# Electric Hand Dryers as a Source of Bacterial Contamination

by

**Kim McLennan**

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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**

The most effective way to prevent disease is through hand washing, which includes the following four steps: using warm water, using soap and friction, rinsing and finally drying. Studies have shown that the ambient air within washrooms can contain bioaerosols which are released into the air through toilet spray, sneezing and coughing. Dryers have been found to be able to transmit these bacteria from the ambient air through to the exhaust air. If this were true, the electric hand driers could be a potential source for bacterial disease transmission. As a result the general public could be at risk of acquiring infectious diseases from electric hand dryers found within these washrooms. The purpose of this study was to demonstrate that the concentration of bacteria in the exhaust air of electric hand dryers was greater than that of the ambient air of the washroom. Sampling was done in 30 female washrooms selected randomly from the same facility. From each washroom 2 samples were taken, one from the hand dryer at the opening of the nozzle and one from the ambient air measured in the centre of the washroom. Samples were taken using settling plates for the dryer and a RCS for the ambient air, both containing nutrient agar. Bacterial counts for each sample were enumerated 48 hours after sampling. Results showed a decrease in bacterial counts in air from the hand dryers when compared to the ambient air. This significant difference ($p < 0.05$) suggests electric hand dryers are beneficial in reducing bacteria numbers found in the air. These electric hand dryers are capable of decreasing the bacterial concentrations found in the ambient air before passing over drying hands. Decreased bacterial concentrations in exhaust air of these dryers can lead to decreased bacterial recontamination of an individual's hands, potentially decreasing disease transmission rates.

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## Introduction

The global population is increasing at an unprecedented rate, with an approximate increase from the current 6 billion people to 10 billion by the year 2050 (Sutherst, 2004). In accordance with this increasing population there is also a shift towards living in urbanized centres as opposed to rural areas, thereby increasing the population density of these communities (Sutherst, 2004). As the population density increases the number of interactions between individuals also increases (Racaniello, 2004). With every interaction with another human, animal or the environment comes the chance of disease spread, ultimately resulting in the propagation of disease throughout the population (Racaniello, 2004). The transmission of such diseases amongst populations is not limited to current known diseases, but also new and emerging ones as well. The spread of emerging infectious disease is the result of, "the increasing growth and mobility of the world's population, and over crowding in cities (Racaniello, 2004)."

In addition to the growing global population in general, there is also an increase in a subpopulation of individuals who are immunocompromised. It has been noted that there is a, "growing number of HIV infected persons, transplant recipients, and elderly persons," all of whom are at greater risks due to their immunodeficient status (Kaplan, Roselle, and Sepkowitz, 1998). The spread of disease among populations has never been as important as it is today due to the structure of today's communities, more immunocompromised individuals and increased interactions between individuals due to closer living conditions. Sutherst (2004) concluded, "the vulnerability of communities depends as much on their capacity to prevent or respond to increases in disease

transmissions as it does on the risks themselves." As a result, more attention needs to be made to reduce the instances which may aid in spreading diseases.

**Disease Transmission**

The transfer of disease is the consequence of both their etiology and their mode of transmission. There are a variety of infectious agents which result in human diseases: fungal, bacterial and viral (Heymann, 2004). For instance, viruses are the etiological agent behind influenza (Heymann, 2004), and the bacteria *Escherichia coli* O157:H7 has been the cause of numerous food borne illness outbreaks (Varma *et al.*, 2003; Heymann, 2004). Due to the relative difficulty in testing for and working with viruses, bacteria will be the main focus of this study.

A disease can be acquired by an individual both directly and indirectly (Heymann, 2004). Direct transmission occurs when the infectious agent from an infected individual is immediately transferred to a susceptible host (Heymann, 2004). Indirect transfer of an infectious agent can occur in a variety of ways, for example: through contaminated inanimate objects known as vehicles, or through an arthropod like a mosquito termed a vector (Heymann, 2004). One such mode of transmission of bacteria is through the fecal oral route, whereby bacteria normally found in the digestive system of an infected individual is shed in bowel movements (Taylor, Brown, Tolvenen and Holah, 2000). The bacteria can then be transferred from the infected person's hand to another individual, which is ultimately transferred to the mouth of the new susceptible host, potentially leading to an infection (Taylor, *et al.*, 2000). The most effective way to prevent

transmission of these organisms and ultimately the disease, is through handwashing (Harrison, Griffith, Michaels, and Ayers, 2003a).

In addition to these modes of transmissions, infectious agents can also be found circulating in the air, leading to airborne transmission of individuals and surfaces (Heymann, 2004). There are a number of bacterial agents which can be found as aerosols: for example *Staphylococcus aureus*, *Escherichia* and *Salmonella* (Gerba, Wallis, and Melnick, 1975; Williams, 1966). Biological aerosols are dispersed into the air through a variety of means such as sneezing coughing and toilet flushing (Gerba, *et al.,* 1975). Once bacteria has been dispersed into the air it is capable of traveling up to at least 15 meters from the source (Marthi, Fieland, Walter and Seidler, 1990). The distance traveled is strictly dependent on the size of the droplet (Marthi, *et al.* 1990). After being dispersed in the air, these aerosols can then settle out contaminating surfaces in the area (Gerba, *et al.,* 1975). Hands can then become contaminated after contacting such surfaces leading to, "self-inoculation by touching of the nose or mouth (Gerba, *et al.,* 1975)." Removal of such contamination from hands can be done through handwashing (Harrison, *et al.*, 2003a).

**Importance of Handwashing**

The importance of handwashing has been well documented both in the health industry and in the food industry. In 1847, Ignaz Semmelweis was the first to understand and observe this phenomenon between handwashing and disease prevention (Taylor, *et al.*, 2000). He was able to link the death rate of mothers from puerperal sepsis after birth and doctors who moved between cadavers and the mothers giving birth without washing

their hands (Gould, 1994). The observation was made when Semmelweis noted the same death rate did not occur when midwives were performing the deliveries, as they did not have contact with cadavers and therefore would be unable to spread the infectious agent (Gould, 1994). After implementing handwashing between procedures the death rate in the mothers dropped dramatically (Gould, 1994).

Due to the importance of handwashing, protocols have even been developed in order to ensure proper handwashing occurs. According to the Canada Communicable Disease Report, handwashing should be done using warm running water, ensuring all jewelry is removed, hands are to be rinsed, lathered for a minimum of 10 seconds with soap and friction, followed by another rinse, and finally by drying (Health Canada,1998). However, although the handwashing steps are well laid out, the method for hand drying is undefined (Health Canada, 1998). It has been proven that washing hands significantly reduces the bacterial count found on the hands and ultimately decreases the potential for disease transmission between individuals (Griffith, *et al.* 2003; Harrison, *et al.*, 2003a; Taylor, *et al.*, 2000). The effectiveness of handwashing is independent of the organism present on the hands (Griffith, *et al.* 2003), therefore the effect is the same for the removal of bacteria, viruses, fungi, etc. As a result, the importance of handwashing has been greatly stressed among the medical community, food service industry and even the general public (Taylor, *et al.*, 2000).

In BC, there is even legislation, Food Premises Regulations 1999, which states employees working in a food establishment must wash their hands as often as possible to prevent contamination of food. However, only the handwashing stage is being stressed amongst these groups (Harrison, Griffith, Michaels, and Ayers, 2003b). According to

Griffith (1994), there are four stages of handwashing which are washing, rubbing, preventing recontamination and drying.

**Importance of Hand Drying**

Drying hands is the last step of handwashing and can be done in a variety of ways, if it is done at all. The four methods of hand drying available are rotating cloth towels, paper towels, mechanical forced air dryer, and "spontaneous evaporation" (Gustafson, *et al.,* 2000). The type of drying method available to the public is ultimately the facilities choice, the decision however, is usually based on economics rather than health concerns (Harrison, *et al.*, 2003b). The importance of proper drying is essential to the handwashing process as long as it reduces the risk for cross-contamination (Griffith, *et al.* 2003; Harrison, *et al.*, 2003b).

There are some concerns with recontamination of the hands as a result of drying. Using continuous cloth dispensers for hand drying is widely known for being communal and aiding in disease transmission, as a result they are rarely used today (Harrison, *et al.*, 2003a). Therefore, most of the work looking into the cross-contamination of hands from dryers has been done with paper towels and their associated dispensers (Gustafson, *et al.,* 2000; Harrison, *et al.*, 2003a; Harrison, *et al.*, 2003b). The concern with recontamination in these instances are from direct contact with the dispenser (Gustafson, *et al.,* 2000; Harrison, *et al.*, 2003a; Harrison, *et al.*, 2003b). Although few, there have been studies looking into electric hand dryers with respect to recontamination of hands after washing (Gustafson, *et al.,* 2000; Taylor, *et al.*, 2000). In these instances direct contact with the dispenser was not the focus of the study, however, the studies concentrated on the

transmission of microorganisms through the exhaust air (Gustafson, *et al.,* 2000; Taylor, *et al.*, 2000).

**Contamination by Air Dryers**

It has been shown in a laboratory setting that the electric hand dryers can transmit bacteria back onto the hand if the supply air is contaminated itself (Taylor, *et al.*, 2000). Taylor *et al.* (2000), studied only five dryers, which were duplicated 30 times in the laboratory with known concentrations of contaminated air. This replication of sampling on the same dryers allows for sampling bias in the final results, instead 30 different dryers should have been used. The few studies that have occurred show that bacteria are not killed by the temperature of the air dryers (Gustafson, *et al.,* 2000; Taylor, *et al.*, 2000), which is approximately 54°C (130°F) (Excel Dryer, Inc., 2001), but rather circulated through and back on to clean hands. The previous tests only looked at the ability of the air dryers to transmit bacteria, and did not look at whether the machines were either increasing or decreasing the bacterial concentrations in the exhaust air.

These same studies determined the transmission of bacteria by sampling hands for total bacterial counts, however samples of bacterial counts prior to drying were not taken (Gustafson, *et al.,* 2000; Taylor, *et al.*, 2000). Without knowledge of what the bacterial counts were prior to drying it is difficult to determine if the drying method is effective in preventing cross-contamination of the hands after being washed which is an essential step in handwashing (Harrison, *et al.*, 2003b). This sampling method also prevents distinguishing between bacteria contaminating the hands from the dryer and the natural flora of the hands (Taylor, *et al.*, 2000). This distinction is important as it has been shown

that resident bacteria are not easily removed by, "normal handwashing (Taylor, *et al.*, 2000)." As a result the natural flora may be combined with the bacterial count associated with hand drying contamination.

As drying is the final step in handwashing it is essential that the method chosen does not introduce new bacteria to the hands. This is the result of multiple studies which have shown that there is an increase in bacterial transfer when the moisture level is increased (Griffith, *et al.* 2003; Patrick, Findon and Miller, 1997). As a result, if electric hand dryers transmit bacteria through the exhaust air, the washing of the hands is a useless step as the hands would be re-contaminated through the drying process. If the washing step was ineffective to begin with, using a drying method as such, the number of bacteria on the hands would only increase from levels prior to washing. It is in situations like this, that "drying assumes greater importance (Gould, 1994)."

Although it has been shown that the electrical dryers can transmit bacteria on to the hands from contaminated air, currently there are no studies showing whether or not the electrical air dryers actually increase the bacterial concentrations relative to the ambient air. There is concern, however, that the air dryers may become reservoirs for pathogenic organisms (Harrison, *et al.*, 2003a). Electric hand dryers are usually found in washrooms where the air can be contaminated with pathogenic organisms (Gerba, *et al.*, 1975). These organisms are released into the air every time someone sneezes, coughs, vomits and even talks (Williams, 1966). The air has also been found to be contaminated with enteric bacteria from flushing a toilet after a bowel movement from an infected individual (Baker and Jones, 2005; Gerba, *et al.*, 1975). Even after subsequent flushes, "large number of microorganisms were persistent on the toilet bowl," and "continued to

be disseminated into the air" (Baker and Jones, 2005). These organisms can contaminate surfaces within the washroom, including hand dryers, leading to the spread of disease (Baker and Jones, 2005). Varma *et al.* (2003) determined the spread of *E. coli* O157:H7 throughout an entire building to be the result of aerial spread. In addition to this finding, the *E. coli* was found to survive up to 42 weeks on these surfaces (Varma *et al.*, 2003). These aerosols can even be taken up by the electric hand dryers and settle on the interior leading to potential bacteria harborage. This harboring of bacteria known as a biofilm, is a concentration of bacterial cells where the outer most cells protect the inner ones from disinfection and desiccation (O'Toole, 2003). An increase in bacterial concentrations from the ambient air would suggest the harboring of bacteria inside the dryer. As most bacteria require temperatures above 60°C (140°F) to be killed (Heymann, 2004), and the dryers do not exceed this temperature (Excel Dryer, Inc., 2001), any bacteria that has created a biofilm can ultimately lead to increased concentration of bacteria being released on to the hands. This release of bacteria in the exhaust air would result in higher concentrations in comparison with the ambient air of the washroom.

**Purpose**

Therefore, the study was designed to demonstrate that the concentration of bacteria in the exhaust air of electric hand dryers is greater than that of the ambient air of the washroom. When the exhaust air from the electric dryer releases higher concentrations of bacteria than the surrounding air, one of the critical stages of handwashing is being defeated (Griffith, *et al.* 2003). As hands are still wet when the contaminated air passes over them, the bacteria will transfer more readily from the dry air to the wet hands (Gould, 1994). Transferring bacteria to clean hands, in general, is not

acceptable (Taylor, *et al.*, 2000). However, when there is potential for the bacteria being aerosolized to be pathogenic, there is much more reason to be alarmed (Baker and Jones, 2005). This concern is real as these hand dryers are found in locations known to transmit pathogenic bacteria through the air, i.e. public washrooms (Baker and Jones, 2005; Gerba, *et al.,* 1975). The concern is intensified when the realization is made, that public washrooms are intended to be used by the entire population. With the continual increase and overcrowding of urban centres (Racaniello, 2004), there will be an increase in individuals using public washrooms. The general public could be at risk of acquiring an infectious disease from an electric hand dryer found within these washrooms. Unfortunately, the population is not entirely composed of healthy individuals, but rather an, "increasing population of immunocompromised persons (Kaplan *et al.*, 1998)." As a result, there are, "public health consequences that arise from failure to execute hand decontamination effectively (Harrison, *et al.*, 2003a)," of which drying is an essential stage (Harrison, *et al.*, 2003b).

**Equipment**

There are many types of equipment that could be used for sampling airborne bacteria (Lundholm, 1982). As a result the sampling of the ambient air was done using the Reuter Centrifugal Sampler (RCS) (Fig. 1) (Table 1), which is an approved form of sampling for airborne bacteria by the National Institute for Occupational Safety and Health (NIOSH) (1994). The RCS uses centrifugal force to impact airborne microorganisms onto agar media (Biotest Diagnostics Corp., 2003). By using the RCS, the amount of time for sampling could be selected from a few preset times of 0.5, 1, 2, 4

and 8 minutes while the rate of flow remained constant at 40 L/min (Biotest Diagnostics Corp., 2003).

| **Equipment:** | **Use:** |
|---|---|
| Reuter Centrifugal Sampler | Ambient Air |
| TSI Anemometer | Hand Dryer Air |

Table 1: List of equipment used and the purpose of the use.

Other methods of sampling air for bacteria have been used previously, for example Hameed and Farag (1999) used liquid impingers to collect aerosolized bacteria in a buffered phosphate solution. This method was not chosen due to the complexity of the apparatus required and the additional steps that are essential in quantifying the bacteria in the sample. In order to count viable bacteria colonies from a liquid impinger the buffered phosphate solution from the impinger must be transferred onto solid agar in a Petri dish (Hameed and Farag, 1999; Heidelberg *et al.*, 1997). This step was not required with the RCS as the bacteria are collected directly onto the agar media (An, Mainelis, and Yao, 2004).

Another common air sampler used to collect microorganisms such as bacteria is the Anderson sampler (Schillenger, Vu and Bellin 1999). With the Anderson sampler, an external vacuum pump is required to draw air through the device at a rate of 28 L/min, which also requires electricity to run, limiting the areas that can be sampled (An et al., 2004). The RCS on the other hand is battery operated and a stand alone device, which means no additional equipment is needed, such as a pump, to perform the sampling (Biotest Diagnostics Corp. , 2003). As a result of being independent of electricity, this

device can be used in locations, "where electricity is unavailable or hazardous to use (An et al., 2004)." A public washroom would fit into this category, as it is rare to find an electrical outlet located within the washroom.

Another instrument used was a TSI hot wire anemometer (Fig. 2) (Table 1). This device was used with the settling plate on the electric hand dryer. By using the hot wire anemometer the rate of air flow passing from the nozzle of the dryer could be determined. Having knowledge of the rate of air flow from the dryer was essential in determining the volume of air passing from the dryer onto the Petri plate. The calculated volume was then used to compare the sampling results from both the settling plate and the RCS method. In order to determine the volume (V), a simple calculation was performed, where the volume rate of flow (Q) was multiplied by the sampling time (t) (TSI Inc., 2005):

$$V = Qt$$

This equation provided a volume which could then be compared to the RCS after a minor conversion of units.

The anemometer was also used to measure and record temperatures of the air that was sampled (TSI Inc., 2005). The temperatures of both the exhaust from the dryer and the ambient air were measured. These measurements were taken only for the purpose of explaining potential bacterial levels or lack there of, as bacteria is unable to survive at temperatures about 60°C (Heymann, 2004).

**Materials**

Regardless of the type of sampling, agar media was required by both the RCS and the Petri plate. The agar media that was used to collect the samples of bacteria was

Nutrient Agar, which was in accordance with NIOSH (1994) (Table 2). In order to compare results the same agar was used for both methods of sampling. The Nutrient Agar was used for its ability to support the growth of most bacteria that may have been present in the sample (Difco Laboratories Inc., 1984). Viable counts of bacteria were determined by using this agar, which allowed for the concentrations of total bacteria in both air samples to be calculated (Baker and Jones, 2005; Taylor et al., 2000).

| **Materials:** | **Amount** |
|---|---|
| RCS test strips | 31 strips |
| Settling Plates | 31 plates |
| Nutrient Agar | 26.68 grams agar pellets |

Table 2: List of materials and the required amounts.

Alternative media could have been used that are selective for specific bacteria, such as Violent Red Bile Glucose Agar or Baird Parker Agar (Taylor et al., 2000). These agars look specifically for enteric coliforms, bacteria which are found in the gut, and select against other types of bacteria (Difco Laboratories Inc., 1984). Unfortunately, the species of bacteria that were found in the samples were unknown prior to sampling, as a result some of the bacteria may have been overlooked if a selective media were used. For that reason, a non selective media such as Nutrient Agar was used to determine general concentrations of bacteria.

**Procedure**

The agar was made in advance according to procedures outlined by Difco Laboratories Incorporated (1984). The media was made using 26.68 grams of dehydrated

Bacto Nutrient Agar with 1.16 Litres of distilled water (Difco Laboratories Inc., 1984). This volume made enough media to make 40 Petri dishes and 40 RCS test strips, which provided enough media for the 30 locations selected with a few spares for handling errors. The agar solution was placed in the autoclave for 15 minutes at 15 pounds pressure and 121°C in order to ensure sterilization (Difco Laboratories Inc., 1984).

Once removed from the autoclave, the media was placed into a hot water bath to prevent solidification before it was dispensed into clean plastic Petri dishes. Once media had cooled to a manageable temperature it was distributed to the Petri dishes and the RCS test strips. Each Petri dish received 20 ml of the media, while 9 ml was distributed amongst the 34 wells on each test strip (Biotest Diagnostics Corp., 2003, An et al., 2004). The Petri dishes were allowed to cool with the covers on to prevent contamination of the agar. The test strips were placed back into their protective cover and allowed to cool free of contamination.

Once the agar had cooled and ultimately solidified enough to move without spilling, the plates and test strips were transferred into a refrigerator. The media remained stored in the refrigerator until they were required for sampling. One solidified plate and test strip were kept aside for a negative control, which were placed in the incubator without sampling to rule out the media being the source of any bacterial growth that may have resulted from sampling.

In order to have statistically significant data, 30 washrooms were selected which contained electric hand dryers (Fig. 3 and 4). These washrooms were all located at the same location to reduce the number of dryer manufactures in use. All of the samples were taken from the women's washroom for practical reasons, as access to men's washrooms

was limited due to gender of researcher. The washrooms chosen were also relatively the same size, containing a minimum of 2 stalls, which allowed for two air samples to be taken without interference from each other. Single washrooms were excluded from the study due to their small size and the low number of people that they would service. Other washrooms that were excluded, were those in which hand dryers were absent. The selection of the washroom was randomized, using a compiled list of all washrooms in the facility of the same size from which every second washroom on the list was selected.

In each washroom two air samples were taken, one from the exhaust of the dryer, and the other from the ambient air in the washroom. The air leaving the dryer was sampled using a settling plate placed at the face of the nozzle. This was to ensure constant placement of the plate, as well as ensuring any bacteria that may be found on the plate was from the dryer itself. The area of the nozzle opening was measured at 6.5 cm and 7.5 cm in diameter for the circular and square nozzles of the dryers, respectively. This information was entered into the anemometer before sampling, so that the volume of air being collected could be established. Once the area parameters were set, the anemometer was placed in the exhaust air at the surface of the nozzle to determine the flow rate and temperature of the air at the plate. An averaging of the velocity was done by taking 6 readings in a perpendicular plane to the stream of air (Fig. 5). The hot wire anemometer is factory calibrated and did not require further calibration prior to use (TSI inc., 2005). The temperature of the washroom was recorded as well, which was compared with the exhaust air to help explain any changes in bacterial counts between the two samples.

Once everything was set up the dryer was turned on for 30 seconds, average duration of drying cycle (World Dryer Corp., 2000). Immediately after sampling was complete, the lid was replaced and secured to prevent introduction of microorganisms not associated with original sampling. The Petri dish was then inverted and securely stored until it could be placed in an incubator back in the lab the following morning.

The bacterial levels in the ambient air were sampled using the RCS. A settling plate was not used for collecting samples from the ambient air due to the extensive time period which would be required to obtain an adequate sample, minimum of 1 hour (Hoffman and Humphreys, 2001). The RCS is factory calibrated therefore no further calibration was required (Biotest Diagnostics Corp., 2004). The RCS sampler was set up in the middle of the washroom in order to obtain a representative sample of the ambient air. This position allowed for relatively equal exposure to anything in the washroom which may have influenced the bacterial count in the ambient air, including the dryers and toilets (Baker and Jones, 2005). Prior to using the RCS, the impeller was cleaned with 70% isopropyl alcohol and aseptically attached to the base of the RCS (Biotest Diagnostics Corp., 2004). The packages of the test strips were opened and immediately inserted into the RCS for sampling, one per sample site. The equipment was then turned on for 30 seconds of sampling at 40 L/min. Immediately after sampling was complete, the test strip was removed, placed back into the protective case and sealed shut. Just like the Petri dishes, the RCS test strips were inverted and stored safely until they were placed in the incubator back at the lab the following morning.

Both the Petri dishes and the test strips remained in the incubator at 35°C. After 48 hours the samples were removed from the incubator and analyzed for bacterial growth.

Each Petri dish or test strip was analyzed for the number of bacterial colonies which were formed and recorded as colony forming units (cfu) per cubic meter ($m^3$) (Hameed and Farag, 1999). If two colonies were touching they were counted as one (Shintani *et al.*, 2004). Once analysis had been completed, the inoculated media was discarded.

**Statistics**

The numerical results obtained from the above sampling were analyzed using Number Crunching Statistical System (NCSS). The viable bacterial counts of the two air samples were compared using a two sample t-test. Other information that was examined included descriptive statistics such as the mean, median, and standard deviation.

**Results**

Statistical analysis of data obtained through sampling (Appendix A), confirmed the sample size was adequate at 30 samples per group (Appendix B). The mean bacterial count for the hand dryer sample was found to be 29.3 cfu/$m^3$ with a standard deviation of 23.6, on the other hand the median was found to be 24.7 cfu/$m^3$ (Fig. 6). Conversely, the ambient air mean was determined to be 350 cfu/$m^3$ with a standard deviation of 230.1 and a median of 325 cfu/$m^3$ (Fig. 7) (Appendix B). Both controls were also found to be free of bacterial colonies as shown in figures 8 and 9.

Using the test of assumptions to determine normality proved difficult, as there was an even split with respect to the data being normally distributed. This was due to the fact that 50% of the tests of assumption implied normality could be rejected and 50% advised could not reject normality. According to statistical procedures outlined in the NCSS program the next step in analyzing similar data was to determine if outliers exist, if

this were true it would be possible to choose a parametric t-test. Upon closer review of the data a few outliers were found (Fig. 10), therefore the data could be assumed to be normally distributed and a parametric t-test could be used (Appendix B).

Using an equal-variance two tailed t-test, it was determined to reject the null hypothesis of no significant difference occurring between the two samples (Appendix B). The decision to reject the null hypothesis is based on the p value which was found to be less then 5% ($p = 0.00$) (Appendix B). In rejecting the null hypothesis, the alternative hypothesis that a difference exists, must be true. As a result of the low p value there is little chance for an $\alpha$ error to have occurred, suggesting the sample size was sufficient. As well, the difference detected was reflecting a true difference as the power of the test was 99%. Given the high power, it was determined that there was little chance for a $\beta$ error to have occurred. Thus, the conclusion that a significant difference exists between the mean colony forming units per cubic meter of the samples is justified. The difference between the samples can be seen by comparing these mean counts as in Figure 10. The bacterial counts of the ambient air were consistently higher than the air of the hand dryers (Fig. 11). As a result, the exhausting air of the hand dryer was found to have significantly lower bacterial counts than those of ambient air.

Along with the analysis of the bacterial counts, the temperatures of the air samples were also analyzed. The mean temperature of the hand dryers was found to be 52.70°C with a standard deviation of 10.47 and a median of 52.8°C (Appendix C). On the other hand the ambient air was found to have a mean temperature of 27.2°C with a standard deviation of 0.46 and a median of 27.5°C. The difference between the air temperatures was also found to be normally distributed, therefore a parametric test was

used. As a result of a low p value ($p = 0.00$), the null hypothesis of no difference existing was rejected. This was done with confidence as there was little chance of an $\alpha$ or $\beta$ error occurring due to the low p value and the high power (power = 100%) of the test. The difference in air temperature was correlated to the number of bacteria in each sample with a decrease in the bacteria with an increase in temperature (Fig. 12).

**Discussion**

Acquiring an infectious disease from electric hand dryers which are found in public washrooms may be possible as bacteria, potentially pathogenic bacteria, have been recovered from the exhaust air. Although the transmission of bacteria from hand dryers has been shown in previous experiments (Taylor, *et al.*, 2000), quantification of bacteria being transmitted has not been previously analyzed. In accordance with Gustafson, *et al.*, 2000 and Taylor, *et al.*, 2000, bacteria was found to pass through the dryer, however there is a relatively lower potential for disease transmission via these dryers when compared to air drying. This potential reduction in the rate of disease transmission is the result of these dryers having the ability to significantly reduce the concentration of bacteria in the air. As many diseases are caused by bacteria (Heymann, 2004), this decrease detected in the exhaust air may lower the transmission of some bacterial diseases, which can be found in washrooms. As moist hands are more susceptible to recontamination by bacteria found in the air (Griffith, *et al.*, 2003), this reduced number of bacteria in the air passing over the hands while drying decreases the potential for hands to become re-contaminated with large numbers of bacterial cells. This is due to the fact that moist hands that are placed under the exhausting air of the dryer will be exposed to fewer bacteria than if air dried. With fewer numbers of bacteria transferring to the

hands from the air, there is a corresponding decrease in the amount of bacteria available to be taken up by the body, through the mouth for example. As fewer bacterial cells are acquired by the body, the potential for becoming ill is reduced as the likelihood of acquiring enough cells to reach the infectious dose of the disease is lowered (Heymann, 2004). If the infectious dose of an illness is not obtained, the illness will not develop in most cases (Heymann, 2004).

The air being released from these hand dryers was also found to be significantly warmer than the ambient air. As noted earlier, the majority of bacteria species cannot survive at temperatures exceeding 60°C (Heymann, 2004). Although this temperature was not achieved in every sample, the warmer temperatures that were reached were significant enough to decrease the concentrations of bacteria in the air. This lower bacterial count also implies that the dryers are not harboring bacteria, therefore biofilms are not forming most likely due to the increased temperatures found within the dryers. This decrease in bacterial count also implies that the manufactures can set the temperatures of the air leaving the dryers to a more comfortable level for an individual and still effectively reduce the bacterial load in the air. As drying is an essential step in the hand washing process (Harrison, *et al.*, 2003b), providing a method of drying with a more comfortable air temperature, may persuade individuals to use the dryers to dry their hands instead of air drying. By being exposed to lower concentrations of bacteria, there is a reduced potential for the moist hands to acquire bacterial counts in sufficient numbers to exceed the infectious dose of the particular disease (Griffith, *et al.*, 2003; Heymann, 2004).

As these electric hand dryers have been shown to reduce the concentration of bacteria in the air, these dryers may be used in areas of heavy public use to reduce transmission of diseases. With increasing populations of immunocomprimised individuals, there is a need to reduce the exposure of potential diseases where ever possible, including public washrooms (Racaniello, 2004). These washrooms are frequented by individuals who are healthy, ill, and/or immunocomprimised. As a result, utilizing these hand dryers in such locations can ultimately reduce the number of bacteria an individual is exposed to when compared to the amount actually aerosolized from an ill individual that has also visited the location (Baker and Jones, 2005).

The above results can be used by health agencies, including public health inspectors, to ensure the public is protected from acquiring communicable diseases, even when in the washroom. This can be done through the public health agencies, which can utilize this information to educate the public with the benefits of drying their hands using hand dryers when compared to air drying.

**Limitations**

The aforementioned study has a couple of limitations with respect to the ability to generalize the results. As sampling was performed only in the women's washrooms, the results may only be applied to these washrooms and cannot be applied to the washroom of men at this time.

Another limitation that exists is the ability to compare whether hand driers provide a greater reduction of bacteria from the ambient when compared to paper towels. The extent to which paper towels may become contaminated with bacteria on their surfaces when hanging from dispensers between uses was not looked at. As well, the

study did not look at the subsequent transfer of such bacteria on the surface of the paper towel to an individual's hands.

Finally, the current study focused on bacteria, neglecting fungi and viruses. As a result the study is only generalizable to bacterial transmission of diseases and not to all communicable diseases.

**Conclusions**

1. Electric hand dryers in public washrooms are capable of transmitting bacteria from the ambient air through the exhaust air on to drying hands.
2. These electric hand dryers are capable of decreasing the bacterial concentrations found in the ambient air before passing over drying hands.
3. Decreased bacterial concentrations in exhaust air of these dryers can lead to decreased bacterial recontamination of an individual's hands, potentially decreasing disease transmission rates.

**Recommendations**

1. Future studies can be completed using men's washrooms to determine if the results found here can be applied universally to the washrooms of both genders.
2. Further sampling can also be completed where the same volume of air is sampled from each source rather than sampling for the same time followed by appropriate conversion to compare the volumes.
3. Another future study can compare the bacterial load found on paper towels to the exhaust air of electric hand dryers. This comparison can include the potential for hands to become recontaminated from these different sources.

4. Finally, identification of the bacteria found in both types of samples can be done to determine if the bacteria that is passing through the hand dryer is pathogenic or not. As well, this study can also look to see if there is a relation between the concentration of a particular type of bacteria in the air and its ability to survive the temperatures of the electric hand dryer.

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**Legislation**

Health Act: Food Premise Regulations
Retrieved October 16, 2005 from
http://www.qp.gov.bc.ca/statreg/reg/H/Health/210_99.htm

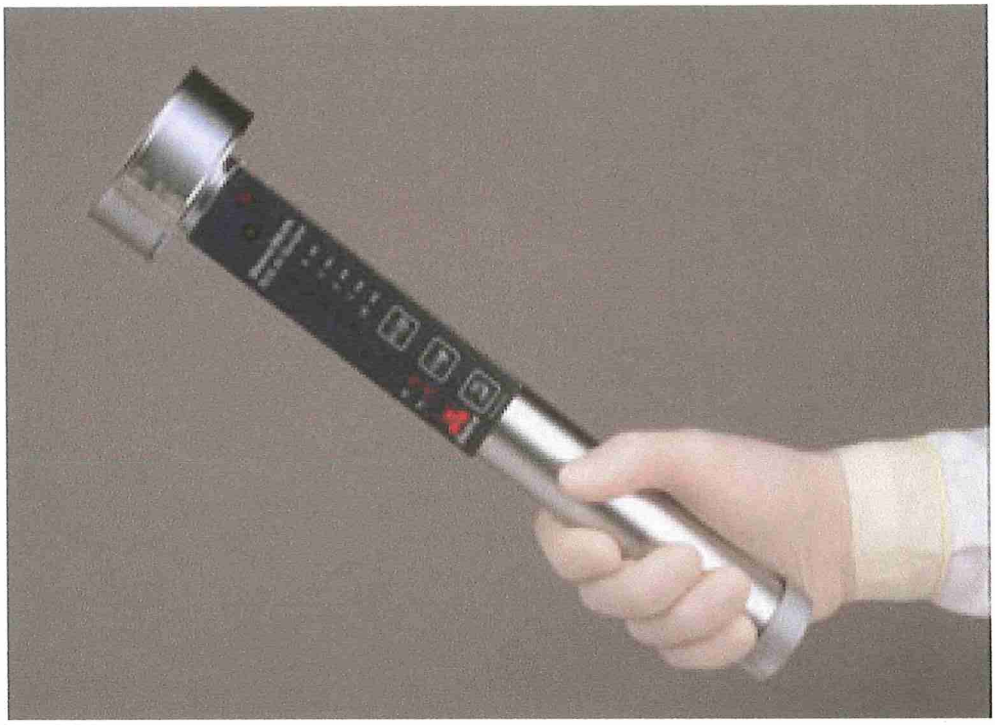

Figure 1: Reuter Centrifugal Sampler. Photo retrieved November 5, 2005 from http://www.biotestuk.com/hycon/rcs.htm


Figure 2: TSI Anemometer. Photo retrieved November 5, 2005 from http://www.tsi.com/Product.aspx?Pid=25

Figure 3. World Dryer. Picture of a World Dryer hand dryer with circular exhaust.

Figure 4. Bobrick Dryer. Picture of a Bobrick hand dryer with square exhaust.

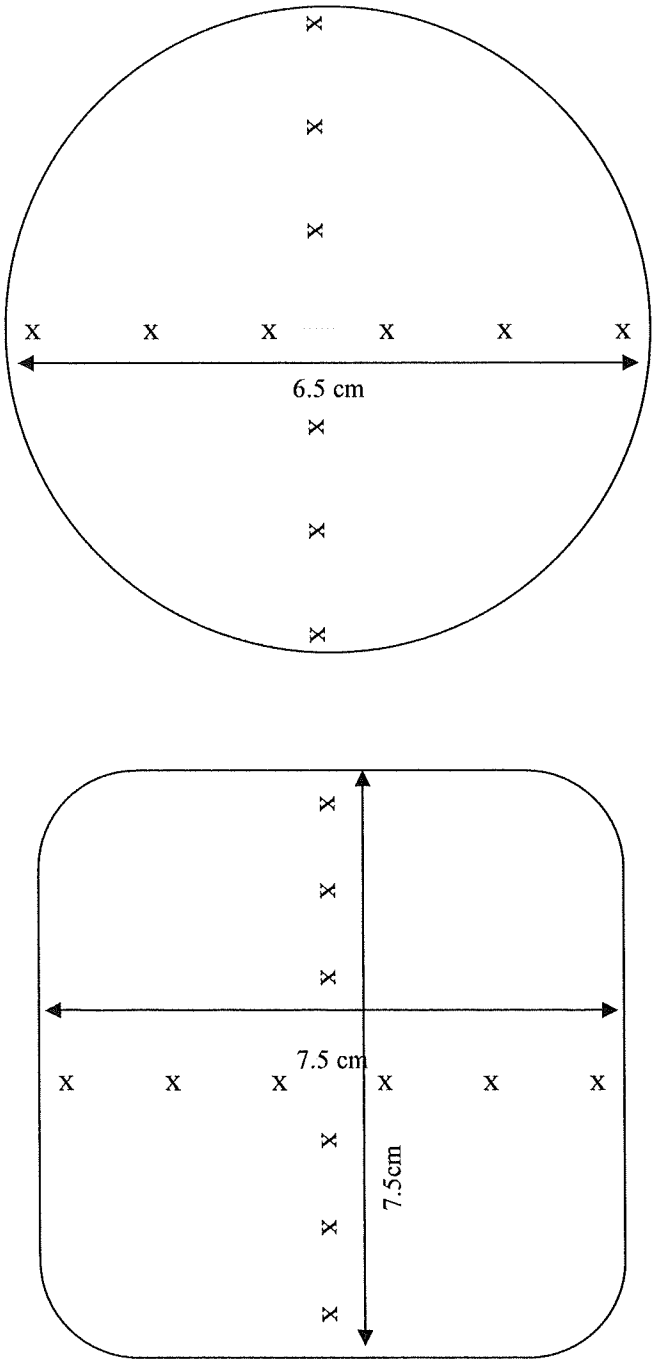


Figure 5. Location of Anemometer Readings. Spatial distribution of anemometer readings in a horizontal plane of the exhausting air at the surface of the nozzle for both the circular and square face exhaust.

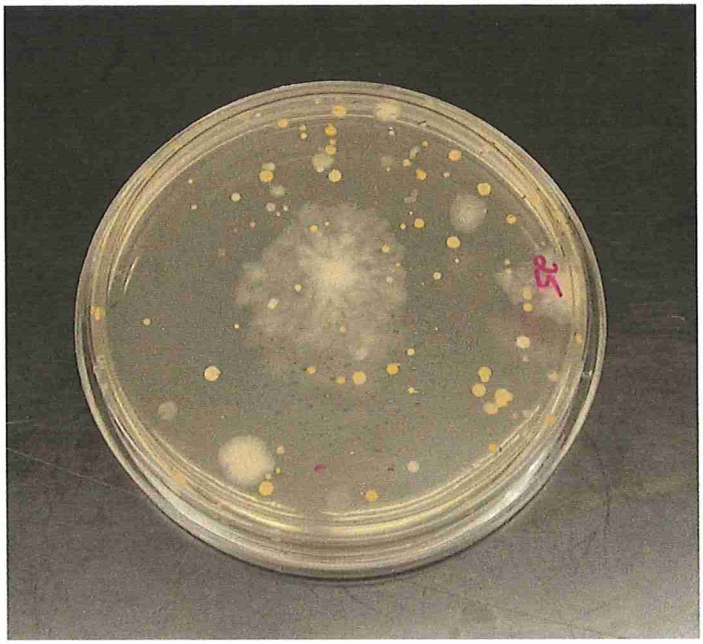

Figure 6. Bacterial Growth of Hand Dryer. Petri plate showing colonized bacteria from approximately 1.17$m^3$ of air from a hand dryer.

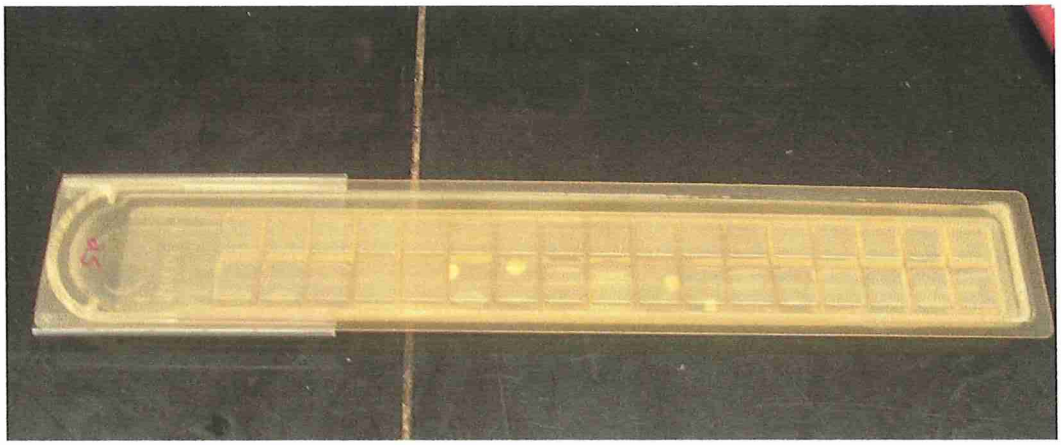

Figure 7. Bacterial Growth of Ambient Air. RCS test strip showing colonized bacteria from approximately 0.02$m^3$ of ambient air.


Figure 8: Settling Plate Control. Picture of control plate showing absence of bacterial colonies.

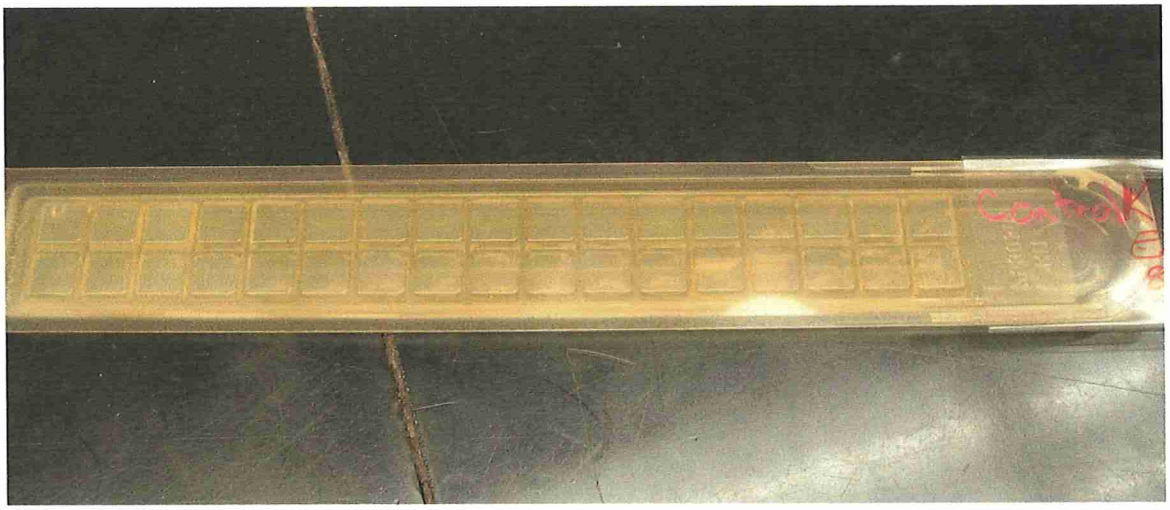


Figure 9: RCS Test Strip Control. Picture of control RCS test strip showing the absence of bacterial colonies.

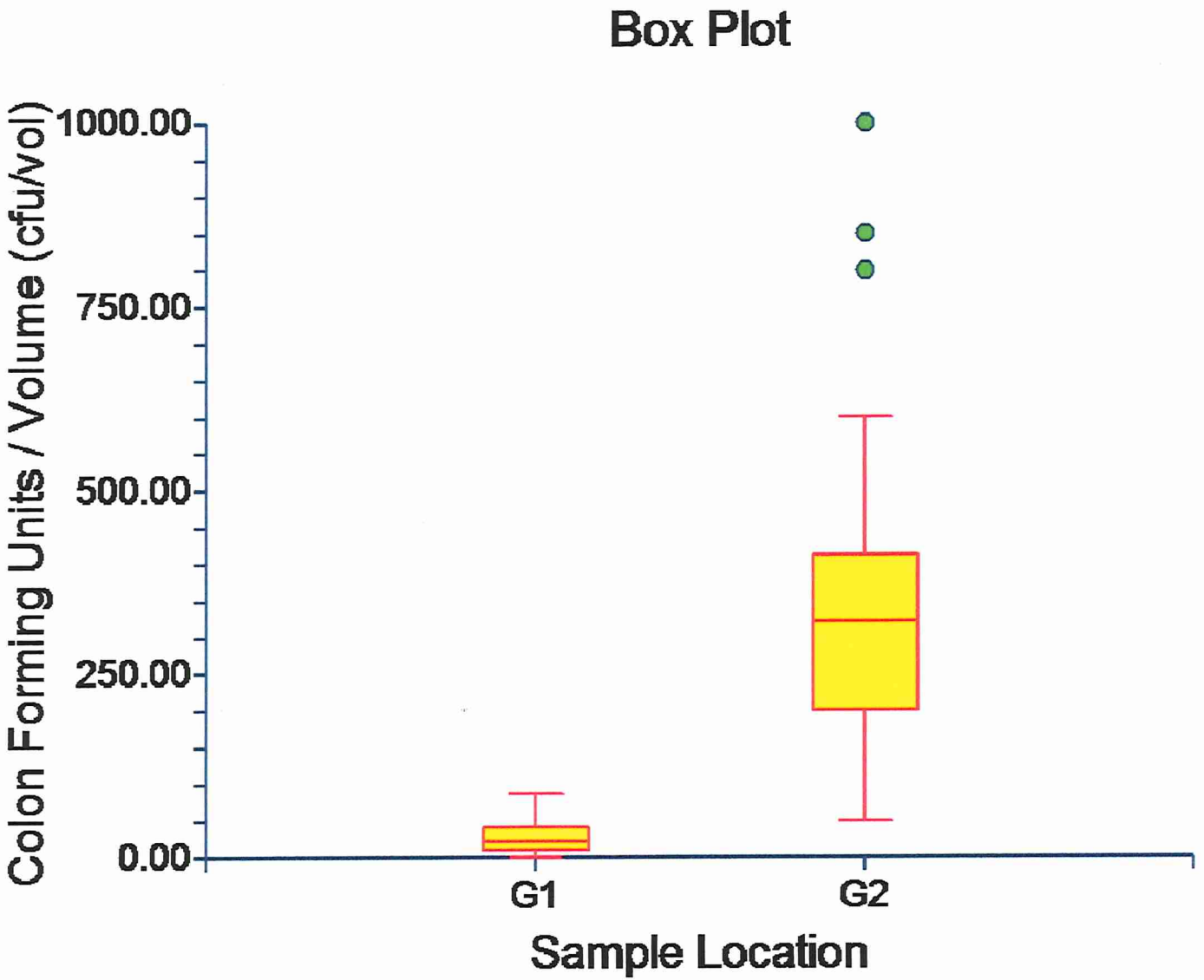


Figure 10. Bacterial Counts as a Function of the Location. Comparison of mean colony forming units per unit volume (m3) for hand dryer exhaust air (G1) and ambient air (G2).

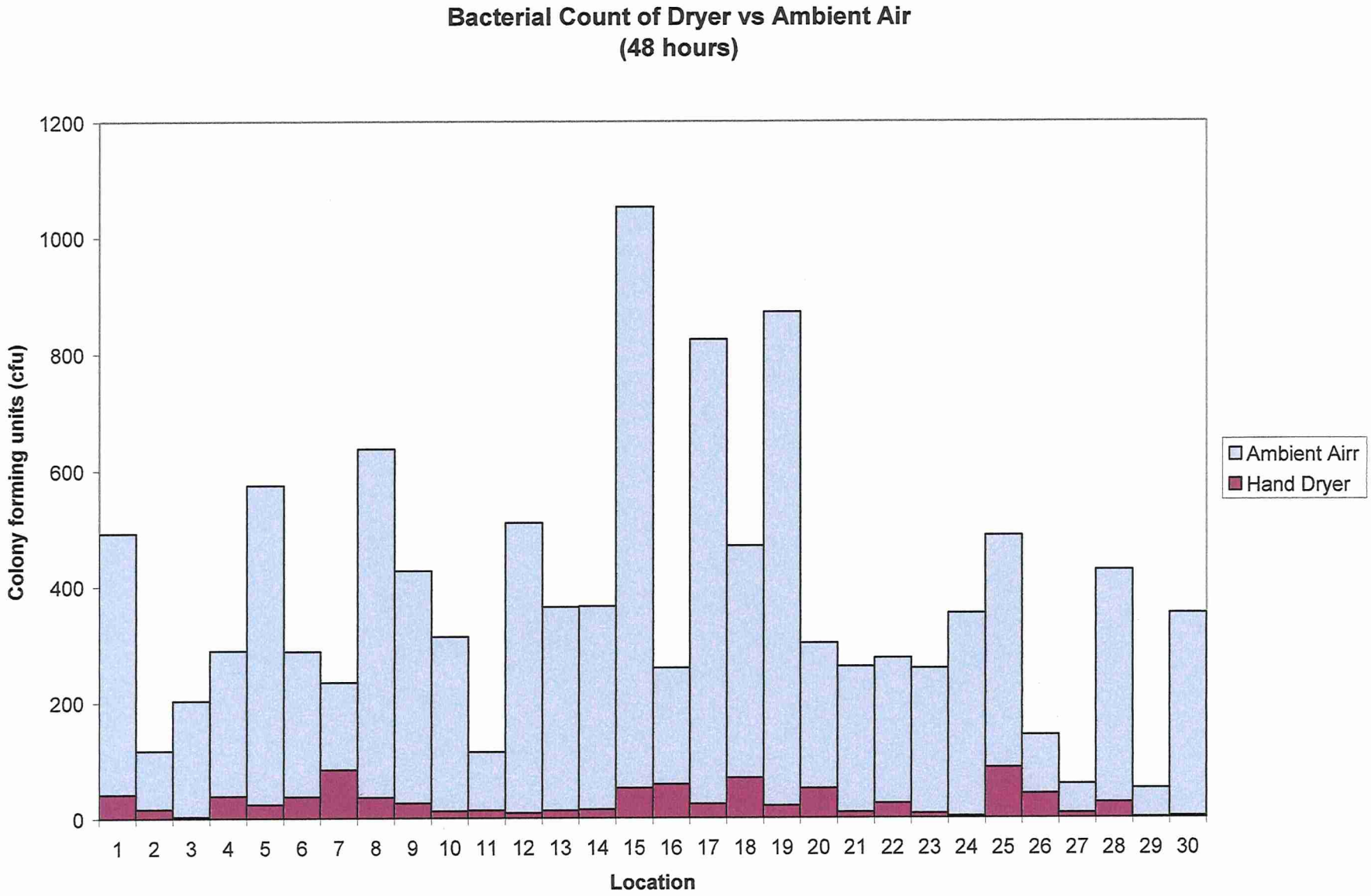


Figure 11. Bacterial Count of Dryer vs Ambient Air. The bacterial counts of the ambient air were consistently higher than the hand dryer air samples.

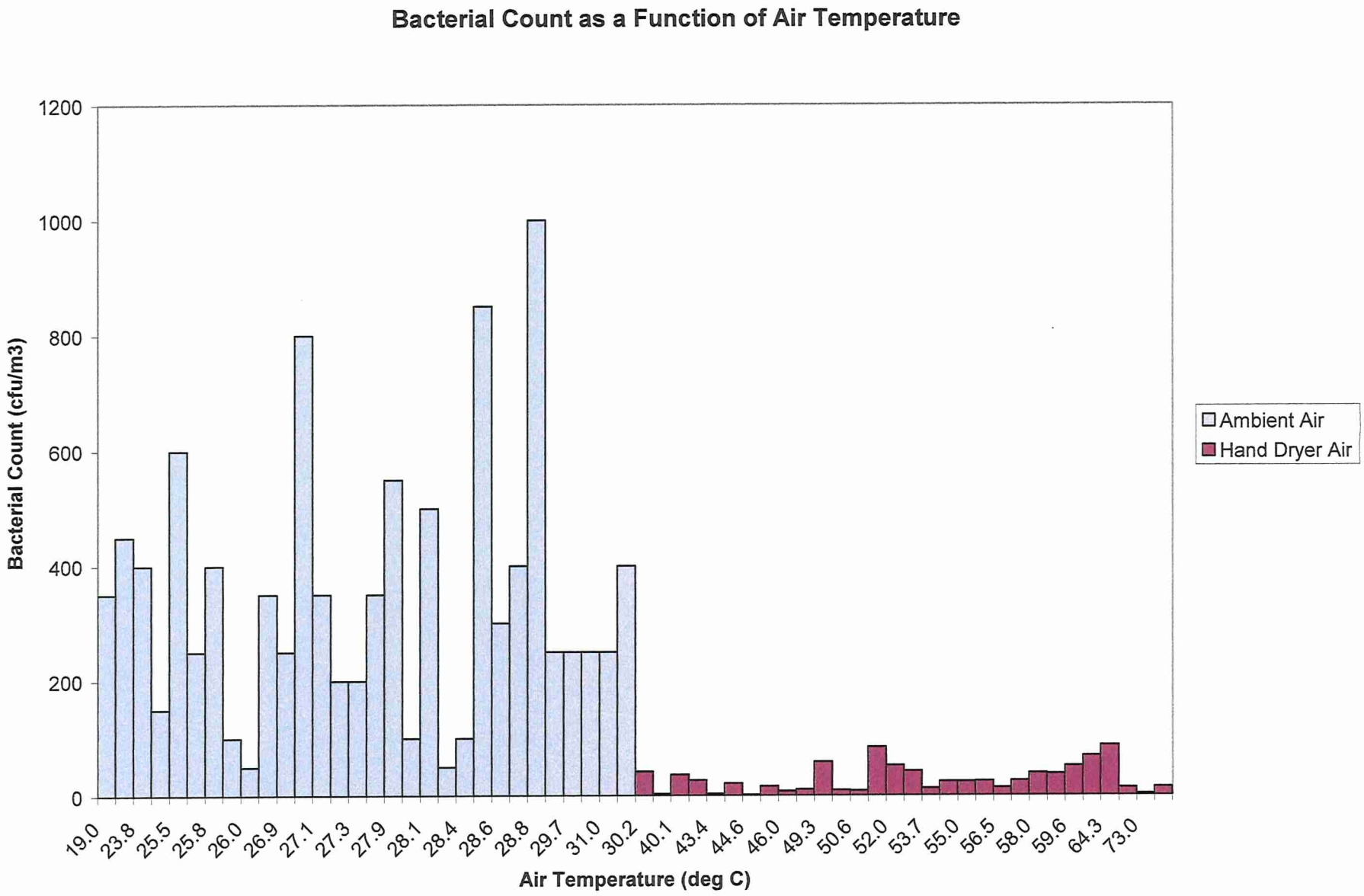


Figure 12. Bacterial Count as a Function of Air Temperature. A decrease in bacterial counts can be seen as the temperature of the air increases.

# Appendix A

| Washroom | Air type** | Count 24 hour | Count 48 hour | Temperature (°C) | Volume ($m^3$) |
|---|---|---|---|---|---|
| 1 | 0 | 36.4 | 42.4 | 30.2 | 0.495 |
| 2 | 0 | 12.8 | 16.8 | 45.1 | 1.725 |
| 3 | 0 | 1.6 | 3.2 | 73 | 0.627 |
| 4 | 0 | 25.9 | 39.5 | 58 | 1.545 |
| 5 | 0 | 21.3 | 24.6 | 54.5 | 1.218 |
| 6 | 0 | 28.6 | 38.1 | 58.5 | 1.26 |
| 7 | 0 | 53.8 | 84.5 | 51.2 | 1.302 |
| 8 | 0 | 33.6 | 37 | 40.1 | 1.458 |
| 9 | 0 | 14.1 | 26.5 | 57.9 | 1.281 |
| 10 | 0 | 11.5 | 13.1 | 53.7 | 1.83 |
| 11 | 0 | 8.3 | 14.3 | 56.5 | 1.68 |
| 12 | 0 | 6.3 | 9.8 | 49.5 | 1.74 |
| 13 | 0 | 11.8 | 14.1 | 66.5 | 0.849 |
| 14 | 0 | 14.3 | 15.6 | 80.1 | 0.768 |
| 15 | 0 | 46.7 | 52.4 | 52 | 1.755 |
| 16 | 0 | 42.7 | 58.9 | 49.3 | 1.359 |
| 17 | 0 | 21.8 | 24.8 | 55 | 1.65 |
| 18 | 0 | 53.3 | 69.4 | 61.5 | 1.8 |
| 19 | 0 | 19.9 | 21.9 | 43.8 | 2.01 |
| 20 | 0 | 29.8 | 51.5 | 59.6 | 1.845 |
| 21 | 0 | 8.2 | 10.8 | 47.7 | 2.325 |
| 22 | 0 | 24.4 | 25.8 | 56.3 | 1.395 |
| 23 | 0 | 6.1 | 8.1 | 46 | 1.98 |
| 24 | 0 | 2.9 | 3.4 | 35.5 | 2.055 |
| 25 | 0 | 77.8 | 87.2 | 64.3 | 1.17 |
| 26 | 0 | 33 | 42.9 | 53.6 | 1.725 |
| 27 | 0 | 5.3 | 8.7 | 50.6 | 1.5 |
| 28 | 0 | 20 | 27.4 | 43.1 | 1.203 |
| 29 | 0 | 0 | 1.5 | 44.6 | 1.32 |
| 30 | 0 | 3.2 | 3.2 | 43.4 | 1.575 |
| 1 | 1 | 350 | 450 | 22.4 | 0.02 |
| 2 | 1 | 0 | 100 | 26 | 0.02 |
| 3 | 1 | 200 | 200 | 27.2 | 0.02 |
| 4 | 1 | 250 | 250 | 30.1 | 0.02 |
| 5 | 1 | 550 | 550 | 27.9 | 0.02 |
| 6 | 1 | 250 | 250 | 26.9 | 0.02 |
| 7 | 1 | 150 | 150 | 25 | 0.02 |
| 8 | 1 | 500 | 600 | 25.5 | 0.02 |
| 9 | 1 | 350 | 400 | 23.8 | 0.02 |
| 10 | 1 | 250 | 300 | 28.6 | 0.02 |
| 11 | 1 | 100 | 100 | 28 | 0.02 |
| 12 | 1 | 300 | 500 | 28.1 | 0.02 |
| 13 | 1 | 250 | 350 | 26.7 | 0.02 |
| 14 | 1 | 300 | 350 | 27.7 | 0.02 |
| 15 | 1 | 850 | 1000 | 28.8 | 0.02 |
| 16 | 1 | 150 | 200 | 27.3 | 0.02 |
| 17 | 1 | 600 | 800 | 27 | 0.02 |

| Washroom | Air type** | Count 24 hour | Count 48 hour | Temperature (°C) | Volume ($m^3$) |
|---|---|---|---|---|---|
| 18 | 1 | 150 | 400 | 28.6 | 0.02 |
| 19 | 1 | 700 | 850 | 28.5 | 0.02 |
| 20 | 1 | 200 | 250 | 29.7 | 0.02 |
| 21 | 1 | 150 | 250 | 29.6 | 0.02 |
| 22 | 1 | 250 | 250 | 31 | 0.02 |
| 23 | 1 | 250 | 250 | 25.8 | 0.02 |
| 24 | 1 | 300 | 350 | 19 | 0.02 |
| 25 | 1 | 250 | 400 | 25.8 | 0.02 |
| 26 | 1 | 0 | 100 | 28.4 | 0.02 |
| 27 | 1 | 50 | 50 | 26 | 0.02 |
| 28 | 1 | 350 | 400 | 31.2 | 0.02 |
| 29 | 1 | 50 | 50 | 28.2 | 0.02 |
| 30 | 1 | 350 | 350 | 27.1 | 0.02 |

** Air type 0 = air from hand dryer

Air type 1 = ambient air

# Appendix B

**Two-Sample Test Report**

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Variable Count_48_hour

**Descriptive Statistics Section**

| Variable | Count | Mean | Standard Deviation | Standard Error | 95% LCL of Mean | 95% UCL of Mean |
|---|---|---|---|---|---|---|
| Air_type=0 | 30 | 29.24667 | 23.55691 | 4.300884 | 20.45037 | 38.04296 |
| Air_type=1 | 30 | 350 | 230.0675 | 42.00438 | 264.0914 | 435.9086 |

Note: T-alpha (Air_type=0) = 2.0452, T-alpha (Air_type=1) = 2.0452

**Confidence-Limits of Difference Section**

| Variance Assumption | DF | Mean Difference | Standard Deviation | Standard Error | 95% LCL of Mean | 95% UCL of Mean |
|---|---|---|---|---|---|---|
| Equal | 58 | -320.7533 | 163.5328 | 42.22399 | -405.2738 | -236.2328 |
| Unequal | 29.61 | -320.7533 | 231.2703 | 42.22399 | -407.0341 | -234.4725 |

Note: T-alpha (Equal) = 2.0017, T-alpha (Unequal) = 2.0434

**Equal-Variance T-Test Section**

| Alternative Hypothesis | T-Value | Prob Level | Decision (5%) | Power (Alpha=.05) | Power (Alpha=.01) |
|---|---|---|---|---|---|
| Difference <> 0 | -7.5965 | 0.000000 | Reject Ho | 1.000000 | 0.999999 |
| Difference < 0 | -7.5965 | 0.000000 | Reject Ho | 1.000000 | 1.000000 |
| Difference > 0 | -7.5965 | 1.000000 | Accept Ho | 0.000000 | 0.000000 |

Difference: (Air_type=0)-(Air_type=1)

**Aspin-Welch Unequal-Variance Test Section**

| Alternative Hypothesis | T-Value | Prob Level | Decision (5%) | Power (Alpha=.05) | Power (Alpha=.01) |
|---|---|---|---|---|---|
| Difference <> 0 | -7.5965 | 0.000000 | Reject Ho | 1.000000 | 0.999998 |
| Difference < 0 | -7.5965 | 0.000000 | Reject Ho | 1.000000 | 1.000000 |
| Difference > 0 | -7.5965 | 1.000000 | Accept Ho | 0.000000 | 0.000000 |

Difference: (Air_type=0)-(Air_type=1)

**Tests of Assumptions Section**

| Assumption | Value | Probability | Decision(5%) |
|---|---|---|---|
| Skewness Normality (Air_type=0) | 2.3037 | 0.021239 | Reject normality |
| Kurtosis Normality (Air_type=0) | 0.7414 | 0.458425 | Cannot reject normality |
| Omnibus Normality (Air_type=0) | 5.8568 | 0.053483 | Cannot reject normality |
| Skewness Normality (Air_type=1) | 2.6301 | 0.008537 | Reject normality |
| Kurtosis Normality (Air_type=1) | 1.6083 | 0.107763 | Cannot reject normality |
| Omnibus Normality (Air_type=1) | 9.5040 | 0.008634 | Reject normality |
| Variance-Ratio Equal-Variance Test | 95.3836 | 0.000000 | Reject equal variances |
| Modified-Levene Equal-Variance Test | 26.4427 | 0.000003 | Reject equal variances |

**Median Statistics**

| Variable | Count | Median | 95% LCL of Median | 95% UCL of Median |
|---|---|---|---|---|
| Air_type=0 | 30 | 24.7 | 14.1 | 38.1 |
| Air_type=1 | 30 | 325 | 250 | 400 |

**Mann-Whitney U or Wilcoxon Rank-Sum Test for Difference in Medians**

| Variable | Mann Whitney U | W Sum Ranks | Mean of W | Std Dev of W |
|---|---|---|---|---|
| Air_type=0 | 12 | 477 | 915 | 67.58046 |
| Air_type=1 | 888 | 1353 | 915 | 67.58046 |

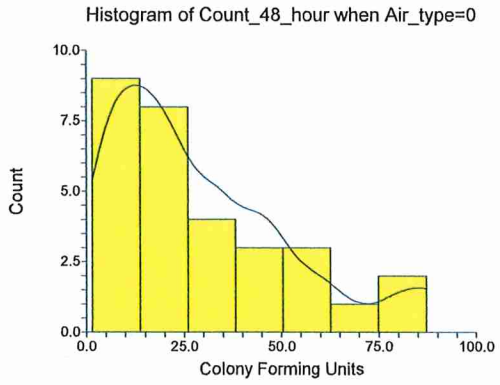
Number Sets of Ties = 7, Multiplicity Factor = 372

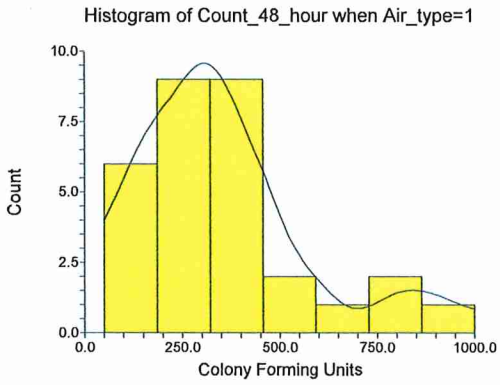
| | Exact Probability | | Approximation Without Correction | | | Approximation With Correction | | |
|---|---|---|---|---|---|---|---|---|
| Alternative Hypothesis | Prob Level | Decision (5%) | Z-Value | Prob Level | Decision (5%) | Z-Value | Prob Level | Decision (5%) |
| Diff<>0 | | | -6.4812 | 0.000000 | Reject Ho | -6.4738 | 0.000000 | Reject Ho |
| Diff<0 | | | -6.4812 | 0.000000 | Reject Ho | -6.4738 | 0.000000 | Reject Ho |
| Diff>0 | | | -6.4812 | 1.000000 | Accept Ho | -6.4886 | 1.000000 | Accept Ho |

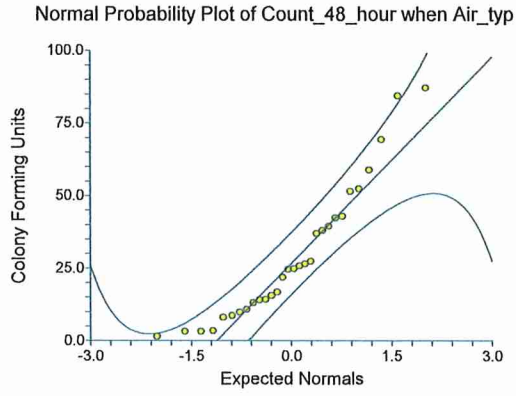
**Kolmogorov-Smirnov Test For Different Distributions**

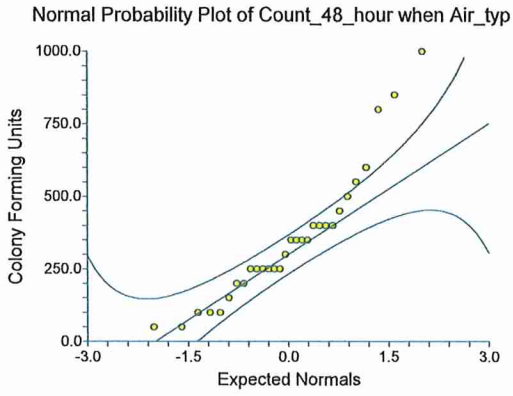
| Alternative Hypothesis | Dmn Criterion Value | Reject Ho if Greater Than | Test Alpha Level | Decision (Test Alpha) | Prob Level |
|---|---|---|---|---|---|
| D(1)<>D(2) | 0.933333 | 0.3512 | .050 | Reject Ho | 0.0000 |
| D(1)<D(2) | 0.933333 | 0.3512 | .025 | Reject Ho | |
| D(1)>D(2) | 0.000000 | 0.3512 | .025 | Accept Ho | |

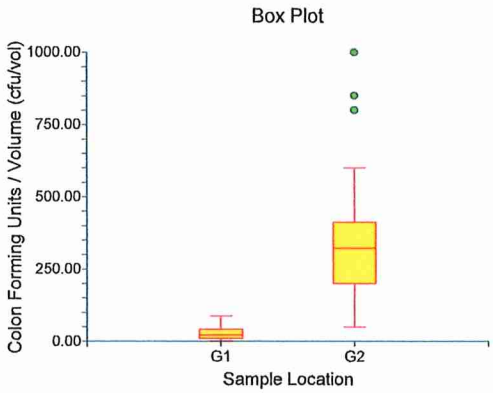
**Plots Section**




Box Plot
Colon Forming Units / Volume (cfu/vol)
1000.00
750.00
500.00
250.00
0.00
G1
G2
Sample Location

# Appendix C

**Two-Sample Test Report**

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Variable Temperature

**Descriptive Statistics Section**

| Variable | Count | Mean | Standard Deviation | Standard Error | 95% LCL of Mean | 95% UCL of Mean |
|---|---|---|---|---|---|---|
| Air_type=0 | 30 | 52.70333 | 10.47218 | 1.91195 | 48.79296 | 56.61371 |
| Air_type=1 | 30 | 27.19667 | 2.494336 | 0.4554014 | 26.26527 | 28.12807 |

Note: T-alpha (Air_type=0) = 2.0452, T-alpha (Air_type=1) = 2.0452

**Confidence-Limits of Difference Section**

| Variance Assumption | DF | Mean Difference | Standard Deviation | Standard Error | 95% LCL of Mean | 95% UCL of Mean |
|---|---|---|---|---|---|---|
| Equal | 58 | 25.50667 | 7.612104 | 1.965437 | 21.57242 | 29.44092 |
| Unequal | 32.28 | 25.50667 | 10.76514 | 1.965437 | 21.50456 | 29.50877 |

Note: T-alpha (Equal) = 2.0017, T-alpha (Unequal) = 2.0362

**Equal-Variance T-Test Section**

| Alternative Hypothesis | T-Value | Prob Level | Decision (5%) | Power (Alpha=.05) | Power (Alpha=.01) |
|---|---|---|---|---|---|
| Difference <> 0 | 12.9776 | 0.000000 | Reject Ho | 1.000000 | 1.000000 |
| Difference < 0 | 12.9776 | 1.000000 | Accept Ho | 0.000000 | 0.000000 |
| Difference > 0 | 12.9776 | 0.000000 | Reject Ho | 1.000000 | 1.000000 |

Difference: (Air_type=0)-(Air_type=1)

**Aspin-Welch Unequal-Variance Test Section**

| Alternative Hypothesis | T-Value | Prob Level | Decision (5%) | Power (Alpha=.05) | Power (Alpha=.01) |
|---|---|---|---|---|---|
| Difference <> 0 | 12.9776 | 0.000000 | Reject Ho | 1.000000 | 1.000000 |
| Difference < 0 | 12.9776 | 1.000000 | Accept Ho | 0.000000 | 0.000000 |
| Difference > 0 | 12.9776 | 0.000000 | Reject Ho | 1.000000 | 1.000000 |

Difference: (Air_type=0)-(Air_type=1)

**Tests of Assumptions Section**

| Assumption | Value | Probability | Decision(5%) |
|---|---|---|---|
| Skewness Normality (Air_type=0) | 0.9702 | 0.331969 | Cannot reject normality |
| Kurtosis Normality (Air_type=0) | 1.1649 | 0.244040 | Cannot reject normality |
| Omnibus Normality (Air_type=0) | 2.2983 | 0.316905 | Cannot reject normality |
| Skewness Normality (Air_type=1) | -2.7468 | 0.006018 | Reject normality |
| Kurtosis Normality (Air_type=1) | 2.4274 | 0.015206 | Reject normality |
| Omnibus Normality (Air_type=1) | 13.4374 | 0.001208 | Reject normality |
| Variance-Ratio Equal-Variance Test | 17.6264 | 0.000000 | Reject equal variances |
| Modified-Levene Equal-Variance Test | 23.3801 | 0.000010 | Reject equal variances |

**Median Statistics**

| Variable | Count | Median | 95% LCL of Median | 95% UCL of Median |
|---|---|---|---|---|
| Air_type=0 | 30 | 52.8 | 47.7 | 56.5 |
| Air_type=1 | 30 | 27.5 | 26.7 | 28.4 |

**Mann-Whitney U or Wilcoxon Rank-Sum Test for Difference in Medians**

| Variable | Mann Whitney U | W Sum Ranks | Mean of W | Std Dev of W |
|---|---|---|---|---|
| Air_type=0 | 898 | 1363 | 915 | 67.63593 |
| Air_type=1 | 2 | 467 | 915 | 67.63593 |

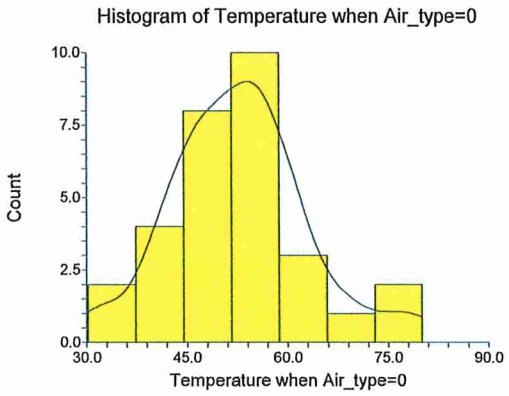
Number Sets of Ties = 3, Multiplicity Factor = 18

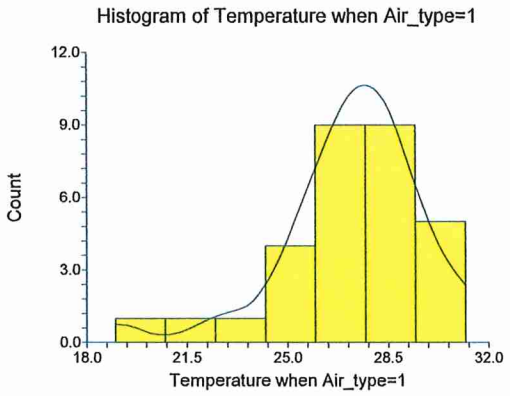
| | Exact Probability | | Approximation Without Correction | | | Approximation With Correction | | |
|---|---|---|---|---|---|---|---|---|
| Alternative Hypothesis | Prob Level | Decision (5%) | Z-Value | Prob Level | Decision (5%) | Z-Value | Prob Level | Decision (5%) |
| Diff<>0 | | | 6.6237 | 0.000000 | Reject Ho | 6.6163 | 0.000000 | Reject Ho |
| Diff<0 | | | 6.6237 | 1.000000 | Accept Ho | 6.6311 | 1.000000 | Accept Ho |
| Diff>0 | | | 6.6237 | 0.000000 | Reject Ho | 6.6163 | 0.000000 | Reject Ho |

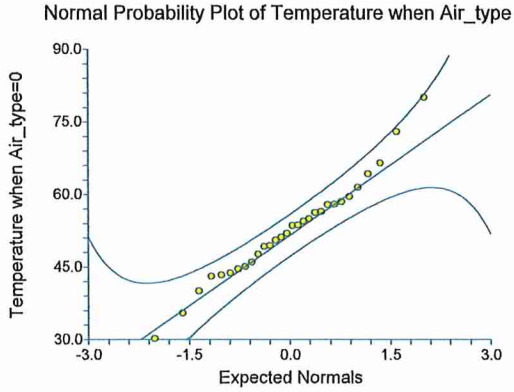
**Kolmogorov-Smirnov Test For Different Distributions**

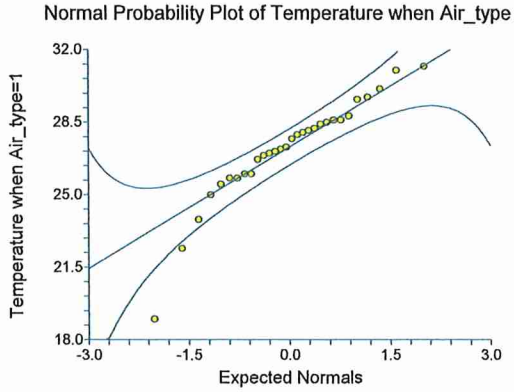
| Alternative Hypothesis | Dmn Criterion Value | Reject Ho if Greater Than | Test Alpha Level | Decision (Test Alpha) | Prob Level |
|---|---|---|---|---|---|
| D(1)<>D(2) | 0.966667 | 0.3512 | .050 | Reject Ho | 0.0000 |
| D(1)<D(2) | 0.000000 | 0.3512 | .025 | Accept Ho | |
| D(1)>D(2) | 0.966667 | 0.3512 | .025 | Reject Ho | |

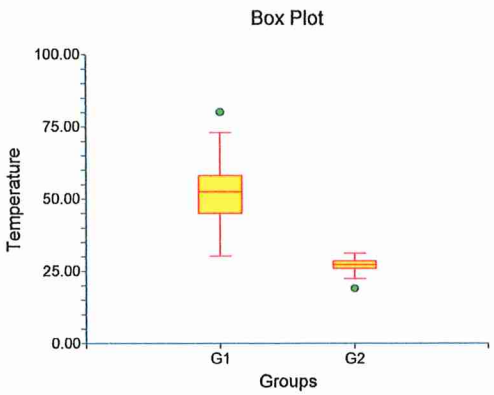
**Plots Section**




Box Plot
100.00
75.00
50.00
25.00
0.00
Temperature
G1
G2
Groups