Air Quality of Indoor Swimming Pools: Are Visits to the Pool Nearly as Healthy as Touted?

Dale Chen

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The views expressed in this paper are those of the author and do not necessarily reflect the official policy, position or view of BCIT, the Environmental Health Program or its faculty.

Abstract

This research project examined the VOC levels in the atmosphere of an indoor pool. The main source of the VOCs within an indoor pool is from chlorination by-products such as chloramines and trihalomethanes. Trihalomethanes has been shown to be carcinogens and chloramines are irritants. There have been numerous reports of increased incidence of breathing problems in frequent swimmers as well as those occupationally exposed. Currently there are no limits established for VOCs within an indoor pool environment.

This study involved using a direct reading instrument (VOC meter) to measure the levels of VOCs within a pool. The measurements took place over the course of a day on Dec 21, 2009 from the opening at 6 am to almost closing at 9 pm. The goal was to determine if the levels of VOCs changed over that period of time due to the build up of wastes within the pool, which would have increased VOC production. The null and alternate hypotheses are as follows

H_o: There is no difference in the VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a hand held VOC meter.

H_a: There is a difference in the VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a handheld VOC meter.

This hypothesis was tested via an ANOVA. Also, since numerous readings were taken anyway, readings were taken at different distances from the water surface in order to perform a regression analysis to see if there is a correlation between the distance from the water surface and VOC levels.

It was determined that there was a significant difference in VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a handheld VOC meter. However, there was no relationship found between the distance from the pool surface and the VOC levels.

Acknowledgements

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Table of Contents

List of Tables

List of Figures

Introduction

As our society progresses, there is an increasing emphasis on healthy living. Central to this promotion of a healthy lifestyle is regular exercise. One form of activity that is popular amongst many is swimming. According to Statistics Canada (2008) from 2000/2001 to 2005 the number of Canadians over the age of 12 who were active or moderately active in their recreational time increased from 43% to 52% and swimming was one of the most popular activities. In 2005, 18.5% of women and 5.5% of men aged 15 or older in Canada said they swam on a regular basis (Ifedi, 2008). What this means is that Canadians spend a significant portion of their time in and around swimming pools especially when one considers that the previous figures do not include other activities that take place in and around indoor swimming pools such as aquafit. While swimming may indeed be an excellent form of exercise and also something that a great many people take pleasure in, there are serious health concerns associated with being in indoor pools.

The health concern that this research project is focused on is the issue of indoor air quality within indoor swimming pools. Beyond the regular indoor air contaminants that may be of concern such as carbon monoxide and particulate matter, indoor pools have some additional concerns which are not found in the average indoor environment. During chlorination, the most common form of pool disinfection, many disinfection by-products are produced (De Graaf, MacKinnon and Marsh, 1995).

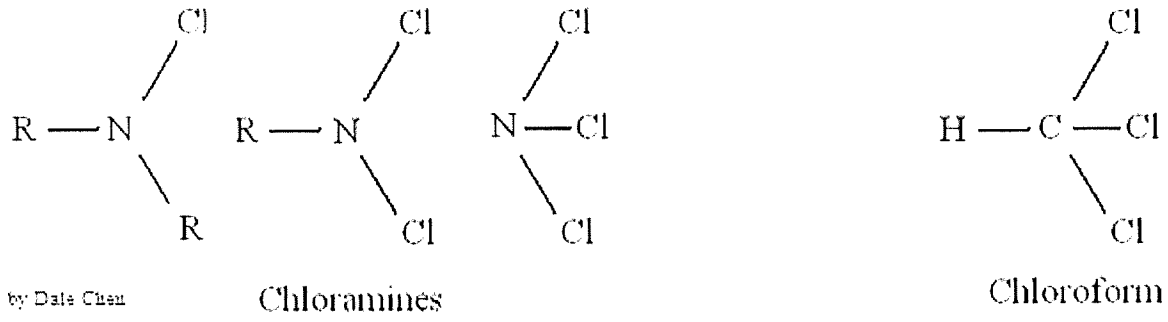

Figure 1. Chemical structures of some generic chloramines and chloroform, the most common trihalomethane (Dale Chen, 2009)

These disinfection by-products include compounds known as chloramines and trihalomethanes (Mills et al, 2000). These compounds are formed when chlorine interacts with organic molecules such as hydrocarbons, urea and ammonia excreted and introduced into the pool by the bathers themselves (WHO, 2006). Chloramines and trihalomethanes are actually two families of compounds which are related to one another. Chloramines have the chemical formulas of R_2NCl and $RNCl_2$ and NCl_3 and trihalomethanes are methane molecules where three of the hydrogen molecules have been replaced by halogens such as chlorine. Outside of the pool environment, trihalomethanes are also of concern when they are produced during drinking water disinfection (Health Canada, 1995). It would be safe to assume that the amounts produced during pool chlorination would be much higher than the drinking water chlorination due to the greater concentrations of contaminants and chlorine. Chloroform, the most common trihalomethane produced, is considered a potential carcinogen and it is also associated with a variety of other negative effects (EPA, 2007). With chloramines, there is some inconclusive evidence of their carcinogenicity and there is evidence that some forms of chloramines are linked with breathing problems (EPA, 2009). Chloramines are irritants which may cause symptoms ranging from wheezing to severe lung disease (CDC, 2007). Both of these substances are volatile organic compounds (VOCs).

Indoor pools are frequented by people all walks of life and of all ages. When one walks into a public swimming pool on any given day you will see individuals ranging from grandparents to babies. Due to this wide range of people who may choose to visit a pool, there are many individuals who may be susceptible to the VOCs that may be present. Also, swimming is a vigorous form of exercise during which people inhale deeply and quickly. These two factors make indoor air quality an issue of special concern in pools. One of the reasons that indoor quality becomes problematic is because there is insufficient air turnover. Therefore, these factors combined with the negative health effects of the VOCs present make this topic area worthy of further study.

Literature Review

The chlorination of swimming pool water has been a method of disinfecting swimming pools since at least 1923 when it was found that chlorination provided a valuable addition to the treatment of pool water in conjunction with other methods such as filtration (Stovall and Nichols, 1923). A large portion of that research examining chlorination by-products derives from the study of chlorination on drinking water supplies rather than swimming pools. While the levels and nature of chlorine and contaminants are different between water supply disinfection and pool disinfection the chemical reactions that take place to form the by-products are the same.

It was discovered in the 1970s that chlorination produced harmful by-products (Morris, Audet, Angelillo, Chalmers and Mosteller, 1992). From this research on these disinfection by-products, it has been concluded that trihalomethanes, the most common form being chloroform, has a positive association with cancer (Morris et al, 1992). However, these studies were conducted on the ingestion of trihalomethanes through drinking water and not upon the respiratory exposure. Although it may be counterintuitive, one of the studies used drinking water supplies which had been chloraminated as the control. Chloramination does indeed reduce the amount of trihalomethanes produced (Morris et al, 1992). However, in the swimming pool environment chloramines themselves are considered to be a hazardous chlorination by-product which is undesirable rather than a safer alternative as is the case with water supply disinfection. Since trihalomethanes has been determined to be a health hazard, there have been limits established to control levels of trihalomethanes in drinking water as well as occupational exposure. According to the Canadian Drinking Water Guidelines (1996) the maximum acceptable concentration for trihalomethanes in drinking water is 0.100 mg/L. The area that is more of concern for the pool environment is the occupational exposure that pool employees experience during their work day. There are several different organizations which set limits for occupational exposure of chemicals. The American Conference of Governmental and Industrial Hygienists' threshold limit value (ACGIH TLV) for chloroform is 49mg/m^3 (EPA, 2007). This value is a time rated average concentration to which most workers can be exposed with no adverse affects. Occupational Safety and Health

Administration's permissible exposure limit (OSHA PEL) for chloroform is 240mg/m^3 and this value is the time weighted concentration to which a worker can be exposed to for 8 hours a day for a 40 hour week with no adverse effects (EPA, 2007). These values are as seen in figure 2.

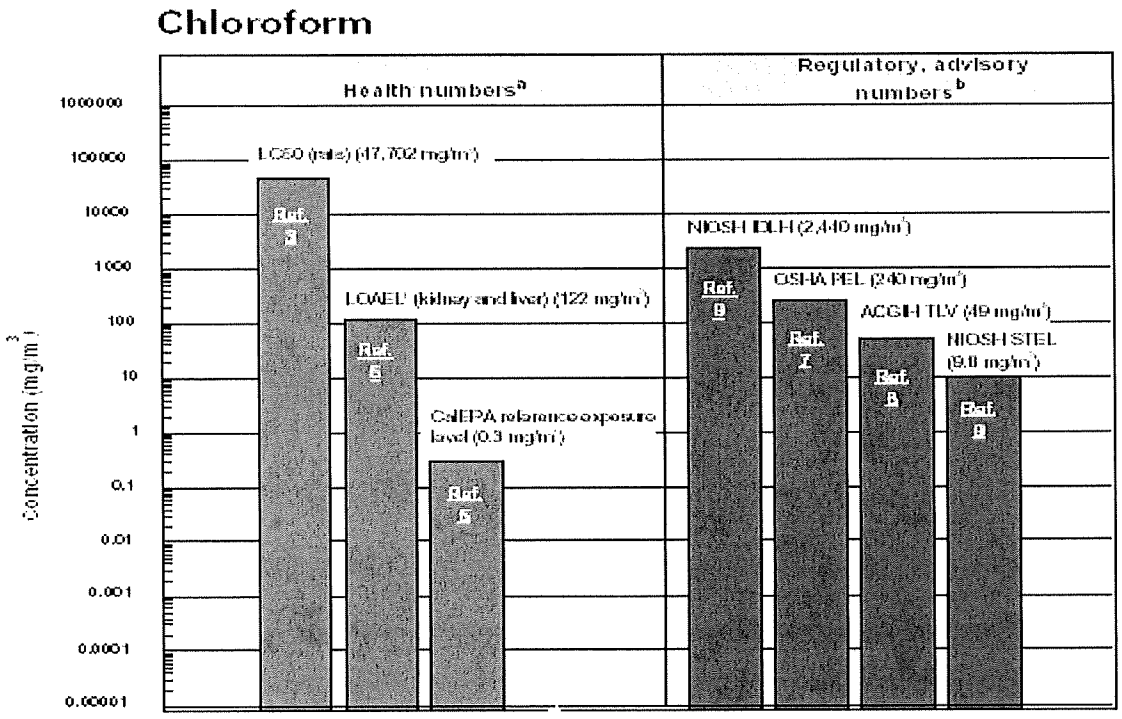

Figure 2. The various different limits and values for chloroform, the predominant form of trihalomethanes. (EPA, 2007)

There are no occupational limits established for chloramines. However, the Canadian Drinking Water Guideline does have a maximum acceptable concentration established at 3ppm (1996). When one inhales chloramines, it dissolves into ammonia and hypochlorous acid which are corrosive to the lungs (Health Canada, 1995). This explains why chloramines are considered an irritant when inhaled as well as when it comes in contact with mucosal layers like the eyes (Health Canada, 1995). Chloramines are generally considered not to be mutagenic and the evidence for its carcinogenicity isn't strong (Health Canada, 1995). This lack of epidemiological data on its negative effects accounts for why there are no limits established. Chloramines are also responsible for the odour complaints within indoor pools. Often when bathers with irritated eyes and noses complain about the excessive amounts of chlorine it is

in fact the free chlorine that is too low and the chloramines that are too high (American Chemistry, 2006).

There are currently no limits established, neither through guidelines nor regulations, specifically for swimming pool indoor air quality. The regulation that governs indoor swimming pools in British Columbia, the Swimming Pool, Spray Pool and Wading Pool Regulations under the BC Public Health Act, makes no mention of indoor air quality beyond the need for ventilation in the room which houses the gaseous chlorine. The only guidelines found during the course of this literature review directly related swimming pool air quality were established by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) which established how much air flow that an indoor pool must have. This rate was 0.5 cubic feet per minute per feet^2 (ASHRAE, 1989).

There have been several studies conducted on the indoor air quality of swimming pools. However, most of these studies were regarding the acute effects of chlorination by-products from substances like chloramines rather than the long term health effects from such compounds such has trihalomethanes. However, this is not to say that such studies do not exist. There have been previous studies such as the one by Yli-Pirilä et al (2002) which examined the concentration of VOCs and aerosols in the atmosphere of a pool. That particular study did not examine the levels of chloramines since the authors were primarily concerned with trihalomethane levels. In another study conducted by Lindstrom, Pleil and Berkoff (1997), the authors collected breath samples from swimmers over a two hour training period. What the authors found was that there was rapid absorption of trihalomethanes during the course of the swim to the point where the concentration of trihalomethanes in the breath of the swimmer became more than three times the ambient air levels of trihalomethanes. The authors concluded from these results that due to the amount of time that was spent in the pool and the vigorous exercise that that athletes were experiencing, 80% of the trihalomethanes were entering the body through absorption through the skin rather than being inhaled. The problem in applying the results of this survey to a more general population is that the participants of this study were all young college athletes which may not display the same physical characteristics or activity levels as your

average swimmer at a public swimming pool. Also, there were only two swimmers examined which means that the sample size was quite small.

One study examined a larger group of people and they examined occupational exposure rather than athletes. In this study by Fantuzzi et al (2000), the authors examined the trihalomethane levels in the breath of the employees in swimming facilities. They selected a range of occupations from trainers, who will spend a large amount of time by the poolside, to receptionists to technicians, who would spend more time in the machine room. The authors found that there was indeed a correlation between the ambient trihalomethane levels and the amounts in the employees' breaths. They found that men and women showed similar levels when compared to one another and that smokers and non-smokers also showed similar levels. The problem with all of these studies is that since the effects of trihalomethanes are more long-term in nature, there are no studies which connect the levels of trihalomethanes to negative health effects in the pool environment. Instead these studies rely on previous studies done with trihalomethanes in drinking water to support possible health effects.

Similarly to the work on trihalomethanes, there are several studies which examine the effect of chloramines on athletes. One such study by Levesque et al (2006) compared young swimmers to young soccer players. It was found that the swimmers had far more respiratory complaints compared to the soccer players. The authors were able to establish that there was link between elevated chloramines levels and a rise in the number of respiratory complaints. Unlike trihalomethanes there are many reports of chloramines causing immediate and measureable health effects. As stated previously, chloramines are irritants which can seriously affect the respiratory system.

In one study, the authors examined 216 exposures to chloramines gas in the home (Mrvos, Dean and Krenzelok, 1993). These exposures chloramines had resulted from the mixing of home cleaning agents such as ammonia and bleach, but it helps to illustrate the potential for chloramines to cause harm. Symptoms ranged from coughing and shortness of breath to abdominal pain and vomiting. 71 of the people had to receive care at a medical facility and one person had to be hospitalized. One of the first thorough studies conducted to measure chloramines in indoor pools was conducted by Hery et al

(1994). The authors conducted a survey of 13 swimming centres where complaints about eye and irritation had taken place. What the authors found was that swimming pools which contained recreational apparatuses such as bubbling pools and slides showed higher levels of chloramines. One thing that this study fails to do however, is that although they discussed the correlation between chloramines and eye irritation complaints, they did not provide any data. Contaminants other than chloramines were relatively low. The authors proposed a "comfort limit" of 0.5mg/m3 since they did not conduct any investigation of the effects of chloramines beyond its irritating properties.

There are numerous examples of the health impact of chloramines. One study was conducted by Kaydos-Daniels et al (2008). The authors examined the guests of a hotel which had an indoor swimming pool. The cases were defined as a guest of the hotel from 5–6 October 2002 and who experienced three or more symptoms associated with chloramines exposure on either of those two days. 32 individuals were found who met the case definition out of 128 individuals interviewed. The most common symptoms among the cases were cough, eye irritation, throat irritation, difficulty breathing and rash. It appeared that attendees of a pool party were the ones who were affected and they did not necessarily have to swim to experience the symptoms since the bystanders experienced them also. The authors were able to associate quite strongly the relationship between presence at the pool party and symptoms of chloramines exposure.

Among newer studies, there is evidence that chloramines also cause chronic diseases such as asthma. In one study, the authors were able to link regular visits to pools with increased likelihood of developing asthma in children (Bernard et al, 2007). The results are quite dramatic as there is a marked rise in the percentage of children with asthma when compared to the cumulative amount of time they spent at the pool as seen in figure 3. Similarly another study demonstrated that occupational exposure was also capable of causing asthma even when the worker did not enter the water (Thickett et al, 2002). From this evidence and the data available describing the acute effects of chloramines, it can be concluded that chloramines definitely pose a health hazard as a component of indoor air in swimming pools.

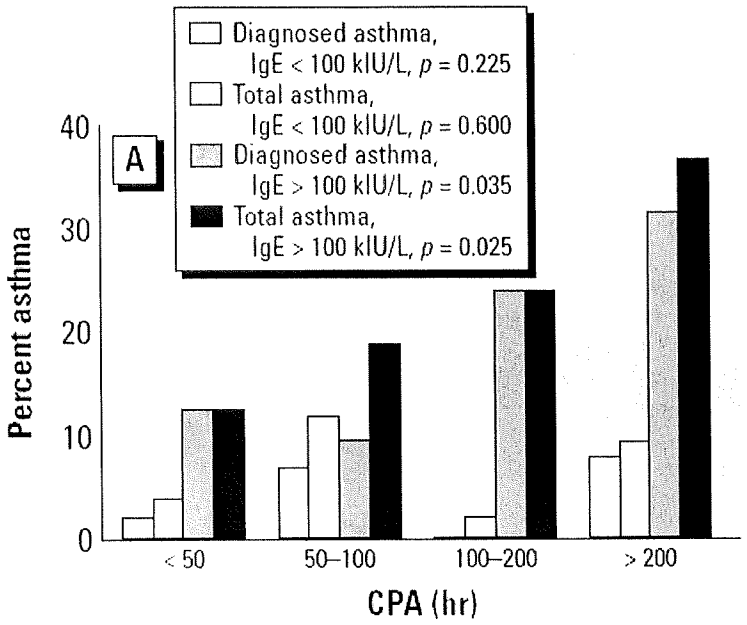

Figure 3. Prevalence of doctor diagnosed asthma in children with low to high IgE levels (Bernard et al, 2007)

Purpose of Study

The purpose of this research project was to try and determine during which times are the levels of volatile organic compounds were the lowest during the course of a regular operating day for a public swimming pool through the use of a direct reading instrument and perhaps whether a significant difference could be detected at all.

H_o: There is no difference in the VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a hand held VOC meter.

H_a: There is a difference in the VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a handheld VOC meter

Another question that was answered in conjunction with the main research question was whether there is a measureable relationship in the amount of VOCs as compared to the total chlorine levels within the pool. Also, through collecting samples consistently from the same areas of the pool and from different distances from the pool surface one was able to determine whether there was a significant difference between the levels of VOCs close to the breathing zone of the swimmers and the breathing zone of the bystanders in the pool facility.

Study Design

The project involved taking VOC readings in an indoor pool over the period of a day. As the day progressed, there could have been a build up of contaminants within the pool as more and more bathers and swimmers entered. With this increase in contaminants, there could have possibly been an increase in the amount of VOCs produced through the increased amount of interactions with the chlorine. In order to detect VOCs in a gaseous phase, there were several methods which could have been used. However, many of these methods involved analytical chemistry methods which would have required specialized laboratory equipment and a significant time investment, such as gas chromatography spectrometry.

The method used involved using a direct reading instrument. This is a handheld unit which is capable of detecting a variety of volatile organic compounds via a photoionization detector. The instrument that was used was the ppbRae 3000. According to the Rae Systems technical support, this instrument is capable of detecting both chloramines and trihalomethanes (personal communication with Rae Systems technical support, September 23, 2009). However, the limitation with this method was that there was no way to quantify the amounts of VOCs or identify them since the gases were in an unknown mixture. However, if only the proportions of VOCs are needed, then this should not have interfered in the execution of this research project.

Materials

Item	**Purpose**
ppbRAE 3000	Direct reading instrument for taking the actual VOC measurements
Tape Measure	For determining the different distances from the surface of the pool
Pen	For recording the data
Data Sheet	For recording the data

Table 1. Table of materials used

With the simplicity of the method, there was not a great deal of materials required to carry out this project. The main piece of equipment required for the chosen procedure was the direct reading instrument itself. The model that was available at BCIT and the one used was the ppbRAE 3000 made by RAE systems. The pbbRAE 3000 is an instrument with high sensitivity with an accuracy of 10ppm to 2000ppm: ±3% at calibration point. It detects volatile organic compounds through the use of a photo-ionization detector (ppbRAE 3000 User's Guide, 2007). The photo-ionization detector uses UV light in order to excite gases into ions and these ions then forms a current which is measured (Chou, 1999). The amount of current is directly proportional to the amount of gases present and which gases are excited is dependent upon the wavelength of the UV light used (Chou, 1999). As such a sensitive instrument, consistent methodology was followed in order to ensure that the results were valid. As a hand held instrument the positioning of the device would have greatly affected the results. Exact product specifications may be found in Appendix B. Other miscellaneous materials that were required for this project included a tape measure, paper and a pen.

Experimental Procedure

The pool visited was the Eileen Dailly Leisure Pool in Burnaby. The first samples were taken at 6am in the morning, which was the opening time for the pool, and then the subsequent samples were taken every three hours until 9pm for a total of six testing periods. These times were chosen to reflect the periods of activity that a pool might experience. Prior to opening, the pool should have been at its cleanest point with the lowest levels of organic materials which may contribute to VOC production (De Graaf, MacKinnon, and Marsh, 2005). Gradually as the day wore on and more pollutants were introduced into the water by bathers, the changes in VOC levels would have been captured by the different sampling windows. The different distances that were measured were set at 10cm above the surface of the water, 1 metre away, 3 metres away and 6 metres away from the surface of the water. These distances were chosen to reflect the different distances at which people may be exposed to VOCs originating from the pool. The smallest distance at ten centimetres, directly above the water surface, is the breathing space occupied by a person when they are actually swimming (Euro Chlor, 2009). The

other distances were chosen to emulate the places that employees and spectators might maintain. A control sample was taken from immediately outside the pool as well to establish VOC baselines in the surrounding environment. For each sampling distance and time period, three individual readings were taken to increase the statistical power of this research project.

The following are step by step experimental procedures and refer to figure 4 for reference on sampling locations

1. A reading was taken outside and then another reading was taken on another side of the building and finally the last replicate reading was taken on the third side of the building.
2. Next, a reading was taken from 10 cm above the pool, afterwards the second reading was taken from another side of the pool, and finally the last reading was taken from a third side of the pool.
3. Step 2 was repeated for 1m, 3m and 6m away from the side of the pool
4. Steps 1, 2 and 3 were repeated for each testing period every three hours.

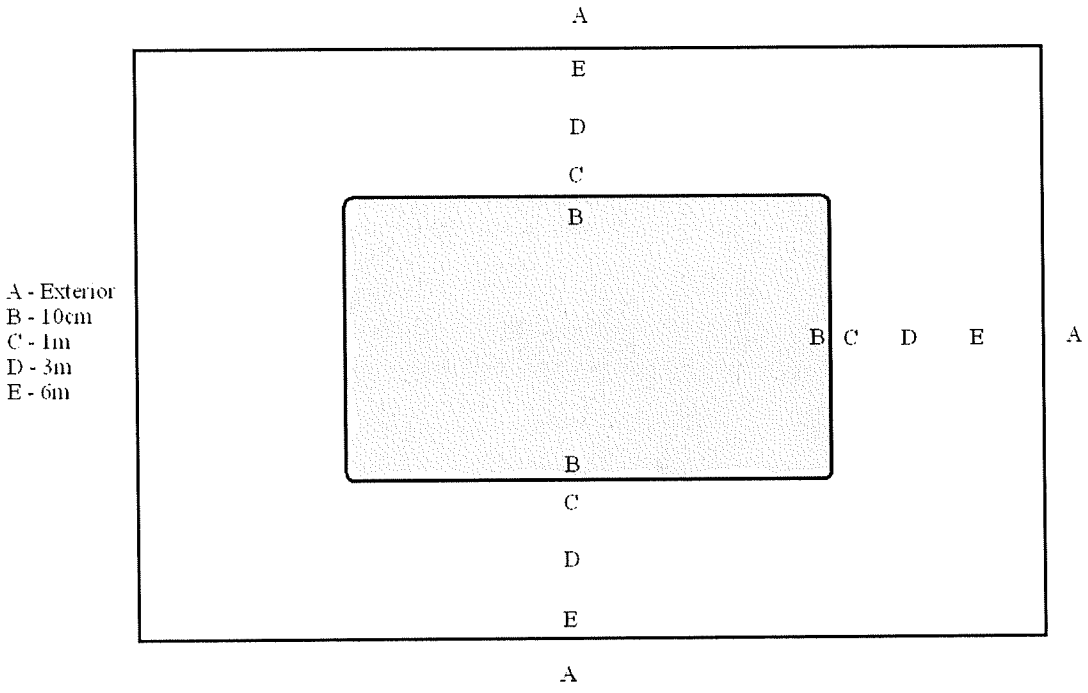

Figure 4. This is diagram showing a representation of locations within the pool as well as the different distances used.

The following are the step by step instructions on how to take the actual readings

1. Turned on the instrument by pressing and holding the MODE button until the display turned on.

2. The instrument was then zeroed by taking a measurement away from VOC sources in the middle of a field and was set to zero.
3. After calibration, the instrument began measuring VOC levels. The instrument was placed in the sampling location and the readings were recorded in the data entry sheet. See Appendix A
4. After readings were completed one pressed and held MODE to turn off the instrument.

Justification of Method Selected

The advantages of using a direct reading instrument were ease of use, rapid data acquisition and cost if the instrument was previously available. Also, a direct reading instrument provided a real time reading of the VOC levels within the air (ppbRAE 3000 User's Guide, 2007). However, there were significant disadvantages to a direct reading instrument. The first and perhaps greatest disadvantage was that you were unable to identify which gases were being detected. Also, since the gases examined for this project were complex mixtures which were not characterized by the manufacturer of the instrument, the quantitative data produced by the instrument were possibly inaccurate as well. The instrument was unable to separate the gas mixture and measure each gas separately. However, since the purpose of this project was to determine the change in VOC levels rather than the absolute VOC levels, the relative data can still be relied upon. Therefore, the data produced by the instrument is still considered valid for its content since it is representative of what we were trying to measure, but the data is invalid for its face value since it is possibly inaccurate.

Alternate Methods

Rather than using a direct reading instrument like the ppbRAE 3000, alternate methods could have been used to determine the airborne VOC concentrations. One such method was used by Yli-Pirilä *et al.* (2002) for their study of air quality in pools. This method involved using air pumps and adsorbing the VOCs onto a solid phase. This allowed the authors to sample a specific volume of air. Then, back in the laboratory, the VOC's were desorbed using heat and fed into a gas chromatograph (GC) coupled with a mass spectrometer (MS). The authors were able to identify the individual compounds using the mass spectrum produced. With this method, unlike the direct reading instrument, the authors were able

to identify VOCs as well as quantify them. This method is similar to Standard Method 18 of the US Environmental Protection Agency.

EPA Standard Method 18 is analysis of VOC by GC (EPA, 2007). In this method, rather than using GC-MS to indentify and quantify the compounds, several different detectors may be used. Detectors such as flame ionization detection and electron capture detection may be used in conjunction with the gas chromatograph. However, the problem with these detection methods is that they do not identify the compounds, unlike the mass spectrometer. The identification of the compounds would be accomplished by comparing the retention times from the sample chromatograph that one obtained from analyzing a standard which has been previously prepared. The sample gathering techniques that may be employed with this method include direct interface, dilution interface, adsorption tube, and Tedlar bag sampling.

The two methods used by Yli-Pirilä and the EPA shared similar advantages and disadvantages. While these methods tend to be far more accurate than the direct reading instrument, they are also far more complex. The sampling techniques require far more time and specialized equipment, such as pumps and filters. In order to collect the samples in an appropriate period of time, more than one sample would have had to be collected simultaneously which meant more than one person working. Also, the analytical instrument, the gas chromatograph is an expensive piece of machinery and requires much more time to analyze each sample. While gas chromatographs and various detectors are available at BCIT, they have not necessarily been configured properly and supervision from experienced personnel would been required in their operation. Due to these factors, limited time and finances, and the availability of equipment, the direct reading instrument method was chosen as the method of choice.

Inclusion and Exclusion Criteria

The first inclusion criterion was a single public indoor swimming pool that is open to the general public. The second criterion was that the pool must use chlorine within the pool. The method of chlorination does not matter. Exclusion criteria are swimming pools that are not open to the general public and outdoor swimming pools.

Reliability and Validity

With a handheld instrument there were increased reliability issues. With respect to reliability, there are internal consistency and test-retest issues, but inter-rater and equivalent forms reliability problems should not be significant. The internal consistency and the test-retest reliability issues arose due to the fact that the instrument was portable and there were a wide range of factors in the environment that simply cannot be controlled. However, there were steps that were taken to minimize these effects and maximize the reliability. These steps are detailed below. The inter-rater and equivalent forms reliability issues should have been low since there was only one operator.

A pilot study was conducted prior to the main study. This involved going to the actual pool location and preliminary readings were taken at the desired locations. The purpose of the pilot study was to ensure that the chose experimental method was effective and appropriate for the experimental design which would increase study validity.

In order to increase the reliability of the experiment, the position of the instrument was crucial. Besides the distance from the pool water variable, which was considered as part of the experiment, the position of the instrument in relation to other objects in the area could have also affected the reading. This arose from the differences in air flow that may have occurred due to the presence of those objects or the fact that those objects released VOCs themselves. In order to account for this error, the way that the instrument was held was always the same. Whenever a reading was to be taken, the instrument was held 1.5 metres above the surface of the floor and 30 cm away from the body with the exception of the 10 cm reading, which was taken exactly 10 cm over the actual water surface. The analyzing end of the instrument was pointed directly away from the body towards the pool. Therefore the back of the instrument handler always faced away from the pool.

Prior to commencing the measurements all the locations at the chosen pool for measurements were predetermined and noted. The distances for the locations were measured with a flexible tape measure to ensure that all distances were accurate. The selection of the sample points was determined during the initial examination of the pool environment. Since there were three sampling sites at each

distance those sites were be chosen so that they are spread evenly apart and did not have any objects near them that may have interfered with air flow.

The measurements were taken as quickly as possible without sacrificing quality. This was important since one of the parameters being tested was the change of VOCs over time. Finally, the instrument was calibrated before taking measurements in order to increase the validity of the measurements.

Therefore, in essence, the reliability of the study was increased since the samples were taken in the same location, at the same times, at the same distances from the pool, at the same pool and by the same researcher.

The large number of sample readings that were taken increased the validity of the study. There were 90 readings in total which allowed the statistical analysis to detect significant differences.

There have not been any previous studies which have been completed that were similar to this study. Therefore, it is not possible to increase the validity or reliability of this study by using previously proven methods.

Calibration and Instrumentation

The first task that was carried out prior to beginning the measurements was to calibrate the instrument. The ppbRAE 3000 is capable of a variety of different calibration modes but the one that was used for this project is known as the zero calibration. This calibration is basically setting the zero point for the instrument. This was done by sampling some air that was considered clean and setting the instrument to zero for that air. For this project, this procedure was done prior to taking any readings by taking a zeroing outside away from any sources of VOCs such as traffic, building and trees. Refer to Appendix E for calibration procedures.

Ethical Considerations

Permission was obtained from the Eileen Dailly Leisure Pool & Fitness Centre in north Burnaby to carry out the measurements at their facility. I will share the results with them after the completion of the project. They did not request that the data be kept confidential so the results of the project can be freely shared.

Results

Descriptive Statistics

The data that was generated by this study was numerical in nature. As such, descriptive statistics were compiled. For this project, the descriptive statistics features the means, modes, medians, ranges and standard deviations were calculated by Microsoft Office 2007. Below in Table 2 is the descriptive data generated for the exterior readings. The full raw data sets as well as the other full descriptive statistics charts are included in Appendix A.

With the current experimental design there were effectively two different sets of data. One set of data corresponded to the different distances and the other set corresponded to the differing times.

Outside Control					
Mean	9.56	**Sample Variance**	191.08	**Maximum**	30.00
Standard Error	3.26	**Kurtosis**	-1.53	**Sum**	172.00
Median	0.00	**Skewness**	0.79	**Count**	18.00
Mode	0.00	**Range**	30.00		
Standard Deviation	13.82	**Minimum**	0.00		

Table 2. Sample descriptive statistics table for outside control measurements

Inferential Statistics

In order to test the hypothesis inferential statistics were used. In this case, a one way analysis of variance (ANOVA) was used, which is a parametric test. ANOVA would have been able to determine if there was a significant difference between three or more means which in this case were the readings for different time periods (ENVH 8400 Manual, 2008). However, there were a few assumptions that had to

be met in order for the ANOVA analysis to be correct. They were that the data must be normally distributed, the data must be independent and the variances must be equal. The data for this project was indeed independent due to the way it was collected, but its normality and variance must be determined.

This analysis was carried out using the computer program NCSS 2007. The full results printout was included in Appendix C. The assumptions of the ANOVA test were met. The results from the ANOVA performed on the data obtained from the different time periods showed that indeed there was indeed a significant difference among the different time periods. The p-value was so low that NCSS displayed it as 0.000000. This was well below the α value of 0.01. Therefore, the null hypothesis that there was no difference in the VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a hand held VOC meter was rejected. The post-hoc tests revealed that the readings from 6 am, 12 pm, and 3 pm were significantly different from the readings at 9am, 6pm and 9pm. However, the readings at 6 am, 12 pm and 3pm are not significantly different from one another and the same applies for 9 am, 6 pm and 9 pm.

Post-Hoc Test Results							
	6:00 AM	**9:00 AM**	**12:00 PM**	**3:00 PM**	**6:00 PM**	**9:00 PM**	S = Significant Difference
6:00 AM	XXXXXX	S	NS	NS	S	S	
9:00 AM	S	XXXXXX	S	S	NS	NS	
12:00 PM	NS	S	XXXXXX	NS	S	S	
3:00 PM	NS	S	NS	XXXXXX	S	S	
6:00 PM	S	NS	S	S	XXXXXX	NS	NS = No Significant Difference
9:00 PM	S	NS	S	S	NS	XXXXXX	

Table 3. Post-hoc test results showing significant differences between the different time periods.

Correlation Analysis

Another portion of the inferential statistics that was carried out was a correlation analysis for the data regarding the different distances. This analysis was again conducted through NCSS on the obtained data. A regression analysis allowed us to determine whether the correlation between the

distance from the pool and the level of VOCs produced (Zar, 1999). The full analysis is included in appendix D.

The correlation analysis revealed that there was no relationship between the different distances and the levels of VOCs. The r value, the correlation coefficient, was determined to be 0.1278. This means that there was not a significant degree of relationship between the two factors (ENVH 8400 Manual, 2008). The r^2 value was 0.0163 which means that only 1.63% of the variation in values can be accounted for by knowing the other value. The p-value for the t-test to test the H_0 of r being zero was 0.2299 which is greater than 0.05. Therefore the null hypothesis of r = 0 was not rejected. Since there was not a significant degree of relationship, any slopes and intercepts that were obtained from the linear regression are not valid.

Possible Errors and Power

Power is the probability of detecting a significant difference when one actually occurs (ENVH 8400 Manual, 2008). With such a low p-value the power of the ANOVA was also very high and calculated by NCSS to be 1.000000. Ideally, the power should be greater than 0.80. With such a high power the β or type II error is negligible since β error is equal to 1 minus the power and therefore, in this I case, equal to almost zero. α errors or Type I are not a concern since this error becomes a concern when your p-value is between 0.01 and 0.05. With the α set at 0.01, this error was minimized

Discussion

The results from the experimental procedures resulted in the rejection of the null hypothesis that there was no difference in the VOC levels during the different times of day within an indoor swimming pool's atmosphere when measured by a hand held VOC meter. If the results featured in Appendix A are to be interpreted literally, they would suggest that the indoor air quality in an indoor

pool is the worst at 9 am, 6 pm and 9 pm when measured according VOC levels. However, when examined more carefully, it can be seen that the results are not as simple as that.

A possible explanation for the results observed could be that those times which feature significantly higher levels of VOCs than the others are periods of peak activity or perhaps times immediately following the periods of peak activity when there are the highest concentrations of chlorination by-products from the increased number of bathers. Another possible explanation could be that fluctuations in the exterior levels of VOCs contributed to the differences in the levels detected in the pool. Examining the results seen in Appendix A, the latter explanation seems to be the most likely. It is observed that for the time periods where the VOC levels are elevated in the interior of the pool, the levels of VOCs detected where also elevated for the exterior except for the very last reading at 9 pm. This therefore suggests that there is in fact no significant change in the levels of VOCs derived from the pool itself throughout the day except for the very last testing period at 9 pm since that is when even though the exterior VOC levels were low; the interior VOC levels were still elevated.

With this interpretation of the results, it would suggest that the levels of VOCs within an indoor pool are heavily influenced by the exterior levels of VOCs. Therefore, this would further suggest that pools do not pose a significant health hazard since the levels of VOCs are not so different from what you would find outdoors. This is in contrast to much of the previous research which point to the additional negative effects of exposure to the pool environment such as respiratory illness and asthma. On the other hand, there is the data obtained from the readings at 9 pm which shows that there are periods during which the VOC levels within the indoor pool environment becomes elevated which would suggest that people who spend long periods of time in and around pools may still suffer from negative health effects such as employees of pools and athletes due to encountering these elevated levels of VOCs.

The correlation analysis revealed that there was no relationship between the distance from the water surface and the levels of VOCs. This means that at the pool tested, there was sufficient airflow to

evenly distribute the VOCs within the environment. This means that there is no significant difference in inhalation exposure for the people who may be in the pool and people on the sidelines. This would support the view that swimmers and people who work around the pool will suffer similar degrees of health risk to their lungs. Previous studies have shown that both athletes and worker suffer from similar problems

Limitations

Besides the possible statistical errors as mentioned above, there are several other limitations present within the design of this project. One of the biggest limitations is imposed by the direct reading instrument itself. It is incapable of distinguishing the different varieties of VOCs. This means that it is unable to determine the origin of the VOCs that it is detecting. If it had such a capability, then one would be able to determine what proportion of VOCs detected is from external sources such as combustion and swimming pool sources such as chlorination by-products, the desired parameter. Also, since this is a handheld instrument, there are inherent inaccuracies in its readings. This is especially true in an extremely high humidity environment of a swimming pool. Even though calibrations were performed, the calibration gas is different from the pool atmosphere in water content and temperature. There is no way to correct for this unless one can obtain a calibration gas which is heated and at 100% humidity like the air of a pool.

Another limitation is the fact that only one swimming pool was examined over the period of one day. Since each swimming pool is unique, differing air flow patterns combined with different pool layouts will affect VOC levels at any one location. Also, since there is evidence that the exterior VOC levels will affect interior VOC levels, the surroundings of a pool will also affect its VOC level. Finally, because this study was conducted on only a single day, the usage pattern of that day may not be typical of a regular day. It is not possible to rule out aberrations from normal usage with only one day observed.

Conclusions

Overall, the results from this project supports the view that there may be some differences in VOC exposure depending on what time of the day you visit the pool. It also suggests that exterior levels of VOCs plays a very important role in the levels found in the interior presumably because there is significant air exchange between the inside and outside. Finally, there is evidence which suggests that no matter where you are within a pool, the VOC exposure will be similar. However, due to the limitation of the study, one cannot definitively support these conclusions.

Recommendations

There are some recommendations that may be derived from the results of this study. Since it was inconclusive that levels of VOCs were elevated within the pool, one would not suggest personal protective equipment (PPE) be used for employees. PPE would be too cumbersome and impractical for the working environment and for what pool employees have to do. Trainers and lifeguards have to be able to dive into the water at a moment's notice to save people and PPE would hinder that ability. Therefore, PPE usage would not be justified by the risk. For individuals who spend a great deal of time in the pool, such as athletes, exposure to VOCs is unavoidable due to the nature of indoor pools. Indeed due to the elevated breathing rate and their proximity to the water surface, athletes may be more at risk than workers, but since the data is inconclusive and so limited, such a claim cannot be considering anything beyond speculation.

On the other hand, since there were instances where elevated levels of VOCs found within the pool, here are some suggestions on practical ways to reduce VOCs within indoor pools. One way would be simply to reduce the quantity of contaminants that gets introduced in to the pool. This can be accomplished by regulating the number of people that can enter the pool or enforcing strict bathing procedures prior to entering the pool. Another method would be to use additional water cleansing methods such as ozonation. This removes the contaminants from the water prior to contact with

chlorine and therefore less chlorination by-products are formed. Finally, increased ventilation would be beneficial and prevent the build up of VOCs within the pool. However, this recommendation is made on the assumption that the pool is not located in an area where the exterior VOC levels are highly elevated.

Future Studies

Possible future studies mirror the limitations previously mentioned of this current study. Therefore, the first recommendation would be to address the limitation of the instrument. One way would be to use a different detection method such as adsorbent tubes coupled with GC-MS. However, this would make the project much more complicated and labour intensive. Another way to address the limitation might be to use a different calibration gas which has been specifically made to mimic a swimming pools environment. Therefore the calibration would become more valid along with the results obtained. There are also different varieties of bulbs that can be used with the photoionization detector. Those different bulbs may provide better results from the standard bulb of the instrument.

As an expansion of this research project, different pools need to be tested over a longer period of time. This will exponentially increase the amount of labour associated with the project but performing such an experiment would greatly increase the validity of the results. One would be able to confirm whether or pools shared similar VOC characteristics and whether there are different usage patterns throughout a week and whether or not these differing usage patterns will result in different VOC levels.

Other possible future projects include the examination of the relationship between ventilation rates and VOC levels, the correlation between combined chlorine levels and VOC levels, a comparison of VOC levels between pools that use different filtration and chlorination methods and finally there could be an examination of the relationship between the levels VOCs and the air temperature, water temperature and humidity of a indoor pool.

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Appendices

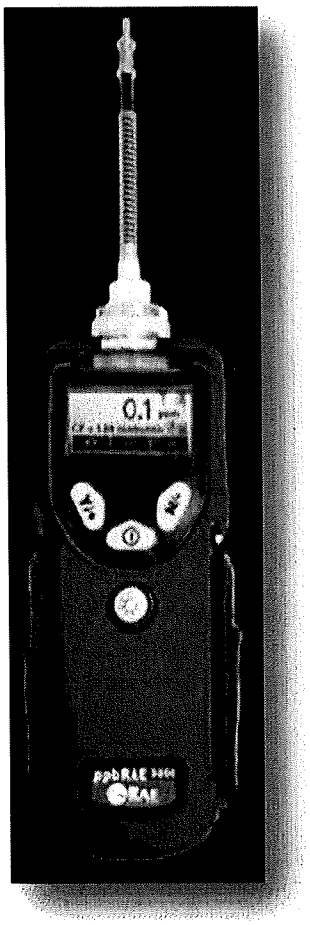
Appendix A: Raw Data Table and Descriptive Statistics

Times	Distances (m)				
	Outside	**0.1**	**1**	**3**	**6**
6:00 AM	0	8	8	10	11
	0	18	18	18	19
	0	36	13	16	12
9:00 AM	29	50	46	46	35
	28	70	53	52	52
	30	52	40	37	39
12:00 PM	0	3	10	0	0
	0	1	0	0	5
	0	0	2	3	1
3:00 PM	0	35	24	26	45
	0	0	0	0	0
	0	10	0	20	30
6:00 PM	29	65	55	57	25
	30	52	50	46	56
	25	20	14	29	29
9:00 PM	0	40	30	38	60
	1	93	54	57	58
	0	65	60	58	54

	Distances				
	Outside	*0.1*	*1*	*3*	*6*
Mean	9.56	34.33	26.50	28.50	29.50
Standard Error	3.26	6.69	5.20	4.98	5.06
Median	0.00	35.50	21.00	27.50	29.50
Mode	0.00	52.00	0.00	0.00	0.00
Standard Deviation	13.82	28.40	22.04	21.14	21.48
Sample Variance	191.08	806.35	485.79	446.85	461.44
Kurtosis	-1.53	-0.85	-1.64	-1.45	-1.46
Skewness	0.79	0.38	0.23	0.01	-0.01
Range	30.00	93.00	60.00	58.00	60.00
Minimum	0.00	0.00	0.00	0.00	0.00
Maximum	30.00	93.00	60.00	58.00	60.00
Sum	172.00	618.00	477.00	513.00	531.00
Count	18.00	18.00	18.00	18.00	18.00

	Times					
	6:00 AM	9:00 AM	12:00 PM	3:00 PM	6:00 PM	9:00 PM
Mean	12.47	43.93	1.67	12.67	38.80	44.53
Standard Error	2.41	2.96	0.71	4.08	4.16	6.93
Median	12.00	46.00	0.00	0.00	30.00	54.00
Mode	0.00	52.00	0.00	0.00	29.00	0.00
Standard Deviation	9.32	11.47	2.77	15.80	16.13	26.83
Sample Variance	86.84	131.50	7.67	249.67	260.17	719.98
Kurtosis	1.84	0.32	5.61	-0.79	-1.50	-0.08
Skewness	0.80	0.49	2.26	0.80	0.13	-0.53
Range	36.00	42.00	10.00	45.00	51.00	93.00
Minimum	0.00	28.00	0.00	0.00	14.00	0.00
Maximum	36.00	70.00	10.00	45.00	65.00	93.00
Sum	187.00	659.00	25.00	190.00	582.00	668.00
Count	15.00	15.00	15.00	15.00	15.00	15.00

Appendix B: Instrument Specifications



ppbRAE 3000

Detector Specifications

Size 10" L x 3.0" W x 2.5" H (25.5 cm x 7.6 cm x 6.4 cm)

Weight 26 oz (738 g)

Sensors Photoionization sensor with standard 10.6 eV or optional 9.8 eV or 11.7 eV lamps

Battery • Rechargeable, external field-replaceable Lithium-Ion battery pack
• Alkaline battery adapter

Operating Hours 16 hours of operation (12 hours with alkaline battery)

Display Graphic 4 lines, 28 x 43 mm, with LED backlight for enhanced display readability

Keypad 1 operation and 2 programming keys, 1 flashlight on/off

Direct Readout Instantaneous reading
• VOCs as ppm by volume
• High values
• STEL and TWA
• Battery and shutdown voltage
• Date, time, temperature

Alarms 95dB at 12" (30 cm) buzzer and flashing red LED to indicate exceeded preset limits
• High: 3 beeps and flashes per second
• Low: 2 beeps and flashes per second
• STEL and TWA: 1 beep and flash per second
• Alarms latching with manual override or automatic reset
• Additional diagnostic alarm and display message for low battery and pump stall

EMI/RFI Highly resistant to EMI/RFI
Compliant with EMC Directive 2004/108/EC

IP Rating • IP67 unit off and without flexible probe
• IP65 unit running

Datalogging Standard 6 months at one-minute intervals

Calibration Two-point or three-point calibration for zero and span. Calibration memory for 8 calibration gases, alarm limits,

span values and calibration dates

Sampling Pump • Internal, integrated flow rate at 500 cc/mn
• Sample from 100' (30m) horizontally and vertically

Low Flow Alarm • Auto pump shutoff at low-flow condition

Communication • Download data and upload instrument set-up from PC through charging cradle or optional Bluetooth™
• Wireless data transmission through built-in RF modem

Frequency 902 to 928 MHz (license-free), 2.400 to 2.4835 GHz (license-free), 433 MHz, 869 MHz

RF Range Up to 500' (152m; 900 MHz, 433 Mhz, 869 Mhz), extendable with RAELink3 Repeater to 2 miles (3.2km)

Hazard Area • US and Canada: , Classified as Intrinsically Safe

Approval for use in Class I, Division 1 Groups A, B, C, D
• **Europe:** ATEX II 2G EEx ia IIC T4

Temperature -4° to 113° F (-20° to 50° C)

Humidity 0% to 95% relative humidity (non-condensing)

Attachments Durable black rubber boot

Warranty 3 years for 10.6 eV lamp, 1 year for pump, battery, sensor and instrument

Sensor Specifications

Range	Resolution	Response Time T90
0 to 9999 ppb	1 ppb	< 3 s
10 to 99 ppm	0.01 ppm	< 3 s
100 to 999.9 ppm	0.1 ppm	< 3 s
1000 to 9999 ppm	1 ppm	< 3 s

Appendix C: Full NCSS ANOVA Report

Analysis of Variance Report
Page/Date/Time 1 06/03/2010 10:31:30 PM
Database
Response Reading

Tests of Assumptions Section

Assumption	Test Value	Prob Level	Decision (0.01)
Skewness Normality of Residuals	-0.8311	0.405906	Accept
Kurtosis Normality of Residuals	2.4980	0.012490	Accept
Omnibus Normality of Residuals	6.9308	0.031261	Accept

Analysis of Variance Table

Source Term	DF	Sum of Squares	Mean Square	F-Ratio	Prob Level	Power (Alpha=0.01)
A: Time	5	26720.19	5344.038	22.02	0.000000*	1.000000
S(A)	84	20381.47	242.6365			
Total (Adjusted)	89	47101.66				
Total	90					

* Term significant at alpha = 0.01

Kruskal-Wallis One-Way ANOVA on Ranks
Hypotheses
H0: All medians are equal.
Ha: At least two medians are different.

Test Results

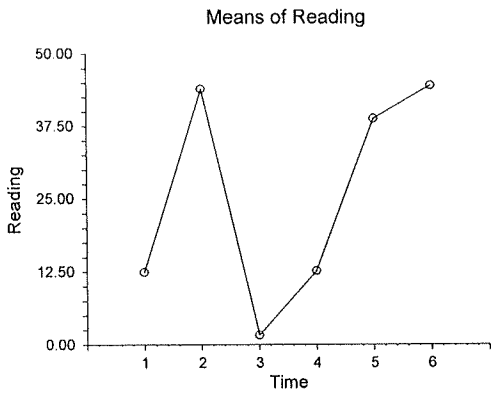
Method	DF	Chi-Square (H)	Prob Level	Decision(0.01)
Not Corrected for Ties	5	49.82838	0.000000	Reject H0
Corrected for Ties	5	50.49255	0.000000	Reject H0
Number Sets of Ties	20			
Multiplicity Factor	9588			

Group Detail

Group	Count	Sum of Ranks	Mean Rank	Z-Value	Median
1	15	489.00	32.60	-2.0950	12
2	15	995.00	66.33	3.3833	46
3	15	272.00	18.13	-4.4443	0
4	15	436.50	29.10	-2.6634	0
5	15	923.50	61.57	2.6092	30
6	15	979.00	65.27	3.2101	54

Database
Response Reading

Plots of Means Section



Fisher's LSD Multiple-Comparison Test

Response: Reading
Term A: Time

Alpha=0.010 Error Term=S(A) DF=84 MSE=242.6365 Critical Value=2.6356

Group	Count	Mean	Different From Groups
3	15	1.666667	5, 2, 6
1	15	12.46667	5, 2, 6
4	15	12.66667	5, 2, 6
5	15	38.8	3, 1, 4
2	15	43.93333	3, 1, 4
6	15	44.53333	3, 1, 4

Notes:
This report provides multiple comparison tests for all pairwise differences between the means. When this procedure is used only after the F-test associated with this term is significant at the same error rate, these tests are approximately accurate.
When the F-test associated with this term is ignored, this procedure does not account for the multiplicity of tests. In either case, the Tukey-Kramer test is better.

Database
Response Reading

Newman-Keuls Multiple-Comparison Test

Response: Reading
Term A: Time

Alpha=0.010 Error Term=S(A) DF=84 MSE=242.6365

Group	Count	Mean	Different From Groups
3	15	1.666667	5, 2, 6
1	15	12.46667	5, 2, 6
4	15	12.66667	5, 2, 6
5	15	38.8	3, 1, 4
2	15	43.93333	3, 1, 4
6	15	44.53333	3, 1, 4

Notes:
This report provides multiple comparison tests for all pairwise differences between the means. According to Hsu(1996, page 127), the specified family-wise error rate (alpha) is overstated and the Tukey-Kramer method is recommended instead.

Scheffe's Multiple-Comparison Test

Response: Reading
Term A: Time

Alpha=0.010 Error Term=S(A) DF=84 MSE=242.6365 Critical Value=4.0269

Group	Count	Mean	Different From Groups
3	15	1.666667	5, 2, 6
1	15	12.46667	5, 2, 6
4	15	12.66667	5, 2, 6
5	15	38.8	3, 1, 4
2	15	43.93333	3, 1, 4
6	15	44.53333	3, 1, 4

Notes:
This report provides multiple comparison tests for all possible contrasts among the the means. These contrasts may involve more groups than just each pair, so the method is much stricter than need be. The Tukey-Kramer method provides more accurate results when only pairwise comparisons are needed.

Database
Response Reading

Tukey-Kramer Multiple-Comparison Test

Response: Reading
Term A: Time

Alpha=0.010 Error Term=S(A) DF=84 MSE=242.6365 Critical Value=4.9228

Group	Count	Mean	Different From Groups
3	15	1.666667	5, 2, 6
1	15	12.46667	5, 2, 6
4	15	12.66667	5, 2, 6
5	15	38.8	3, 1, 4
2	15	43.93333	3, 1, 4
6	15	44.53333	3, 1, 4

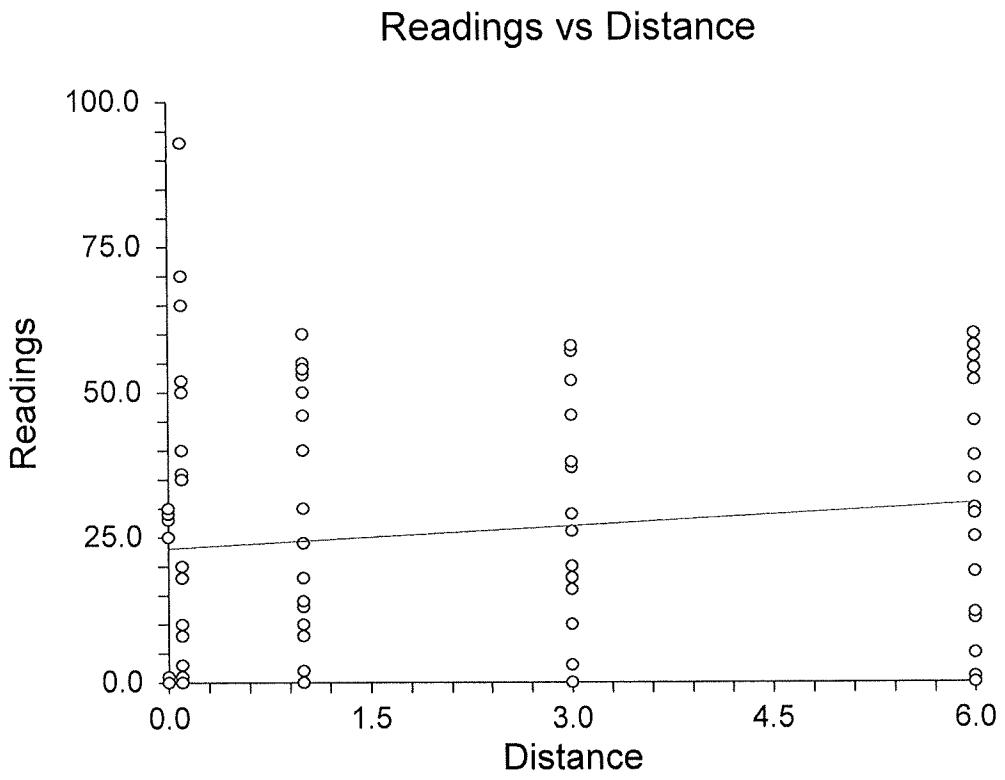
Notes:
This report provides multiple comparison tests for all pairwise differences between the means.

Appendix D: Full NCSS Correlation and Regression Report

Linear Regression Report

Page/Date/Time 1 06/03/2010 11:01:46 PM
Database
Y = Readings X = Distance

Linear Regression Plot Section



Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	Readings	Rows Processed	90
Independent Variable	Distance	Rows Used in Estimation	90
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	23.0678	Rows Prediction Only	0
Slope	1.2921	Sum of Frequencies	90
R-Squared	0.0163	Sum of Weights	90.0000
Correlation	0.1278	Coefficient of Variation	0.8936
Mean Square Error	526.5013	Square Root of MSE	22.94562

Linear Regression Report

Page/Date/Time 2 06/03/2010 11:01:46 PM
Database
Y = Readings X = Distance

Regression Estimation Section

Parameter	Intercept B(0)	Slope B(1)
Regression Coefficients	23.0678	1.2921
Lower 95% Confidence Limit	16.6249	-0.8318
Upper 95% Confidence Limit	29.5106	3.4160
Standard Error	3.2420	1.0687
Standardized Coefficient	0.0000	0.1278
T Value	7.1152	1.2090
Prob Level (T Test)	0.0000	0.2299
Reject H0 (Alpha = 0.0500)	Yes	No
Power (Alpha = 0.0500)	1.0000	0.2232
Regression of Y on X	23.0678	1.2921
Inverse Regression from X on Y	-134.0746	79.0854
Orthogonal Regression of Y and X	-132.5371	78.3242

Notes:
The above report shows the least-squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. Note that these results are based on several assumptions that should be validated before they are used.

Estimated Model
(23.0677609427609) + (1.29208754208754) * (Distance)

Linear Regression Report

Page/Date/Time 3 06/03/2010 11:01:46 PM
Database
Y = Readings X = Distance

Correlation and R-Squared Section

Parameter	Pearson Correlation Coefficient	R-Squared	Spearman Rank Correlation Coefficient
Estimated Value	0.1278	0.0163	0.2629
Lower 95% Conf. Limit (r dist'n)	-0.0811		
Upper 95% Conf. Limit (r dist'n)	0.3247		
Lower 95% Conf. Limit (Fisher's z)	-0.0814		0.0590
Upper 95% Conf. Limit (Fisher's z)	0.3263		0.4457
Adjusted (Rbar)		0.0052	
T-Value for H0: Rho = 0	1.2090	1.2090	2.5559
Prob Level for H0: Rho = 0	0.2299	0.2299	0.0123

Notes:
The confidence interval for the Pearson correlation assumes that X and Y follow the bivariate normal distribution. This is a different assumption from linear regression which assumes that X is fixed and Y is normally distributed.

Two confidence intervals are given. The first is based on the exact distribution of Pearson's correlation. The second is based on Fisher's z transformation which approximates the exact distribution using the normal distribution. Why are both provided? Because most books only mention Fisher's approximate method, it will often be needed to do homework. However, the exact methods should be used whenever possible.

The confidence limits can be used to test hypotheses about the correlation. To test the hypothesis that rho is a specific value, say r0, check to see if r0 is between the confidence limits. If it is, the null hypothesis that rho = r0 is not rejected. If r0 is outside the limits, the null hypothesis is rejected.

Spearman's Rank correlation is calculated by replacing the orginal data with their ranks. This correlation is used when some of the assumptions may be invalid.

Database
Y = Readings X = Distance

Tests of Assumptions Section

Assumption/Test	Test Value	Prob Level	Is the Assumption Reasonable at the 0.2000 Level of Significance?
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9225	0.000048	No
Anderson Darling	2.3623	0.000006	No
D'Agostino Skewness	2.1129	0.034612	No
D'Agostino Kurtosis	-1.2428	0.213932	Yes
D'Agostino Omnibus	6.0088	0.049567	No
Constant Residual Variance?			
Modified Levene Test	0.0878	0.767709	Yes
Relationship is a Straight Line?			
Lack of Linear Fit F(3, 85) Test	3.9558	0.010826	No

No Serial Correlation?
Evaluate the Serial-Correlation report and the Durbin-Watson test if you have equal-spaced, time series data.

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

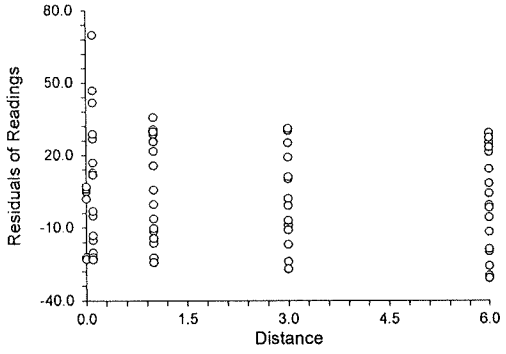
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

Database

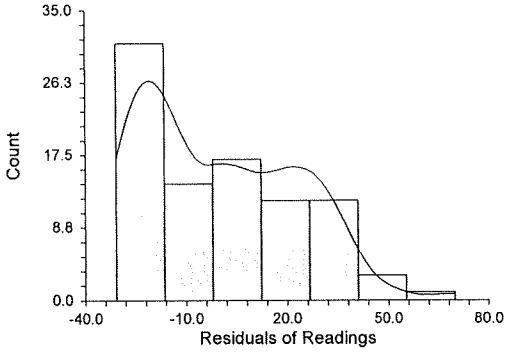
Y = Readings X = Distance

Residual Plots Section

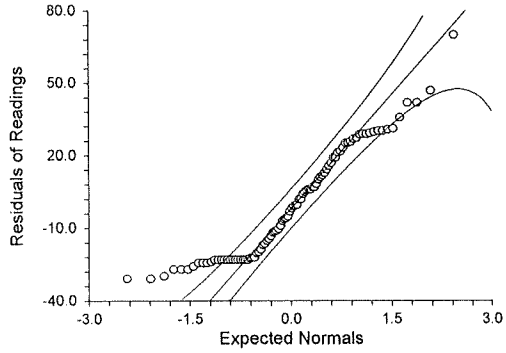
Residuals of Readings vs Distance



Histogram of Residuals of Readings



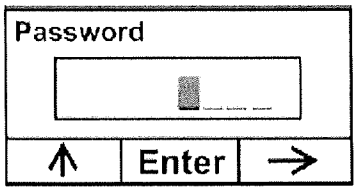
Normal Probability Plot of Residuals of Readings



Appendix E

Entering Calibration

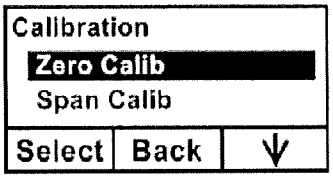
1. Press and hold [MODE] and [N/-] until you see the Password screen.



2. In Basic User Level, you do not need a password to perform calibrations. Instead of inputting a password, enter calibration by pressing [MODE].

   Note: If you inadvertently press [Y/+] and change any of the numbers, simply press [MODE] and you will be directed to the calibration menu.

The Calibration screen is now visible with Zero Calibration highlighted.



These are your options:

- Press [Y/+] to select the highlighted calibration (Zero Calib or Span Calib).
- Press [MODE] to exit calibration and return to the main display and resume measurement.
- Press [N/-] to toggle the highlighted calibration type.

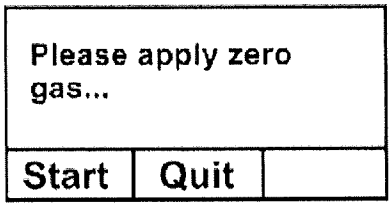
Zero (Fresh Air) Calibration

This procedure determines the zero point of the sensor calibration curve. To perform a fresh air calibration, use the calibration adapter to connect the instrument to a "fresh" air source such as from a cylinder or Tedlar bag (optional accessory). The "fresh" air is clean, dry air without organic impurities and an oxygen value of 20.9%. If such an air cylinder is not available, any clean ambient air without detectable contaminants or a charcoal filter can be used.

At the Zero Calibration menu, you can proceed to perform a Zero calibration or bypass Zero calibration and perform a Span calibration. You may also go back to the initial Calibration menu if you want to exit calibration.

- Press [Y/+] to start calibration.
- Press [MODE] to quit and return to the main calibration display.

If you have pressed [Y/+] to enter Zero calibration, then you will see this message:



1. Turn on your Zero calibration gas.
2. Press [Y/+] to start calibration.

   Note: At this point, you may press [MODE] if you decide that you do not want to initiate calibration. This will take you directly to the Calibration menu, highlighted for Span calibration.

3. Zero calibration starts a 30-second countdown and displays this message:

    Zeroing...

During the zeroing process, the instrument performs the Zero calibration automatically and does not require any action on your part.

Note: To abort the zeroing process at any time and proceed to Span calibration, press [N/-] at any time while zeroing is being performed. You will see a confirmation message that says "Zero aborted!" and then the Span calibration menu appears.

When Zero calibration is complete, you see this message:

    Zeroing is done!
    Reading = 0 ppb

The instrument will then show the Calibration menu on its display, with Span Calib highlighted.