62	57	53	49	47	47	49	57	65	72	77	79	79	84	87	89	04:56	46	14:28

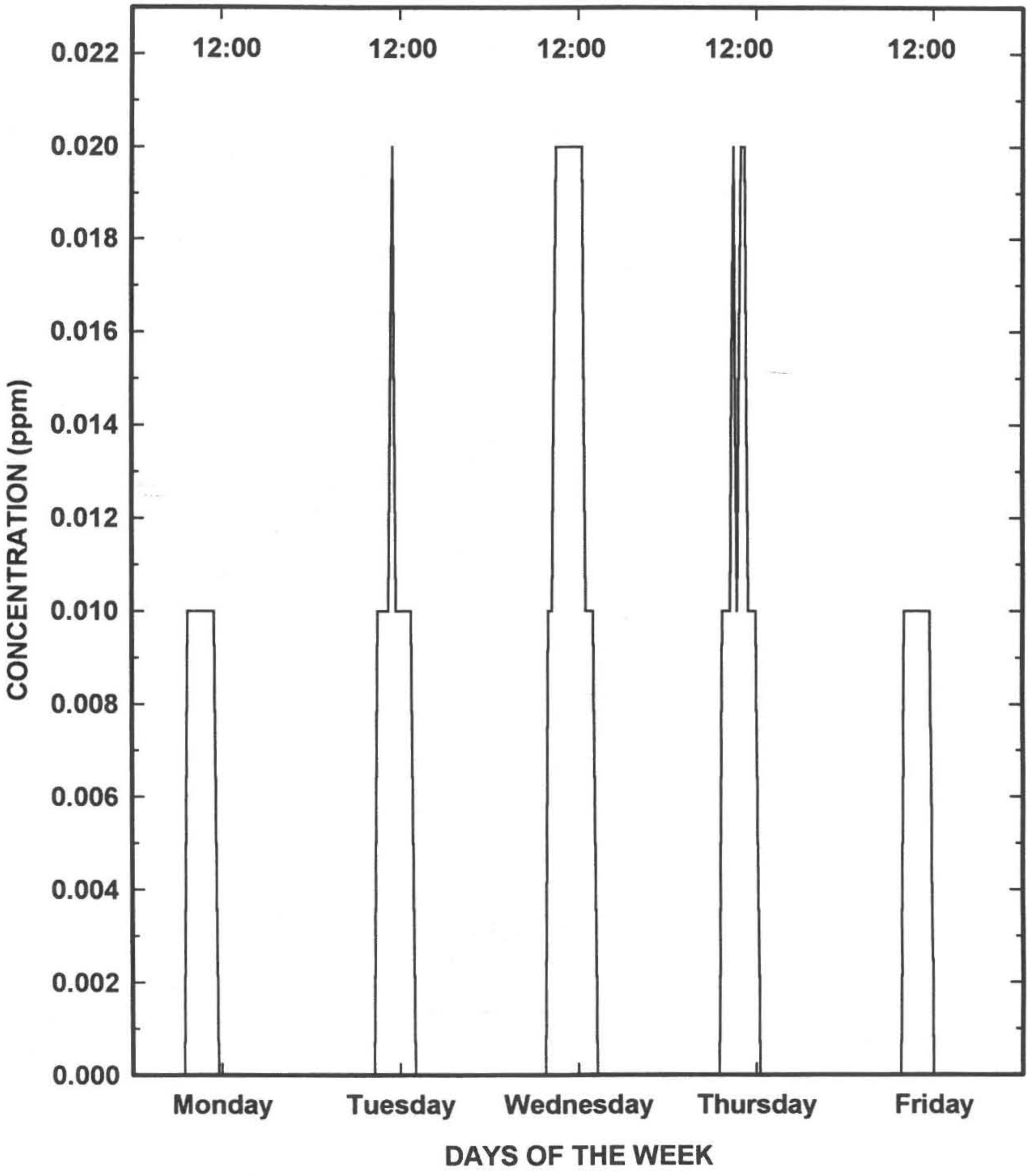

FIGURE 12: PH_3 concentrations (ppm) measured in welding shop air during May 1997

3.2.3 July

Sampling conducted during July 1997 showed the presence of the following gases: C_2H_4O, O_2, H_2, HCl and CO. The 8-hour TWA concentration for each day is depicted in Table 18.

TABLE 18: Work shift 8-hour TWA concentrations measured during July 1997 (21/07/97 - 25/07/97)

SUBSTANCE	SAMPLING DAYS				
	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
CO	n/d	0.06 ± 0.25	n/d	0.58 ± 1.60	0.73 ± 1.21
C_2H_4O	n/d	0.36 ± 0.24	0.14 ± 0.12	0.77 ± 1.49	0.26 ± 0.54
H_2	18.44 ± 5.96	13.38 ± 4.29	7.00 ± 2.00	5.00 ± 1.79	3.81 ± 0.98
HCl	0.29 ± 0.24	0.41 ± 0.27	0.32 ± 0.22	0.12 ± 0.10	0.09 ± 0.09
O_2	20.48 ± 0.13	20.51 ± 0.15	20.54 ± 0.09	20.42 ± 0.13	20.44 ± 0.14

n/d = not detected during sampling.

Carbon monoxide: A maximum CO concentration of 5.2 ppm with a TWA concentration of 0.09 ± 0.55 ppm were detected. Carbon monoxide concentrations are shown in Figure 6B.

Ethylene oxide: The measured C_2H_4O concentration with a TWA concentration of 0.15 ± 0.47 ppm are shown in Figure 7C. The maximum concentration was 5.2 ppm and the minimum concentration was 0 ppm.

Hydrogen: Hydrogen gas showed a TWA concentration of 6.18 ± 5.96 ppm with a daily fluctuation between 0 ppm and 25 ppm. The H_2 concentrations are depicted in Figure 8C.

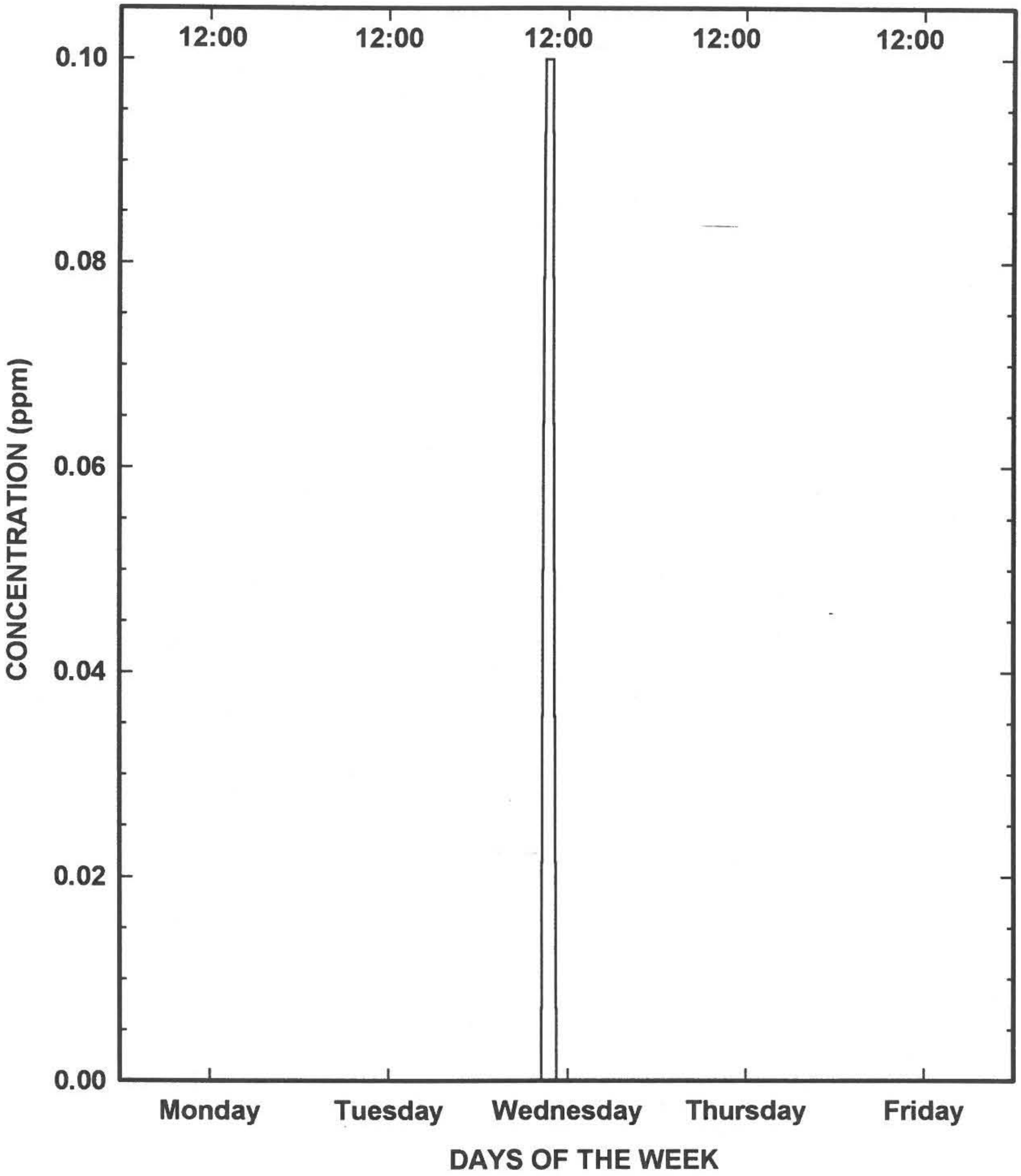

FIGURE 13: SO_2 concentrations (ppm) measured in welding shop air during May 1997

Hydrogen chloride: Hydrogen chloride concentrations are shown in Figure 9C. It ranged from 0 ppm to 0.8 ppm and a mean concentration of 0.12 ± 0.20 ppm was calculated.

Oxygen: Oxygen concentrations varied between 20.1 % and 20.7 % with a TWA concentration of 20.39 ± 0.16 %. The O_2 concentrations are shown in Figure 10C.

Ammonia: Ammonia concentrations present in the welding environment were below the detection limit (0-100 ppm) of the instrument.

Chlorine gas: No Cl_2 concentrations were detected during July 1997.

Chlorine dioxide: Chlorine dioxide concentrations present in the studied environment were below the detection limit (0-3 ppm) of the ClO_2 sensor used.

Hydrogen cyanide: No HCN concentrations were detected during the sampling period in July 1997.

Hydrogen sulphide: No H_2S concentrations were present in the studied environment.

Nitric oxide: No meaningful NO concentrations were detected with the instrument used in this study.

Nitrogen dioxide: All the sampled values for NO_2 were below the detection limit (0-30 ppm) of the instrument.

Ozone: Ozone concentrations were below the detection limit (0-1 ppm) of the PMS-64.

Sulphur dioxide: No SO_2 concentrations were detected for the duration of July 1997 sampling period.

Phosphine: Phosphine concentrations were below the detection limit (0-1 ppm) of the PMS-64.

Weather data: The maximum and minimum temperatures, obtained from the weather station, for the July 1997 sampling period are depicted in Table 19. The percentage humidity during July 1997 is shown in Table 20.

TABLE 19: Maximum and minimum temperatures (°C) during the July 1997 sampling period

TEMPERATURE (°C)	SAMPLING DATE				
	21/07/97	25/07/97	26/07/97	27/07/97	28/07/97
Maximum	25.0	25.7	26.0	20.9	21.5
Minimum	-0.4	-5.8	-1.8	-1.9	-3.6

TABLE 20: Percentage (%) humidity detected during the July 1997 sampling period (21/07/97 - 25/07/97)

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	HIGH	TIME	LOW	TIME
21/07/97	64	72	73	76	80	74	77	72	40	28	18	13	10	11	11	12	16	22	30	38	43	45	33	34	81	05:01	10	12:29
22/07/97	44	41	34	36	34	38	46	43	35	24	18	16	12	11	13	15	20	35	46	52	55	57	60	74	75	23:20	11	13:29
23/07/97	84	85	89	89	88	90	90	88	65	51	45	40	31	29	24	24	25	32	42	55	59	65	71	76	93	07:41	22	14:54
24/07/97	80	79	82	86	86	89	88	79	58	38	31	27	24	22	17	17	17	19	25	20	21	34	44	45	90	07:23	15	16:05
25/07/97	54	49	50	54	64	71	74	59	36	26	22	14	11	8	6	6	8	18	26	38	43	47	48	57	75	06:34	6	14:17

4. DISCUSSION

A variety of clinical syndromes have been associated with indoor air quality in buildings. Individuals encounter a broad range of air pollutants as they travel through a succession of micro-environments during the course of their daily activities. Although human beings construct buildings to protect them from the elements, it is obvious that buildings do not protect their inhabitants from pollution. An important outcome of human activities within a building is the release of a variety of pollutants into the environment. The aforementioned is especially applicable to indoor air pollution which is a well-known problem in industry (Bardana, Montanaro and O'Hollaren, 1992).

Estimates of the results of exposure to potentially toxic gases based on production rates measured by means of simulations in a laboratory may be useful, but unreliable because of the influence of local ventilation and workplace design on the actual concentrations found in the welders' breathing zone. The determination of occupational exposure to gases should therefore be based on the ambient air in the workplace. The concentrations of toxic elements found in the ambient air surrounding the welding process, represents the minimum amount of exposure to which welders are subject, even if they are not welding for a full 8-hour shift (WHO, 1990).

During regular welding in workshops, welding gases are present in the work area (ambient air). Therefore, gas collected from a given process is a mixture from the gases generated by the process and the gas in the workshop. The concentration of background gas depends on the intensity of the welding in the workshop, as well as the efficiency of the ventilation. Intensive welding and efficient ventilation result in low background levels when compared with breathing zone levels, but welding in a poorly ventilated room generates background levels that are close to those of the breathing zone (Karlsen *et al.*, 1992).

The gases associated with welding follow the normal laws of diffusion and mix freely with the general atmosphere. It is also affected by air movement and gravity. It could therefore pass through the respiratory system along with the other gaseous constituents of the atmosphere (AWS, 1987).

Welders are exposed to a variety of airborne contaminants arising from the welding process and other operations in the workplace. A wide range of gaseous pollutants are produced by welding, either through the decomposition of compounds in the flux coating or core of the consumable materials, or through oxidation, dissociation or other chemical reactions in the air, surrounding the arc region (WHO, 1990; NIOSH, 1988a). The chemical composition and physical properties of welding fumes and gases as well as details of occupational exposure of welders in the workplace, were reviewed during 1990 by the WHO (1990).

Although the possibility of long-term deleterious effects on lung function after inhalation exposure is well recognised, the actual risk of such an adverse outcome has not yet been quantified (Blanc *et al.*, 1993a).

In considering the health of welders, emphasis is placed on specific gases found in the welding environment and associated with respiratory or other effects. Due to a lack of South African indoor air quality standards or guidelines for the gases measured in this study, the values published by various authoritative organisations abroad were used during the evaluation and determination of possible harmful exposure. The primary sources of criteria for the regulation of exposure to environmental contaminants include NIOSH criteria documents; the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values; U.S. Department of Labour (OSHA) standards; South African Regulations for Hazardous Chemical Substances; ASHRAE indoor air quality standards; and the U.S. Environmental Protection Agency (USEPA) guidelines. The first four sources are usually used to assess industrial worker exposure to airborne contaminants for an 8-hour work day and a 40-hour work week to ensure a working lifetime without adverse health effects. The remaining two standards, on the other hand, are applicable to the general population and refer to a 24-hour day of continuous exposure without known toxic effects.

The results were also compared with indoor air quality guidelines retained from WHO Air Quality Guidelines for Europe, 1997 (van Leeuwen, 1997). The American Society for Heating, Refrigeration, and Air Conditioning (ASHRAE) and ACGIH state that: "If the air is thought to contain any contaminant not listed, guidance on acceptable exposure... should be obtained by reference to the standards of the Occupational Safety and Health Administration. If such guideline values are applied to the general population, the concentration of these contaminants should not exceed one tenth ($^{1}/_{10}$) of the limits which are used in industry" (ACGIH, 1971). In the absence of such an OSHA standard, a tenth of the standard or guideline prescribed by another authoritative agency was used for comparison purposes in this study.

In South Africa the guideline for a safe environmental threshold limit value is proposed by Schröder and Schoeman (1994). The general public can be exposed to this threshold limit without any health risk to a normal individual. It is calculated by using the predetermined TWA.TLV concentration (for the occupational environment) divided by a factor of forty (40).

4.1 Ammonia

No NH_3 concentrations were detected during the study. The concentrations present in the ambient air could have been below the detection limit (0-100 ppm) or completely absent from the studied environment. However, it is envisaged that NH_3 should be present in trace quantities as a trace gas in normal ambient air.

Ammonia is formed during putrefaction and is found in human breath, as well as in the air above forests. It is normally used as a component in cleaning agents and as a laundry additive. Ammonia dissolves readily in water and forms the ammonium ion and hydroxide. Household NH_3 has a concentration of about 3 moles (Meyer, 1983). Although NH_3 concentrations were monitored during this study, it was not envisaged that NH_3 would be detected because it is not a by-product of welding or any other process in the welding workshop. The findings of this study confirmed the mentioned expectation. Welders should not have any work-related risk as a result of NH_3 exposure.

4.2 Carbon monoxide

Carbon monoxide is a deadly poison that interferes with the transportation of O_2 by the blood, in competing with O_2 for the ion-binding sites in haemoglobin. Low concentrations of this gas, such as found in automobiles, garages and downtown streets during rush hours, cause impairments of judgement and vision. Evidence has shown that intermittent exposure to CO at low levels can cause a stroke and hypertension in susceptible individuals. Exposure to high concentrations of CO cause headaches, drowsiness, coma, respiratory failure and even death (Sackheim and Lehman, 1990).

Carbon monoxide is a product of incomplete combustion of fossil fuels(Truter *et al.*, 1996). The CO_2 in the shielding gas of the welding process produces CO through reduction. (Sferlazza and Beckett, 1991). Carbon monoxide can also be transformed to CO_2 if another pollutant such as NO_2 is present in the environment ($CO + NO_2 \rightarrow CO_2 + NO$) (Krimsley, 1994).

An occupational TWA-TLV concentration of 50 ppm for CO is prescribed by the South African Government (1995). If an environmental air quality guideline is calculated as described before, a value of 1.25 ppm is recommended. However in accordance with the WHO Air Quality Guidelines for Europe, a environmental TWA concentration of 9 ppm is recommended (van Leeuwen, 1997).

Summer concentrations: The CO concentrations during the summer months were below the detection limit (0-1000 ppm) of the instrument. It is therefore below any of the recommended air quality standards or guidelines and no welder should be at risk when exposed to such concentrations.

Winter concentrations: Carbon monoxide was detected during two of the three sampling periods during the winter months. Carbon monoxide concentrations reached a maximum value of 7.7 ppm and a weekly TWA concentration of 0.45 ± 1.34 ppm was calculated. During the sampling period in May 1997, the calculated 8-hour work shift TWA concentrations (Table 12) exceeded the calculated TLV indoor air quality guideline of 1.25 ppm for 3 consecutive days. The maximum work shift 8-hour TWA concentration for the week was measured on a Wednesday (14/05/97) when a concentration of 2.26 ± 2.12 ppm was calculated. During the colder winter months coal fires were made inside the welding shop to keep the workers warm. Most of the doors and windows were also kept closed during these months. It is well known fact that CO is the result of incomplete combustion of fossil fuels, and this could be the reason for the measured CO concentrations. A definite relationship exists between the CO concentration and the carboxyhemoglobin (COHb) levels in the blood of a person exposed to different concentrations of CO. Elsom (1992) explained that workers who are exposed to CO concentrations below 10 ppm, should not show any visible health effect as a result of the exposure. It was also stated that an 8-hour exposure to 10 ppm CO can only result in a 1.4 % COHb increase.

The welders were not exposed to CO concentrations which could cause the COHb to rise to dangerous levels. Non-exposed persons normally have an average level of 1 % COHb (heme metabolism is an endogenous source of CO) (NIOSH, 1972). Excessive cigarette smoking, together with the simultaneous exposure to CO, could, however, cause the levels of COHb to rise to a level where symptoms such as headaches and drowsiness occur. The blood of cigarette smokers usually contains between 2 % and 10 %, although a maximum of 18 % COHb has been recorded. If accidental exposure to high levels of CO occurs, breathing normal air will result in a 50 % clearance of blood in approximately 5 hours (Dinman, 1974).

When the results of this study are compared to studies for the determination of COHb levels (Elsom, 1992; Dinman, 1974), it can be concluded that no welder, whether smoking or non-smoking would be at risk as a result of CO exposure. The COHb levels of the welders should be below 10 % COHb which is regarded as safe.

No CO concentrations were detected during the sampling period in June 1997. The absence of CO could be due to the absence of coal fires during the sampling period (the average maximum ambient temperature was higher than during May 1997). It could also be ascribed to the fact that normal working activities were not performed, because the workers were waiting for new assignments and material.

Carbon monoxide concentrations measured during July 1997 showed work shift 8-hour TWA concentrations to be below the calculated environmental TLV of 1.25 ppm (Schröder and Schoeman, 1994). This could be attributed to the ambient temperature during the sampling period. The mean air temperature for July 1997 was higher than the corresponding temperature measured during May 1997. The workers still made fires for heating purposes, but the ambient temperature increased more rapidly during the morning compared to the sampling period during May 1997. It resulted in the opening of doors and windows at an earlier stage in the morning and dilution of the contaminants in the air took place which resulted in lower CO concentrations. It is expected that the welders who were exposed to these concentrations, will not suffer from any health effects or adverse symptoms, because the CO concentrations detected were quite low.

4.3 Chlorine gas

No Cl_2 was detected during the study. Chlorine gas can easily, when in the presence of H_2, be converted to HCl, as illustrated by the following equation (Krimsley, 1994):

$$H_2 + Cl_2 \rightarrow 2HCl$$

The above-mentioned could possibly be the reason that Cl_2 was not detected, or the chemical reaction taking place in the ambient air was too rapid to detect, or Cl_2 concentrations were below the detection limit (0-10 ppm) of the instrument. Chlorine gas can be used in metal fluxing and the sterilisation of water supplies (Hathaway *et al.*, 1991). Metal fluxing is one of the processes used in the studied environment and it was envisaged that Cl_2 could be present in the ambient air. During this process, exposure to Cl_2 can cause multiple toxic effects on the respiratory system, including immediate airflow obstruction, reactive airway dysfunction syndrome (RADS), and even death. The long-term effects can include abnormalities in gas transfer, restriction and airflow obstruction. These conditions generally resolve to a variable degree with the passage of time. Additionally, the severity and resolution of these effects appear to be related to the degree of exposure, the pre-morbid pulmonary status and the degree of hypoxemia on initial exposure (Moore and Sherman, 1991). The above-mentioned health effects can occur when Cl_2 concentrations vary between 0.2 ppm and 1000 ppm (Hathaway *et al.,* 1991). Welders were never exposed to any of these concentrations during the entire study, and it is expected that no work-related health effects will occur as a result of exposure to Cl_2.

4.4 Chlorine dioxide

No ClO_2 concentrations were detected during the study. The ClO_2 concentrations present in the welding environment were below the detection limit (0-3 ppm) of the instrument or not present at all. Chlorine dioxide is not normally associated with welding and related processes. It was monitored, however, because it is classified as a severe respiratory and eye irritant (Hathaway *et al.*, 1991). Welders were not exposed to any detectable ClO_2 concentration and it is expected that no health risk will occur due to ClO_2 exposure in the welding shop.

4.5 Ethylene Oxide

At room temperature and normal atmospheric pressure, C_2H_4O is a colourless gas. It can be condensed to a clear liquid at 10 °C. In the gaseous state, C_2H_4O is extremely flammable and can be subject to explosive decomposition.

Golberg (1986) postulates three exposure zones in terms of uniform, 8-hour daily, 5-days-a-week exposure conditions or equivalent work periods generally used for the determination of TWA concentrations. These postulations are applied to make a hazard assessment of the presence of C_2H_4O, since it is believed that in the case of C_2H_4O, the expression of its carcinogenic potential takes the form of low-level enhancement of the incidence of spontaneous tumours. The first postulation is a zone of increased probability of adverse health effects in humans that might extend to C_2H_4O levels above 10 ppm. The second zone of uncertain consequence includes 8-hour work shift TWA concentrations within the range of exposure between 5 ppm to 10 ppm C_2H_4O. The third zone is believed to involve inconsequential exposure with no apparent hazard being presented by exposure at levels at or below 1 ppm (TWA concentration). NIOSH (1988b) recommends an occupational C_2H_4O TWA.TLV concentration of <0.1 ppm for 8-hours. The above-mentioned data indicate the adverse effects of exposure to C_2H_4O on human pregnancies, and are based on animal and human evidence of problems occurring due to the inhalation of C_2H_4O. This chemical proved to be a powerful mutagen and neurotoxin (ACGIH, 1991a).

Summer concentrations: During the summer months, consistent concentrations of C_2H_4O were found in the ambient air in the welding shop. These concentrations varied throughout the day and night. During February, the C_2H_4O concentration never dropped to below 0.1 ppm. In Table 3, the 8-hour work shift TWA concentration measured from 8:00 to 16:00 is shown. The calculated mean concentration exceeded the recommended occupational threshold limit value of NIOSH (1995) and the calculated environmental threshold limit of 0.1 ppm (Schröder and Schoeman, 1994). No short-term exposure limit is prescribed in South Africa, although a limit of 5 ppm for a period of 10 minutes per day is recommended by the ACGIH (1991a). The maximum measured concentration during February 1997 was 1.4 ppm, which never exceeded the STEL.TLV during the sampling period. In a chronic inhalation bio-assay study, conducted by Snellings, Weil and Maronpot (1984), in rats exposed to 100 ppm, 33 ppm, and 10 ppm of C_2H_4O for 6 hours/day during 5 days/week for 2 years, a dose-related increase in the occurrence of mononuclear cell leukaemia in both sexes at all concentrations was observed. Hospital staff exposed to C_2H_4O in sterilising operations during pregnancy were also found to experience a higher incidence of spontaneous abortions (16.7 %) compared with a control group (5.6 %). The association between these factors persisted even after an analysis for potential confounding factors, such as age and smoking status, had been done (Yager, Hines and Spear, 1983). With regard to the above-mentioned studies, it is expected that welders exposed to the measured C_2H_4O concentrations with simultaneous exposure to cigarette smoking, could experience mild carcinogenic effects, as nicotine is classified as a suspected human carcinogen by the ACGIH (1997).

During the March 1997 sampling, C_2H_4O concentrations dropped to 0 ppm at irregular intervals, but the work shift 8-hour TWA concentration for each day of the week still exceeded the recommended level of 0.1 ppm (Schröder and Schoeman, 1994). The maximum concentration (1.1 ppm) measured during the sampling period was below the recommended occupational STEL.TLV (ACGIH ,1991a; South Africa, 1995). In studies conducted by Finelli *et al.*, (1983) and Kuzuhara (1982), a number of cases of sub-acute sensory motor polyneuropathy among sterilising workers exposed to C_2H_4O concentrations have been described. This caused weakness with bilateral foot drop, sensory loss, loss of reflexes and neuropathological changes as indicated by electromyography (EMG) done on the lower extremities. Workers exposed to the measured C_2H_4O (1.1 ppm) concentrations could experience the above-mentioned work-related effects.

The detected C_2H_4O concentrations during the sampling period in April 1997 showed calculated work shift 8-hour TWA concentrations exceeding the recommended environmental TWA.TLV concentrations (Schröder and Schoeman, 1994) on the Monday, Wednesday, Thursday and Friday. The work shift TWA concentration on Tuesday (15/04/97) was calculated at 0.04 ± 0.05 ppm which is much lower than the recommended environmental TWA.TLV concentration of 0.1 ppm (Schröder and Schoeman, 1994). The lower concentrations measured on that Tuesday during April 1997 could have been caused by numerous factors. Firstly, the amount of welding done on the specific day could have been less than on the other days. Secondly, the weather for e.g. the wind, could have diluted the concentration rapidly before it could be detected. The ambient temperature was higher than on the previously sampled days, and the windows and doors were left open to increase ventilation. It is expected that welders who are chronically exposed to concentrations similar to those detected on that Tuesday, will not suffer from any work-related health effects.

It is evident from Figure 2 that concentrations normally increase with the commencement of daily tasks. This increase could be related to a specific process used in the welding shop, or another C_2H_4O source in the surrounding environment. In the welding process, pressurised acetylene (composed of equal parts of C and H) is used to bind with O_2 in the air, in order to produce the hottest flame possible. Acetylene is a very unstable combustible gas due to the hydrogen bonds in its composition (Baird, 1991). When taking the following chemical formula into consideration, ethylene can bind with water (H_2O) to form a more stable gas:

$$C_2H_2 + H_2O \rightarrow C_2H_4O$$

The result could be the formation of C_2H_4O. This could also explain the increase in the concentration of C_2H_4O during working hours when oxyacetylene welding was in progress.

Winter concentrations: C_2H_4O was not as frequently detected during the winter as during the summer months. Even though higher maximum concentrations in comparison to the summer months were detected, these exposures only lasted for short periods of time. The concentrations of ethylene oxide exceeded the recommended indoor air quality guideline of 0.1 ppm (Schröder and Schoeman, 1994) during sampling done between 12/05/97 and 16/05/97. On Tuesday (11/05/97) the 8-hour work shift TWA concentration was calculated at 0.01 ± 0.03 ppm. This could be as a result of a difference in the workload, or the higher diffusion rates that were applicable on that specific day. The exposure on the Wednesday, Thursday and Friday were respectively 13.5, 14 and 10.1 times more than the environmental TWA.TLV concentration of 0.1 ppm recommended by Schröder and Schoeman (1994). The maximum C_2H_4O concentration of 1.7 ppm detected during May 1997 did not exceed the STEL.TLV as recommended by the ACGIH (1991a).

The daily C_2H_4O TWA concentration during June 1997 is depicted in Table 15. On Tuesday and Wednesday, concentrations were below the prescribed environmental TWA.TLV concentration of 0.1 ppm. The remaining days of the period, however, showed concentrations above this level which means that the workers were overexposed to C_2H_4O for 3 days of the week.

Ethylene oxide sampling during July 1997 followed almost the same pattern as in June, with the exception of Monday when the substance was not detected. It could be as a result of less acetylene welding carried out or general maintenance tasks being performed, which meant that the plant was not fully operational. A maximum concentration of 5.2 ppm was detected on Thursday between 14:00 and 14:30. This concentration is well above the STEL.TLV of 5 ppm recommended by NIOSH (1983). NIOSH further recommends that a person must not be exposed to a concentration of more than 5 ppm for 10 minutes per day. In South Africa, no STEL.TLV for C_2H_4O is prescribed.

Reported symptoms from long-term chronic exposures are skin sensitisation, numbing of the sense of smell, and susceptibility for respiratory infection (ACGIH, 1991a). It is expected that workers could suffer from the above-mentioned symptoms as a result of the inhalation of the measured concentrations of C_2H_4O.

4.6 Hydrogen

Hydrogen is mainly used in the production of NH_3, synthetic methanol and HCl. During the manufacturing of tungsten and the processes of metal-welding and -cutting, H_2 is also used. Hydrogen is a colourless, tasteless gaseous element, highly flammable and explosive when exposed to heat or flame or when mixed with Cl_2, O_2 (in the air) or other highly oxidising or combustible materials. Hydrogen is non-corrosive, but acts as a simple asphyxiant (ACGIH, 1997).

Since water molecules are polar, it is expected that the H_2 binding site of one molecule will be attracted to the O_2 binding site of one or more other molecules. This type of attraction is called hydrogen bonding and is a very weak type of bond (Sackheim and Lehman, 1990). Since hydrogen bonds are very weak bonds, they are easily dissolved during the welding operation. The dissolved H_2 has its origin in hydrogen-containing compounds in the filler metal or in the welding auxiliary materials, in the moisture of the electrode coating, in impurities on the surface of the welded part and in moisture in the ambient air. It is also known that H_2 solubility is higher when the metal is in the liquid state. Metals are frequently in the liquid state when heat is applied to the welding area. The molten zone of a welded joint may thus contain large amounts of dissolved (i.e. atomic) H_2 molecules which are trapped in the pores of the freshly welded metal. When the metal is cooled down, the solubility of H_2 decreases rapidly, while the metal changes from the liquid to the solid state. The pores containing effused H_2 molecules, may especially be formed under conditions of extremely rapid cooling. After the metal has cooled considerably, the H_2 molecules are released into the atmosphere by diffusion through the pores in the metal (Radaj, 1992).

No TLV for H_2 is recommended by either the ACGIH or the South African Government. The TLV is not prescribed, since the limiting factor for H_2 is the available O_2 present in the surrounding air. The minimum O_2 content by volume under normal atmospheric pressure should be 18 % (ACGIH, 1991b, South Africa, 1995).

Summer concentrations: Very high H_2 concentrations were found during the sampling period in February 1997. A weekly TWA concentration of 65.06 ± 20.41 ppm and a maximum concentration of 100 ppm were detected respectively. In Figure 3A, a possible relationship between the daily activities and the detected H_2 concentration is shown. This can be attributed to the presence of some water vapour in the ambient air during rainy spells. During rainy spells, H_2 atoms are more abundant in the air and more likely to be dissolved during the welding process. In Figure 14, a comparison is made between the ambient air humidity and the H_2 concentration in the welding shop. When the humidity increases, the atmosphere becomes stable and the relationship increase accordingly. As O_2 is the limiting safety factor for H_2 exposure, a mean O_2 concentration of 20.58 % (v/v) was calculated during February 1997. Such a concentration is sufficient to cancel out the possibility of danger and discomfort when human beings are exposed to the measured H_2 concentrations.

The hydrogen emitted during March 1997 ranged from 14 ppm to 42 ppm with a weekly TWA concentration of 30.46 ± 6.53 ppm. It is shown in Figure 15 that the atmosphere was unstable and that no distinct comparison could be found between the humidity of the ambient air and the concentration of H_2 inside the welding shop. It is expected that welders exposed to the measured H_2

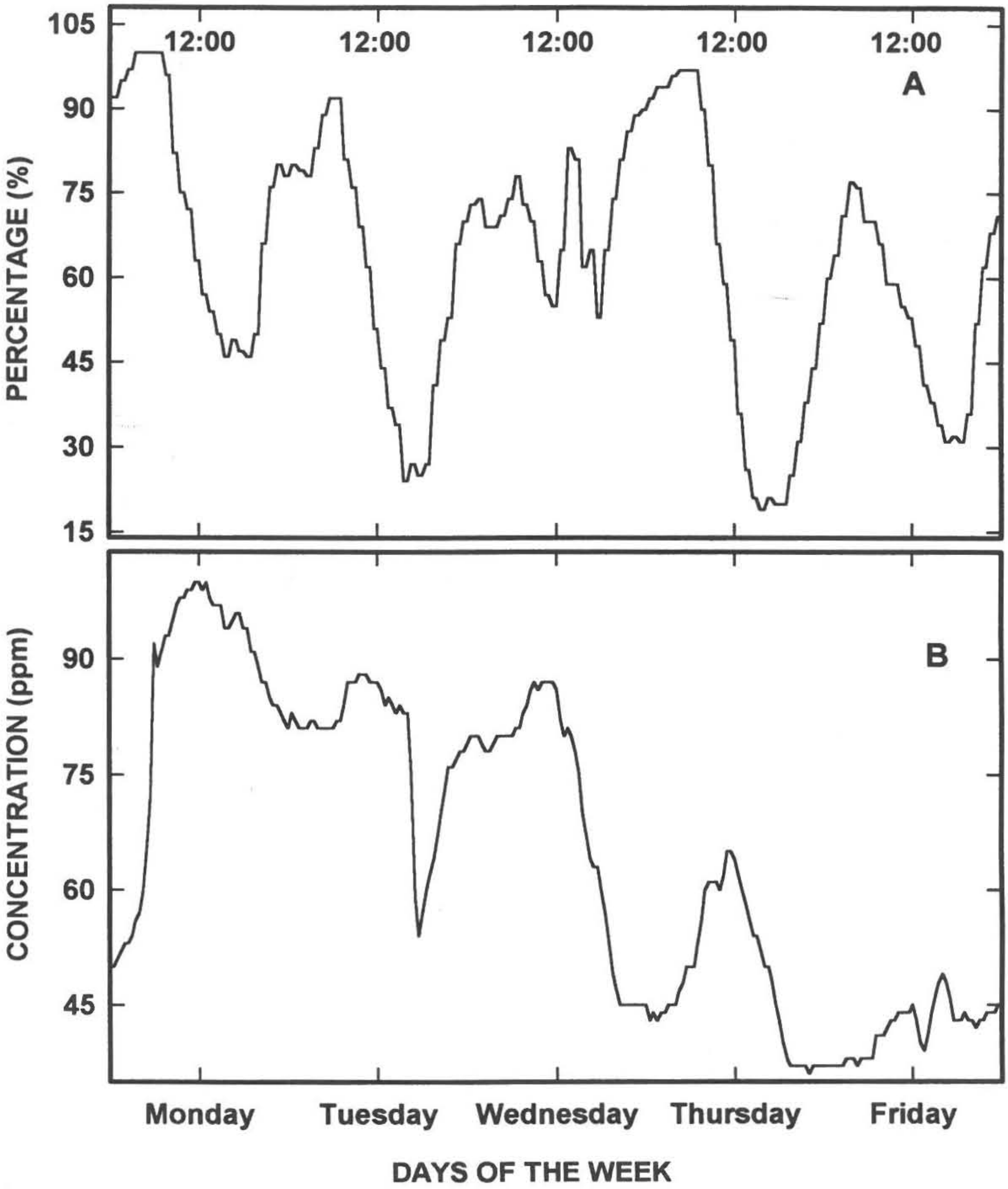

FIGURE 14: A: Percentage (%) humidity measured in ambient air during February 1997
B: H_2 concentrations (ppm) measured in welding shop air during February 1997

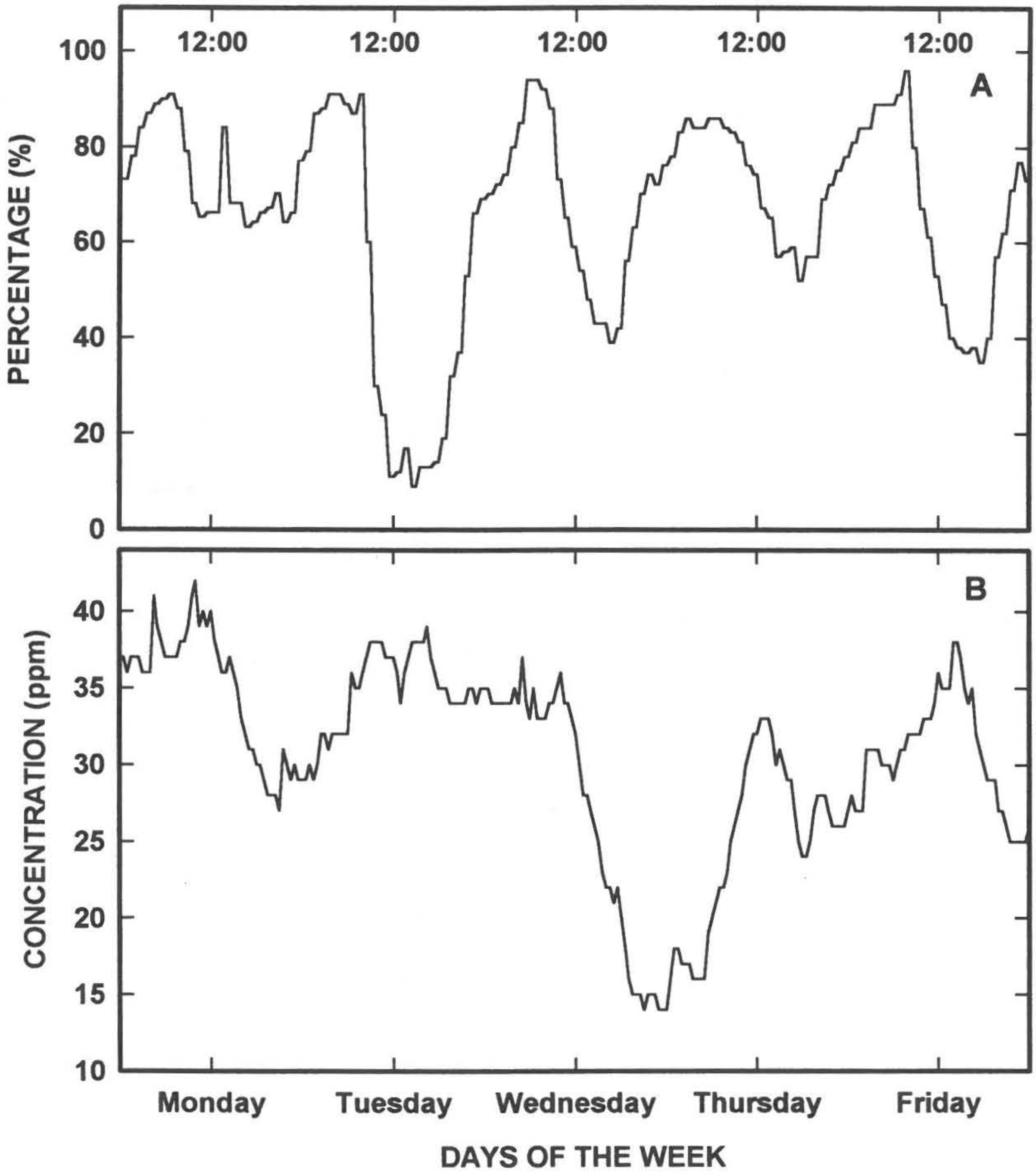

FIGURE 15: A: Percentage (%) humidity measured in ambient air during March 1997
B: H_2 concentrations (ppm) measured in welding shop air during March 1997

concentrations will not experience any irritation due to the H_2 exposure, because the O_2 concentrations measured during the same period were above 18 % (v/v).

The hydrogen concentrations detected during April 1997 were lower than those of the previous two months. A weekly TWA H_2 concentration of 10.3 ± 4.99 ppm with a minimum value of 5 ppm and a maximum value of 22 ppm were measured respectively. A definite pattern was established throughout the week (as indicated in Figure 3C). A comparison of the concentrations of H_2 in the welding shop and the ambient humidity is given in Figure 16. It was observed that an increase in vapour pressure resulted in an increase in the H_2 concentration. Figure 16 shows that the increase of H_2 followed the increase of humidity by a few hours at each occasion. This phenomenon can be explained by the fact that humidity measurements were taken outside the building in ambient air at the weather station which is approximately 5 km from the studied indoor environment. Due to restricted air flow into the welding shop, the humidity inside the workshop did not change immediately with the change in weather, which explains the slower increase in H_2 concentrations.

Winter concentrations: The H_2 concentrations detected during May 1997 showed a maximum of 7 ppm and at times even dropped to 0 ppm. A weekly TWA concentration of 1.92 ± 2.13 ppm was calculated. These concentrations were the lowest H_2 concentrations detected during the entire study. In Figure 17 the relationship between the concentration of H_2 and the humidity is shown. As the vapour pressure increased, the H_2 concentration increased accordingly within a few hours. It is expected that welders will not experience irritation as a result of the H_2 concentrations present in the ambient indoor air, mainly as a result of sufficient O_2 concentrations in the workroom air.

Hydrogen gas sampled during June 1997 showed a weekly TWA concentration of 7.98 ± 6.09 ppm and a maximum concentration of 22 ppm. It was observed

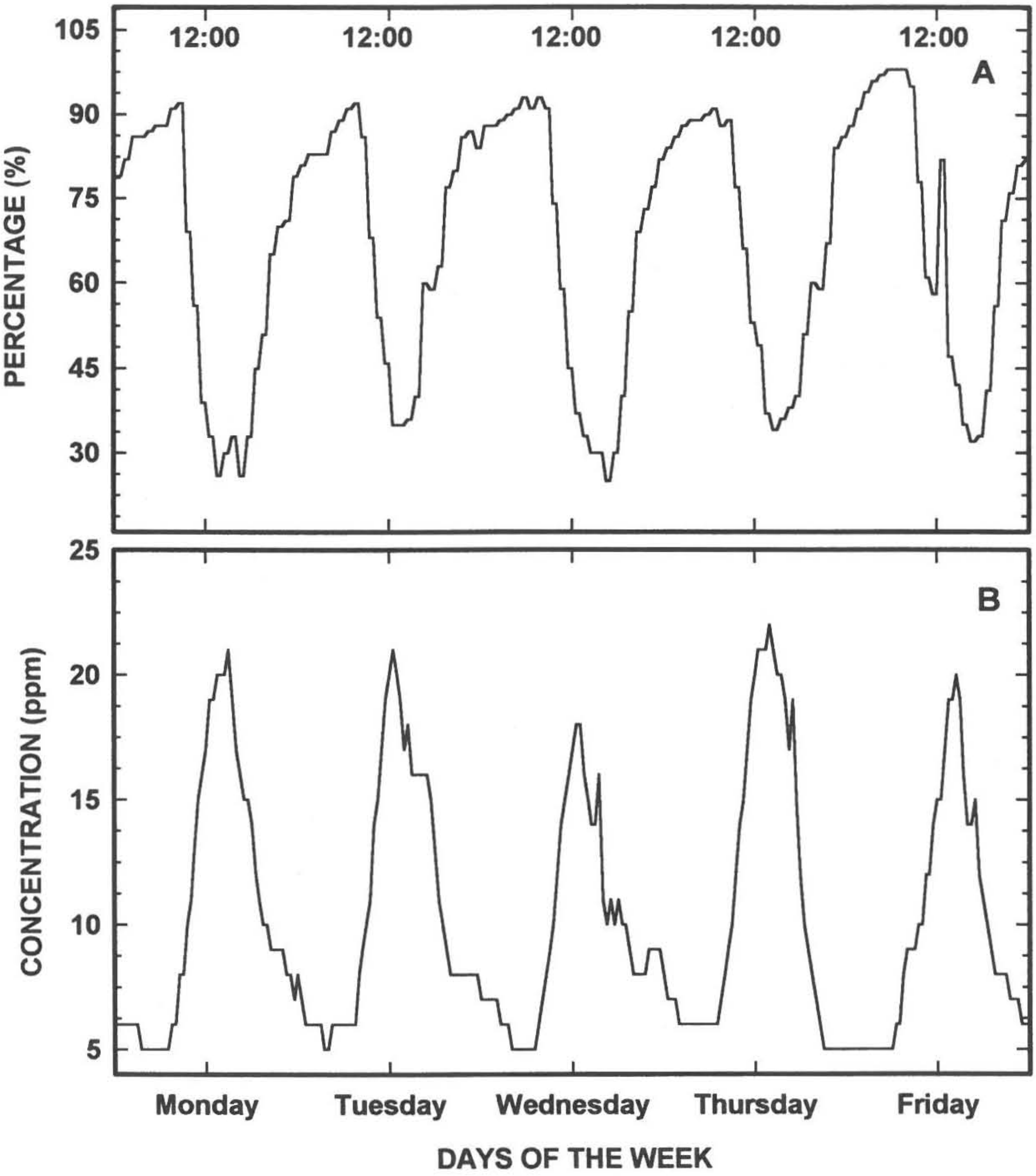

FIGURE 16: A: Percentage (%) humidity measured in ambient air during April 1997
B: H_2 concentraions (ppm) measured in welding shop air during April 1997

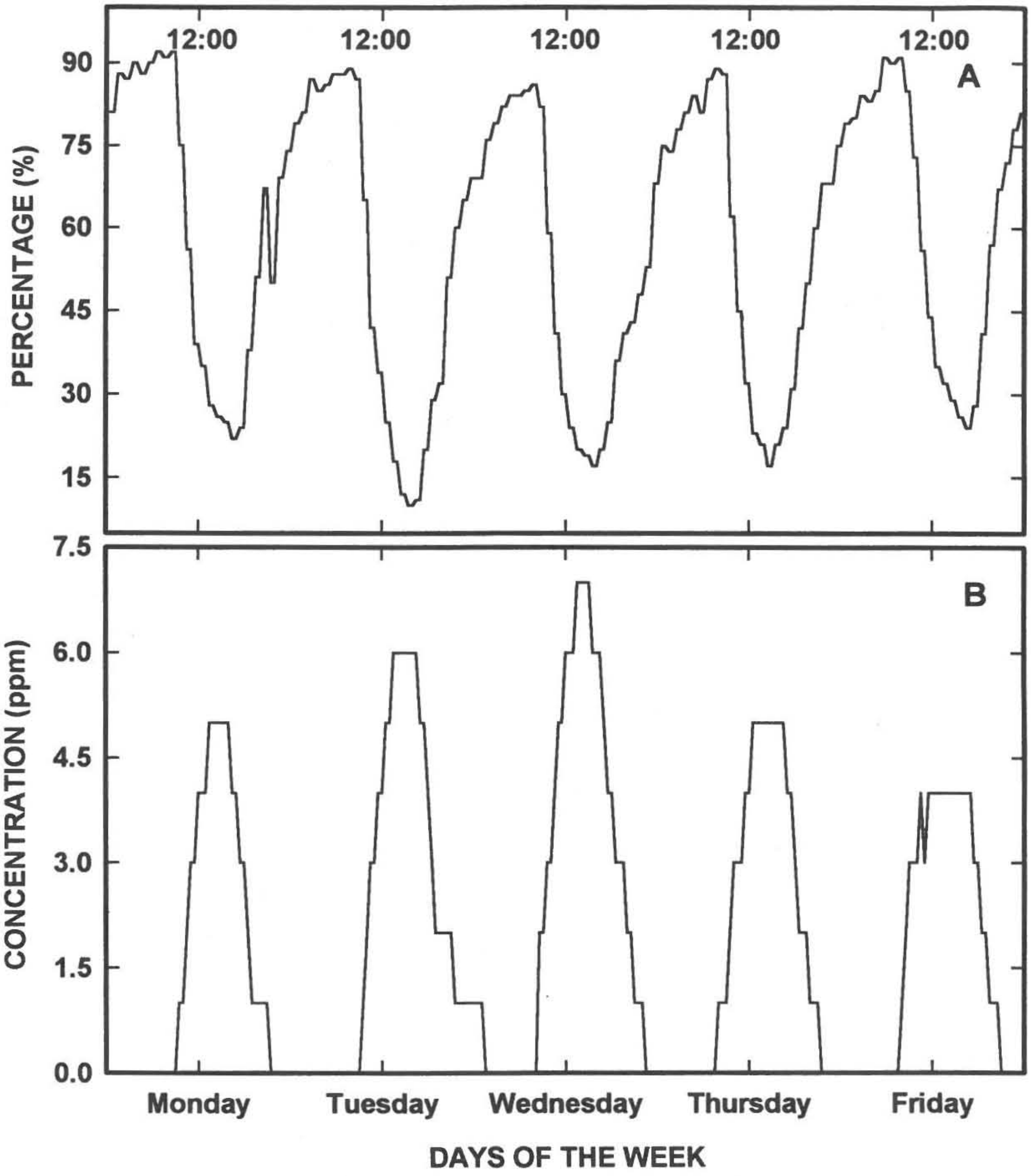

FIGURE 17: A: Percentage (%) humidity measured in ambient air during May 1997
B: H_2 concentrations (ppm) measured in welding shop air during May 1997

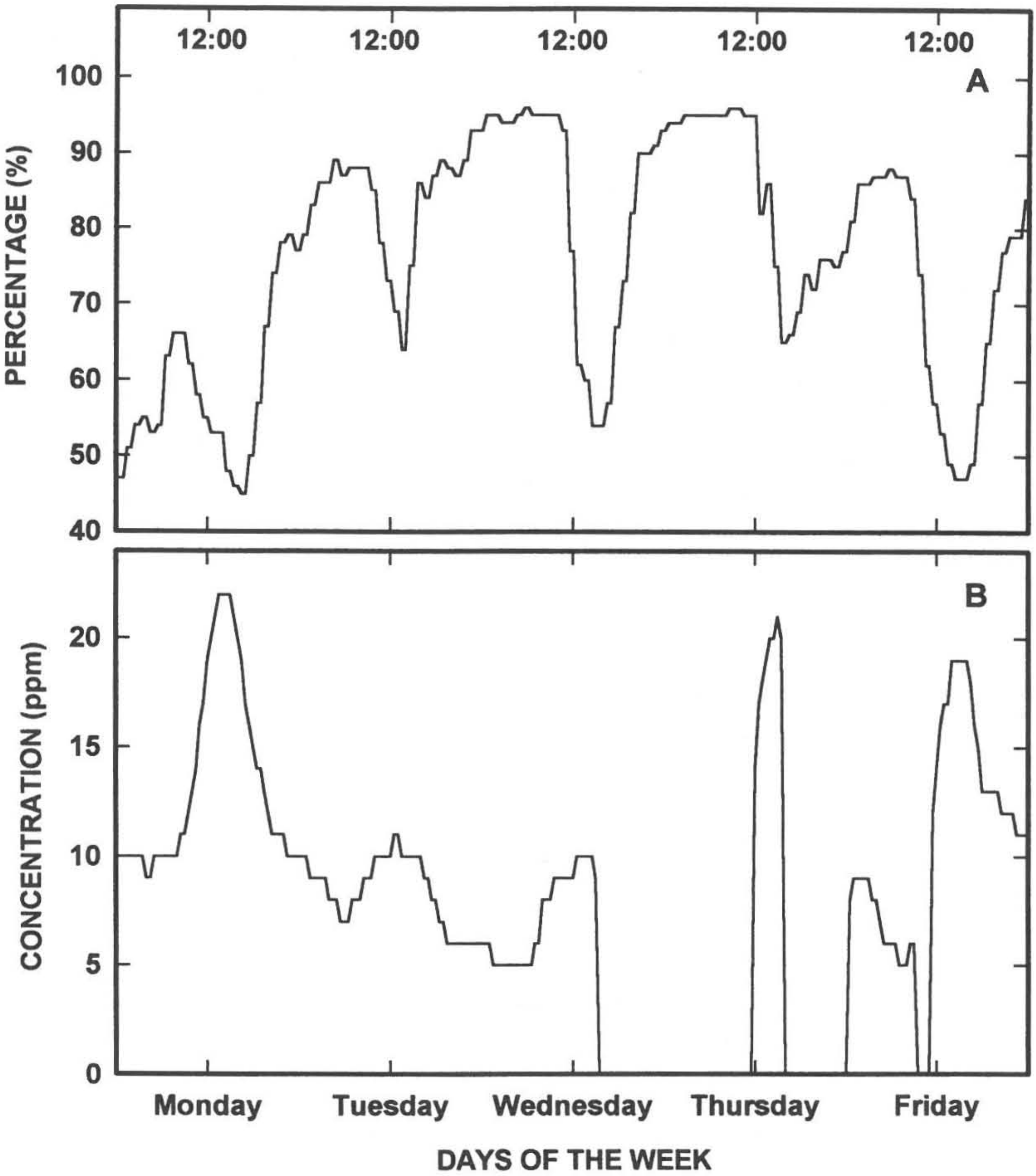

FIGURE 18: A: Percentage (%) humidity measured in ambient air during June 1997
B: H_2 concentrations (ppm) measured in welding shop air during June 1997

(Figure 18) that the atmosphere was unstable and that the H_2 concentrations did not follow the same pattern as during the previous months. The unstable environmental conditions could be the main reason for the H_2 concentrations detected on Thursday (12/06/97), when the H_2 concentration remained below the detection limit of the instrument for some time. Welders could therefore not experience any irritation as a result of H_2 concentrations measured during this period.

Hydrogen emissions during July 1997 showed a weekly TWA concentration of 6.18 ± 5.96 ppm and the concentrations varied between 0 ppm and 25 ppm. Figure 19 depicts the humidity and the H_2 concentrations detected. A relationship between the two different measurements in terms of time-variation is clearly visible. However, no similarity between the actual H_2 concentration (amount of ppm) and the percentage humidity could be found. It is therefore not possible to predict the H_2 concentrations in the studied environment when the percentage of humidity in the air is known. Due to the continuous presence of sufficient O_2, the H_2 emissions should not pose a health risk to the exposed work population.

4.7 Hydrogen Chloride

The general public is potentially exposed to small amounts of HCl vapour caused by inhaling ambient air contaminated with emissions from a variety of industrial sources, including incinerators and coal-burning power plants (Bond, Flores, Stafford and Olsen, 1991). Hydrogen chloride, a water-soluble, colourless gas, is categorised as non-flammable by the US Department of Transportation and as a hazardous substance by the US Environmental Protection Agency (EPA) (Sitting, 1981). Hydrogen chloride in the atmosphere is expected to exist primarily in the gaseous phase. During very humid conditions, HCl can condense to become a component of acid fog. At elevated

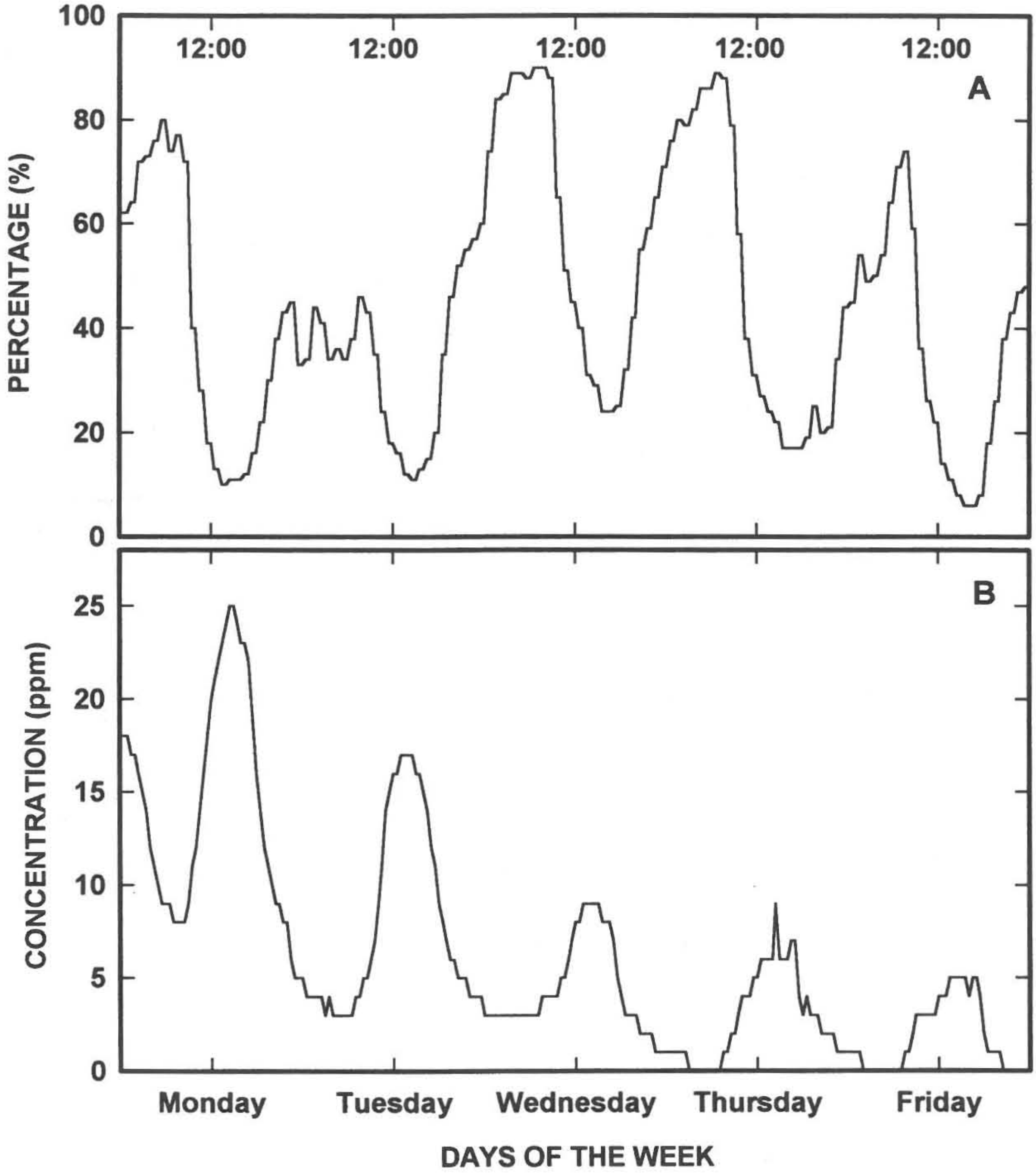

FIGURE 19: A: Percentage (%) humidity measured in ambient air during July 1997
B: H_2 concentrations (ppm) measured in welding shop air during July 1997

concentrations, HCl can appear in the form of particles, but this form will be short-lived in the atmosphere. In the gaseous phase, HCl is highly reactive and is quickly neutralised or removed from the atmosphere by means of interaction with surfaces or reactions with other gases (Kamrin, 1992).

Hydrogen chloride is known to have adverse health effects. High concentrations of HCl gas cause corrosion to mucous membranes, producing burns, ulceration and scarring. Eye contact can result in reduced vision or blindness. Dental discoloration and erosion of exposed incisors have occurred at prolonged low-level exposures (Malek and Alarie, 1989). During a study conducted in 1991, which entailed sampling with Dräger's glass ampule, a measurement was made of the emerging fumes during the welding of steel, painted with Backrysol and Realux. Hydrogen chloride levels above 100 ppm were measured, but no HCl was detected when only steel was welded (Sjögren *et al.*, 1991). It can thus be expected that HCl will be emitted during the welding process, if welding is done on painted steel.

Almost no human data exist of controlled studies investigating exposure to low levels of HCl. Stevens *et al.* (1992) documented that no HCl ambient standards or guidelines exist in the United States. In South Africa, no occupational related TLV concentrations for exposure to HCl are available, however only a STEL.TLV concentration of 5 ppm is recommended by the Hazardous Chemical Substances Regulations, 1995 (South Africa, 1995).

Summer concentrations: Hydrogen chloride was detected throughout the study. The concentrations detected during February varied between 0.1 ppm and 2.2 ppm with a calculated weekly TWA concentration of 0.73 ± 0.51 ppm. As mentioned before, a degreasing plant is located in the welding shop. Smith (1993) recommended that degreasing plants should not be installed in a fabrication shop in which welding is being done. Exposure of the degreasing vapour to naked flames or red-hot surfaces such as welding arcs and open space-heaters could produce acidic gases. The HCl concentrations could therefore be a result of the presence of the degreasing plant inside the welding shop. In a study in which workers were exposed to concentrations between 50 ppm and 100 ppm per hour, the situation became barely tolerable, while a short exposure to 35 ppm caused irritation of the throat, and 10 ppm was considered to be the maximum allowable concentration for prolonged exposure (Toyama, Kondo and Nakamura, 1962; Henderson and Haggard, 1943). Hydrogen chloride strongly irritates the eyes, the mucous membranes and the skin, but the warning properties of HCl in the air are good and most people can detect 5 ppm HCl easily. It is not expected that the welders will experience any occupational related health effects as a result of the minute HCl concentrations present in the welding air.

The hydrogen chloride concentrations detected during March 1997 resulted in a weekly TWA concentration of 0.49 ± 0.4 ppm. The HCl concentrations varied between 0 ppm and 1.8 ppm. In Figure 4B, it is shown that the HCl concentrations increase when work commences. The density of HCl (Table 1) is higher than the atmosphere which results in the descending of HCl as soon as the welding process stops. This explains the behaviour of the gas when concentrations drop to 0 ppm long after the work has stopped. It is reasoned that the HCl concentrations were too low to cause any health-related effects among the welders.

The hydrogen chloride concentrations detected during April 1997 varied between 0 ppm and 1 ppm with a weekly TWA concentration of 0.28 ± 0.28 ppm. Once again the relation between the work shift and the HCl concentration is shown in Figure 4C. The detected HCl concentrations could have been emanated by the degreasing plant which is located in the welding shop.

Winter concentrations: During the sampled winter months, concentrations of HCl were continuously present in the ambient air. The concentrations detected during May 1997 showed a calculated weekly TWA concentration of 0.20 ± 0.24 ppm with a maximum concentration of 0.8 ppm. The concentrations detected were very low and it is expected that no health effects will occur in welders as a result of exposure to HCl.

During sampling done in June 1997, the welding or related processes emitted a maximum HCl concentration of 0.8 ppm and a calculated weekly TWA concentration of 0.11 ± 0.18 ppm. The maximum HCl concentrations for each month are depicted in Figure 20A, while the calculated weekly TWA concentrations are reflected in Figure 20B. From these figures it can be derived that the changes in temperature or season can play an important role in the concentration of HCl present in the studied environment. In February the highest concentration was measured. During the three winter months the maximum concentrations remained stable. The weekly TWA concentrations declined as the ambient temperature dropped. This could be due to the fact that the doors and windows in the welding shop were not opened during the winter months, which resulted in the air in the shop being more stable and less subject to the changes in weather (for example wind) outside. The HCl concentrations detected remained almost stable for the three sampled winter months, and it is expected that the HCl concentrations in the air during the winter will not cause any health effects in welders.

The concentrations of HCl detected during July 1997 resulted in the same exposure pattern as during June. The weekly TWA concentration was 0.12 ± 0.20 ppm and the maximum concentration detected was 0.8 ppm.

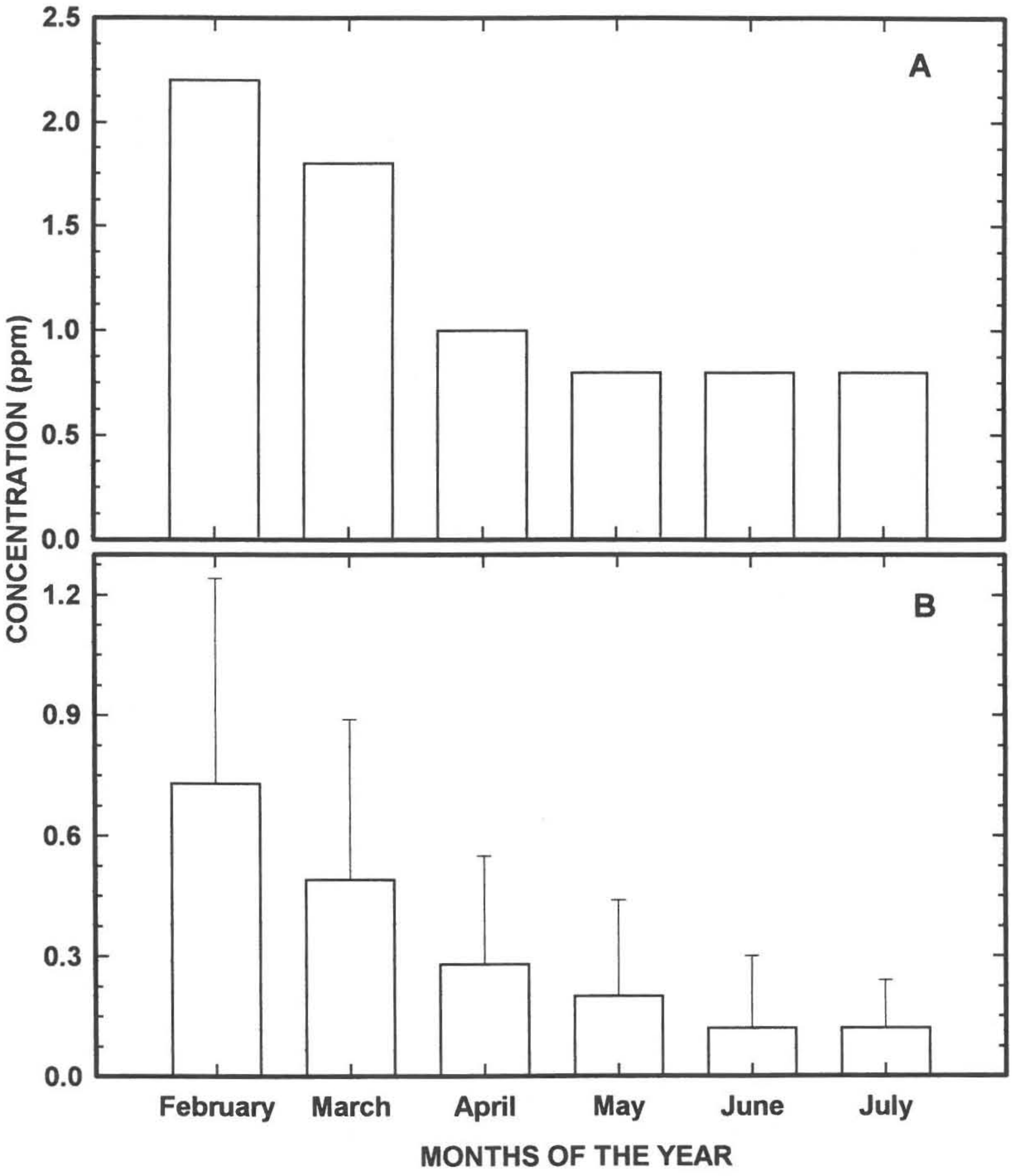

FIGURE 20: A: Maximum HCl concentrations (ppm) measured in welding shop air during 1997
B: Mean HCl concentrations (ppm) measured in welding shop air during 1997

4.8 Hydrogen cyanide

No concentration of hydrogen cyanide was detected during the study. Hydrogen cyanide is a highly toxic gas which can occur as a workplace hazard in cases where cyanides are used (for example in electroplating and mining) (Plunkett, 1987). Although HCN is known as a toxic gas, it will not normally occur in a welding environment. However, it was included in the study because of its high toxicity.

Due to the fact that no HCN concentrations were detected during the study, none of the above-mentioned health effects could occur as a result of HCN exposure.

4.9 Hydrogen sulphide

The concentrations of hydrogen sulphide present during the study were invariably below the detection limit of the instrument. Hydrogen sulphide is a natural gas found in the atmosphere. It is known for its strong odour, and is emanated during anaerobic decay in soils, wetlands, salt marches and other areas of stagnant water. Maximum concentrations occur over wet tropical forests, but a lack of measurements prevent an estimate of global production. The offensive odour is the first indication of the presence of H_2S gas. However, the odour should not be used as a warning signal, as at concentrations of approximately 150 ppm or greater, rapid paralysis of the olfactory nerve occurs (Haley and Berndt, 1987). No H_2S was expected in the welding environment as it is not known to be a by-product of welding or any other related process. H_2S was included in the study, however, because it can be found in areas where petroleum products are stored or used. It was observed that forklift trucks were operated in the studied environment which could emit small amounts of the gas during operation.

4.10 Nitric oxide

The detection limit of the instrument was above the NO concentrations present in the ambient air. Nitric oxide is formed by a combination of nitrogen (N_2) and O_2 in the air at elevated temperatures, as found in the presence of electric arc and especially oxy-gas welding processes. When generated at high temperatures, NO has been shown to comprise 95 % of the nitrogen oxides (Norwood *et al.,* 1966). Most fires and the exhausts of internal combustion engines emanate varying amounts of NO (Freeman *et al.,* 1968). Although no concentrations of NO were expected in the studied environment, it was observed that fires were made and that forklifts were operated in the environment. It was expected that the natural ventilation would be sufficient to dilute the NO concentrations to such an extent that no NO concentrations would be detected. In a study conducted in 1970, seven volunteers inhaled 0.33 ppm, 0.5 ppm, 1 ppm or 5 ppm NO and 85 % to 93 % of the inhaled NO was retained (Wagner, 1970). No effects in humans have been reported from NO inhalation alone (ACGIH, 1991b; Hathaway *et al.,* 1991), and it is expected that the welders will not experience any adverse health effects as a result of NO inhalation.

4.11 Nitrogen dioxide

No NO_2 concentrations were detected during the study. Nitrogen dioxide is a pollutant as dangerous as CO, even though environmental groups do not recognise it equally. The first effect of nitrogen oxide upon humans is irritation of the eyes and respiratory passages. Nitrogen dioxide concentrations of between 1.6 ppm and 5 ppm after one hour of exposure cause increased airway resistance and diminish the diffusing capacity of the lungs (Sackheim and Lehman, 1990). Concentrations of between 25 ppm and 100 ppm cause acute but reversible bronchitis and pneumonitis. Nitrogen dioxide concentrations of above 100 ppm are usually fatal, with death resulting from pulmonary oedema

(Sackheim and Lehman, 1990). It was not expected that NO_2 would be detected during the study, as it is normally used as an intermediate substance in nitric and sulphuric acid production and in the nitration of organic compounds and explosives (Hathaway *et al.,* 1991). Nitrogen dioxide acts as a primary irritant. However, during a preliminary walk-through study, the presence of an irritant was experienced in the environment. The monitoring of NO_2 was included in the study, due to the possibility of being one of the causes of such irritation.

4.12 Oxygen

Oxygen is one of the five elements required to sustain life. It is also one of the most important gases present in the environment. For decades it has been successfully used to treat sick people. Oxygen deficiency or O_2 starvation is arguably the greatest cause of disease. Oxygen provides life and energy to every human cell. If the body is abused by poor eating and drinking habits, air pollution, the misuse of drugs or a lack of exercise, cells are deprived of O_2 and the immune system is weakened. Many people do not inhale enough O_2 to live a healthy life. Less than adequate oxygenation of tissues and cells (a condition called hypoxia) can lead to a number of degenerative illnesses, such as circulatory problems, digestive disorders and even cancer (Heuer, 1997).

Carbon monoxide can interfere with the O_2 supply to tissue by virtue of its strong ability to replace O_2 in haemoglobin. Ozone is also one of the pollutants that have been associated with such effects. In addition, the uneven distribution of air supply can impair the O_2 supply (Lipfert, 1994).

A recommended TLV for O_2 is stipulated in the ACGIH documentation (1991b) where a minimum of 18 % (v/v) is recommended (ACGIH, 1991b). The same concentration has also been described in the Regulations for Hazardous Chemical Substances, 1995 (South Africa, 1995).

Summer concentrations: Oxygen was detected in stable concentrations throughout the study. The oxygen concentrations measured during February 1997 varied between 20.4 % and 20.8 % with a TWA concentration of 20.58 ± 0.12 %. The 8-hour TWA concentration for each day of the week (Table 3) showed that the O_2 concentration to which workers were exposed, was constantly close to 21 %. The lowest 8-hour TWA O_2 concentration of 20.48 % was detected on Thursday (13/02/97). Oxygen concentrations increased (Figures 5A, 5B, 5C, 10A, 10B and 10C) when welding commenced in the morning, and dropped as the welding stopped at the end of the working day. There is some speculation about the cause of this phenomenon. The first is that a gas in the welding environment binds with O_2 when the atmosphere in the workshop is stable, and it results in lower O_2 concentrations. Secondly, the actual O_2 concentration in the environment, without any activities, is lower than 21 %. According to Schröder and Schoeman (1994), the O_2 concentration in the air is approximately 21 %. If the assumption is made that the normal O_2 concentration in the specific workshop is 20 %, it is evident that the O_2 concentration rises as the working activities commence. If this is the case, the rising O_2 concentration can be explained by the presence of O_2 in the welding process, and O_2 could also be released into the air during the welding.

The most likely reason for the O_2 pattern is the fact that O_2 levels decrease slightly during night-time when O_2 is not produced naturally. Smouldering fires or any O_2 burning appliances would contribute to the lower levels in the welding shop during the night. In the morning, when the doors and windows are opened, the stale air is replaced with fresh air and the O_2 concentration increases.

The oxygen measurements during March 1997 resulted in a calculated TWA concentration of 20.52 ± 0.13 %. The concentrations varied between 20.3 % and 20.8 %. The calculated 8-hour TWA concentrations for each day of the week (Table 6) showed that the minimum 8-hour TWA concentration for O_2 was detected on Wednesday (12/03/97). This concentration was still not below the recommended TLV (ACGIH, 1991b; South Africa, 1995), and although it is considered as a low concentration, sufficient O_2 was present in the air.

The oxygen concentrations detected during sampling done in April 1997 resulted in almost the same concentrations as during the previous two summer months. A calculated TWA concentration of 20.40 ± 0.15 % was obtained. The O_2 concentrations varied between 20.2 % and 20.7 %. The minimum O_2 concentration was well above the recommended 18 % (ACGIH, 1991b; South Africa, 1995).

Winter concentrations: The average O_2 concentrations detected during the winter months were lower than during the sampled summer months. Sampling done in May 1997 showed a calculated TWA concentration of 20.35 ± 0.18 %. The oxygen concentrations varied between 20.1 % and 20.7 %. The calculated 8-hour TWA for each day (Table 15) showed that the O_2 concentrations were above the recommended minimum value of 18 % (ACGIH, 1991b; South Africa, 1995). It is expected that welders will not experience work related illness due to a lack of O_2.

The lowest 8-hour TWA concentration was detected during the sampling period in June 1997 (13/06/97). Measurements during this sampling period showed a TWA concentration of 20.29 ± 0.11 % and the concentrations varied between 20.1 % and 20.6 %. All the measured concentrations were above the recommended minimum value of 18 % (v/v) (ACGIH, 1991b; South Africa, 1995) and no work-related health effects are expected to occur.

Sampling done in July 1997 showed O_2 concentrations between 20.1 % and 20.7 % with a calculated TWA concentration of 20.39 ± 0.16 %. The 8-hour TWA concentrations shown in Table 18 were higher than the concentrations detected during June 1997, and comply with the minimum recommended value of 18 % (v/v) (ACGIH, 1991b; South Africa, 1995).

4.13 Ozone

Ozone is a photochemical oxidant and the major component of smog. While O_3 in the upper atmosphere is beneficial to life by shielding the earth from harmful ultraviolet radiation from the sun, high concentrations of O_3 at ground level are a major cause of health and environmental concern. Ozone is not emitted directly into the air, but is formed by means of complex chemical reactions between precursor emissions of volatile organic compounds (VOC) and oxides of nitrogen (NO_x) in the presence of sunlight. These reactions are stimulated by sunlight and temperature and cause peak O_3 levels to occur typically during the warmer times of the year. Both VOC's and NO_x are emitted by transportation and industrial sources (USEPA, 1997).

The reactivity of O_3 causes health problems because it damages lung tissue, reduces lung function and sensitises the lungs to other irritants. Scientific evidence indicates that ambient levels of O_3 not only affect people with impaired respiratory systems such as asthmatics, but healthy adults and children as well (Rom, 1992). Exposure to O_3 for several hours at relatively low concentrations has been found to significantly reduce lung function and induce respiratory inflammation in normal healthy people who are exercising. This decrease in lung function is generally accompanied by symptoms such as chest pains, coughing, sneezing and pulmonary congestion (Roan, 1989).

An 8-hour occupational TWA O_3 concentration of 0.1 ppm for light work is recommended by the ACGIH (1997). The 8-hour occupational TWA concentration for workers exposed to O_3 during moderate work is 0.08 ppm, and during heavy work 0.05 ppm (ACGIH, 1997). The South African Government and SMACNA (1993) recommend a maximum exposure concentration of 0.05 ppm (South Africa, 1995).

Summer concentrations: No O_3 concentrations were detected during the summer sampling periods. Although O_3 concentrations did not occur during these periods, it is expected that no work related health effects will occur as a result of O_3 exposure.

Winter concentrations: During the study, O_3 concentrations were detected only during the sampling period in May 1997. Measurements showed a maximum concentration of 0.03 ppm and a calculated weekly TWA concentration of 0.001 ± 0.004 ppm. The measured concentrations were below the guideline value (0.05 ppm) recommended by ASHRAE (SMACNA, 1993). The detected O_3 and PH_3 concentrations in the welding environment might have a possible relationship. The O_3 concentrations showed an increase at the same time when the PH_3 concentrations increased. A study conducted by van der Wal (1990) showed that the concentrations of O_3 generated during welding were very high. The study was conducted by measuring the O_3 levels in the breathing zones of the welders (behind the face shield). Van der Wal (1990) stated that the concentrations were very high, because the distance between the torch and the breathing zone of the welder was very small. Ozone concentrations deceased with an increase in the distance to the torch. The measured concentrations were below the SMACNA (1993) recommended guideline (0.05 ppm) at a distance of 500 cm from the welding torch.

The minute concentrations detected during the study could be a result of the distance between the welding process and the stationed sampling base in the welding shop. The reason why O_3 was detected only during one sampling period could be explained by the fact that the ambient temperature was very low and the windows and doors were kept closed to keep the heat inside. The O_3

concentrations could not diffuse as quickly as during the previous sampling periods, and were detected by the instrument. The measured O_3 concentrations should not cause any work-related health effects in the exposed welders.

4.14 Phosphine

Phosphine is formed by the action of moisture on metallic phosphates or from caustic acid on elemental phosphorus, and it may be present where these substances are handled or stored. Phosphine can evolve when metallic phosphides come into contact with moisture (Plunkett, 1987). It is also a dipping agent for electronic components and is used in chemical synthesis. Rom (1992) stated that PH_3 could also be an airborne by-product of acetylene production. The death of an acetylene generator operator from pulmonary oedema was documented as early as 1958 by Harger and Spolyar. Phosphine was regarded as the probable cause during the event, a concentration of approximately 8 ppm with 1 or 2 hours exposure per day, was found. Several fatalities ascribed to inhaled PH_3, generated from aluminium phosphate fumigation and its decomposition in ship cargo holds, have been reported (Eilson *et al.,* 1980).

Exposure to PH_3 can result in pulmonary oedema, diffuse cardiovascular injury and focal myocardial necrosis. Symptoms such as diarrhoea, nausea and vomiting, tightness of the chest and coughing, headaches and dizziness have been reported in workers exposed to PH_3 concentrations of up to 35 ppm, but averaging 10 ppm in most cases (Jones, Jones and Longley, 1964; WHO, 1988).

The ACGIH (1997) recommends a TLV for PH_3 of 0.3 ppm and in South Africa a STEL.TLV of 0.3 ppm (South Africa, 1995) is recommended. No guidelines for the ambient air quality regarding PH_3 exist, thus an environmental guideline value was calculated as mentioned previously. One fortieth of the recommended TLV concentration is 0.0075 ppm.

Summer concentrations: No PH_3 concentrations were detected during the study in the summer months, and no work-related health effects should occur as a result of exposure to PH_3 concentrations.

Winter concentrations: Phosphine concentrations were detected only during the sampling period in May 1997. The PH_3 concentrations measured showed a maximum concentration of 0.02 ppm and a calculated weekly TWA concentration of 0.003 ± 0.005 ppm. The work shift TWA concentrations for this sampling period were below the calculated environmental guideline value of 0.0075 ppm. When the PH_3 concentrations (Figure 12) are compared to the humidity (Figure 17A) during the same period it can be seen that concentrations increased at the same interval at the same time. This could be explained as a result of metallic phosphides that were in contact with moisture and PH_3 emissions were formed. In Table 12 the 8-hour work shift TWA concentrations for May 1997 are shown. All the 8-hour work shift TWA concentrations were below the calculated guideline value, except for concentrations measured on Wednesday (14/05/97). An 8-hour work shift TWA concentration of 0.013 ± 0.01 ppm was calculated. This means that workers were exposed to 1.7 times more than the calculated environmental threshold limit value.

Inhalation of PH_3, released after fumigation with aluminium phosphide on a grain freighter, resulted in acute illnesses amongst 29 of 31 crew members and two children, one of whom died. Air concentrations measured 2 days after the onset of illness ranged from 0.5 ppm, in some of the living quarters, to 12 ppm at an air intake. The most common symptoms were headaches, fatigue, nausea, vomiting, coughing, and shortness of breath. Congestive heart failure with pulmonary oedema and myocardial necrosis with inflammation were noted in the child who died. The other child had echocardiography evidence of poor left ventricular function and an abnormal EKG, with resolution of abnormalities within 72 hours (Wilson *et al.*, 1980). Although the concentrations in the above-mentioned incident were higher than the measured PH_3 concentrations in this study, it is expected that welders will suffer from some of the mentioned health effects. If personal sampling on workers is done, it is expected that PH_3 concentrations would be higher and therefore causing severe health effects.

4.15 Sulphur dioxide

Ambient SO_2 results largely from stationary sources such as coal and oil combustion, steel mills, refineries, pulp- and paper-mills and from non-ferrous smelters. High concentrations of SO_2 affect breathing and could aggravate existing respiratory and cardiovascular disease. Sensitive populations include asthmatics, individuals with bronchitis or emphysema, children and the elderly. Sulphur dioxide is also a primary contributor to acid deposition and acid rain, which causes acidification of water sources (USEPA, 1997). The exposure to low levels of SO_2 can promote allergy sensitisation in guinea pigs (Reidel *et al.*, 1988).

The South African Government recommends an occupational TLV of 2 ppm (SO_2) as the exposure limit (South Africa, 1995), and the USEPA recommends an environmental guideline value of 0.14 ppm for SO_2 (USEPA, 1989). Sulphur dioxide is seen as a "hot house" gas and at the moment it is under discussion to set a environmental guideline for the future. The ACGIH recommended in 1991 a occupational TLV of 2 ppm (SO_2) with a STEL TLV of 5 ppm (ACGIH, 1991c).

Summer concentrations: No SO_2 concentrations were detected during the sampling period and no work-related health effects should occur as a result of SO_2 exposure.

Winter concentrations: Sulphur dioxide concentrations were detected during measurements in May 1997. A weekly TWA concentration of 0.001 ± 0.01 ppm was calculated. Sulphur dioxide was detected during one day of the week only. In Table 12, the 8-hour work shift TWA SO_2 concentration on Wednesday (14/05/97) was calculated at 0.019 ± 0.04 ppm. It should be mentioned that detection of SO_2 is very complex since SO_2 will diffuse very easily in air and transform to SO_3. The measured concentration was below the recommended guideline suggested by the USEPA (1989), and the possibility of work-related health effects occurring in the welders is small.

5. CONCLUSION AND RECOMMENDATIONS

Ambient gas exposure of welders at a large engineering plant was characterised to identify possible health hazards, as a result of chronic exposure, and to detect a possible relationship between summer and winter exposures.

Ambient air in the workshop was analysed for the following gases: NH_3, CO, Cl_2, ClO_2, C_2H_4O, H_2, HCl, HCN, H_2S, NO, NO_2, O_2, O_3, PH_3 and SO_2. The collected data were analysed and processed in 8-hour TWA concentrations and weekly TWA concentrations.

The calculated TWA concentrations were compared to recommended environmental TLV's or a calculated environmental TLV if an official TLV was not available.

The following gases showed concentrations below the detection limit of the instrument used in this study: NH_3, Cl_2, ClO_2, HCN, H_2S, NO and NO_2.

It was found that the workers in the welding shop were exposed to low CO concentrations during winter months and no occupational related health effects are expected as a result of CO inhalation. To eliminate CO concentrations, it is however recommended that fires should not be made inside the workshop.

Measurements of C_2H_4O showed that welders were exposed to high C_2H_4O concentrations during the 8-hour work shifts. These emissions are possibly caused by the oxyacetylene welding process. It is recommended that natural ventilation be increased by opening the doors and windows during the welding process or a different welding process should be used to reduce the C_2H_4O concentrations. It is envisaged that the welders could show mild respiratory irritation after chronic exposure to the measured C_2H_4O levels.

Hydrogen concentrations were also detected during the study. These concentrations cannot be regarded as a health hazard because the O_2 concentrations were always above the safe level of 18 % (v/v). It is expected that the high H_2 concentrations measured were a result of ambient humidity. When the humidity increased, the moisture levels in the ambient air were exposed to the welding process and the H_2 was released from the original chemical binding to result in the increased H_2 levels.

Hydrogen molecules appeared to be trapped in the pores of freshly welded metal. When metal cooling takes place, the solubility of the H_2 decreases rapidly and the H_2 molecules are released into the workroom air.

The relationship between relative humidity and H_2-gas were observed. The increase in relative humidity resulted in an increase of H_2-gas. However, the H_2 concentrations were not compared to relative humidity percentages for the establishment of specific correlations. It is recommended that such correlations be determined with further research.

Low HCl concentrations were frequently detected during the study. It is expected that HCl concentrations are emitted by the degreasing plant which is located inside the workshop. Although HCl emissions did not reach dangerous levels, it is recommended that degreasing activities should either be moved to an open area or a localised ventilation system should be installed to remove the gases before it escape into the welding environment.

Oxygen detected during the study never dropped below 18 % (v/v), and no work-related health effects due to insufficient O_2 are expected in welders. The minimum O_2 content during the study was 20.1 %.

Ozone measurements, during the study, resulted in low concentrations detected during winter only. The presence of fires in the welding shop emit a variety of pollutants that could form O_3 as secondary pollutant. In order to eliminate pollutants causing O_3 formation, it is recommended that fires for workshop heating should not be allowed in the workshop.

The PH_3 emissions in the welding shop were detected only during one winter month. The work shift TWA concentrations were not high enough to cause occupational health hazards, however individual events on specific days were above the recommended environmental TLV. It could be as a result of pre-treatment of metals or contact between phosphides and moisture. A visual relationship between an increase in both relative humidity and PH_3 appeared to exist. It is recommended that PH_3 concentrations should be monitored frequently to control emissions when ventilation is restricted as a result of closed doors and windows.

Sulphur dioxide emissions were only detected on one day during the sampling period. The SO_2 concentrations were low and no health effects in welders are expected from SO_2 inhalation.

Gas concentrations increased shortly after the commencement of welding activities during every day. Such increases were especially found during winter when fires were made inside the workshops. The gas concentration levels decreased after the doors and windows were opened and ventilation took place.

This study concentrated on chronic gas exposure to indoor air of a welding workshop. The gas emissions were diluted with normal indoor air at the sampling point. It is expected that the workers are exposed to higher concentrations at their respective work stations. Such quantification should be done with further investigation and research projects. The measured exposures are representative of minimum gas exposure in a welding shop.

Gas characterisation over 24-hour periods is essential for the comparison of activities and gas emissions during which specific processes can be identified as hazardous gas emitters. Such characterisation can lead to better engineering control measures at the source as well as controlling of gases during winter months when more pollutants are present in the air of the welding workshop.

Further research is also recommended by utilising numerous sampling bases at specific processes to identify the sources of different gas emitters and to quantify the emissions. Such results could be useful in providing local ventilation systems as engineering control method.

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