AN ABSTRACT OF THE THESIS OF

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Title: AN EVALUATION OF AIRBORNE BACTERIA CONCENTRATIONS AND VENTILATION RATES IN AN INDUSTRIAL OFFICE ENVIRONMENT

Redacted for privacy

Abstract approved: ______________________

David C. Lawson

This study investigated the relationship between airborne bacteria densities and varying ventilation rates in industrial office areas. The two objectives of this study were as follows:

to determine the correlation of bacteria density and ventilation rates in each sample area.

to measure the reported incidence of respiratory illness in each sample area.

Fifty-four samples were collected from three companies in the local area. Six sampling sites in each company were sampled three times each, 30 days apart. At each sampling site a survey was administered to all employees working in that area. The study design consisted of two sets of data. The first was a

correlation of bacteria density to seven independent variables, consisting of important factors associated with each study area. The second was a comparison of the percentage of healthy office workers with eight factors taken from the survey questionnaire. A correlation coefficient distribution was used to compare bacteria density to the independent variables listed above.

Analysis of the results of this research provided the following conclusions:

1. The necessary sampling period for industrial office area environments to obtain adequate bacteria colony formation on the cascade impaction collection media was 45 minutes.

2. The normal airborne bacteria density in industrial office areas appeared to be 30 colony-forming units per meter cubed.

3. The air exchange rate, in the range normally experienced in industrial office areas, seemed to have no significant effect on airborne bacteria densities.

4. Illness prevalence among the employees working in the areas sampled in this study appeared to be approximately 50 percent.

5. Negative correlations of temperature and time of day to airborne bacteria density occurred at one of three corporations. Since this was the only company with a variable ventilation system which operated only during the day, further study in this area is warranted.

6. Sixty-five percent of the people who had allergies considered themselves to be in good health. It can be hypothesized that some of the illness reported by the nonhealthy people was really due to allergies.

7. Fifty-eight percent of the respondents who had a low opinion of their air-handling systems considered themselves to be unhealthy. These individuals tended to attribute their illness to the poor ventilation system.

AN EVALUATION OF AIRBORNE BACTERIA CONCENTRATIONS AND VENTILATION RATES IN AN INDUSTRIAL OFFICE ENVIRONMENT

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DEDICATION

To April, my wife, for her understanding of the hours necessary to complete this undertaking.

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Chapter I

INTRODUCTION

One of the most important concerns facing safety or industrial hygiene professionals is the number of complaints and claims of health effects from possible contamination of workroom air. Since 1970 energy conservation measures have led to increased limitations of air movement within office spaces and to the increased recirculation of ventilation air (Bishop, Custer, & Vogel, 1985). Since most ventilation systems only bring in approximately 10 percent fresh make-up air, contaminants, especially microorganisms, that may be produced within the work place may not be effectively diluted or removed (Melius, 1984). How much effect ventilation rates have on the concentrations of microorganisms in the work place is currently not known.

Statement of Problem

The major focus of this study was to compare the relationship between the concentration of airborne bacteria and known ventilation rates in selected industrial office environments. Respiratory illness incidence was surveyed in each of the environments studied. The respiratory illness data were collected using an epidemiological survey to identify the frequency of symptoms.

The Objectives

The objectives in the study were as follows:

1. To correlate the background concentrations of total airborne bacteria and the different ventilation rates in specific office settings.

2. To measure the incidence of respiratory illness in specific industrial office settings.

Assumptions

For the purpose of this study the writer assumed the following:

1. The ventilation rates and bacteria densities were representative of the average rates and densities for each sample location.

2. The flow sensor sampler collected a representative sample of bacterial organisms at the flow rate used to give a medium density of colonies on the plate.

3. The bacterial sampler collection period represented a true indication of bacterial concentrations over the day.

4. Bacterial organisms collected were an indication of pathogenic organisms in the same environment at a relative concentration comparable to the other testing locale.

5. Each bacteria colony was collected as a seperate organism and plated successfully on the growth medium.

Limitations

Any generalization and inferences made as a result of this study by the reader should take into consideration the following limitations:

1. The sample size may not have been large enough to adequately represent the true population.

2. The companies used in this study were from the Corvallis area only which may not have reflected conditions elsewhere.

Definition of Terms

For the purpose of this study several key terms are defined as follows:

ACGIH: American Conference of Government Industrial Hygienists; an organization of industrial hygienists who do not work for industry (ACGIH, 1985).

ASHRE: American Society of Heating Refrigerators and Air Conditioning Engineers (ASHRE, 1981).

Bacteria Colony: an isolated spot of bacteria on a growth agar which usually starts from a single organism and multiplies forming a colony (Flow Sensor, 1980).

Bacteria density: the concentration of bacteria present in the air of the sample location measured in colony-forming units/meter cubed (Morris, 1986).

Cascade impaction: a multi-orifice instrument which will separate airborne particles by size and impact those particles onto a petri dish or filter (Flow Sensor, 1980).

Colony forming unit: an airborne bacteria which can form a colony of bacteria when impacted onto a petri dish of growth agar (Morris, 1986).

Correlation coefficient: used as an index measuring the closeness of fit of $\underline{n}$ observed points to the estimated line of regression (Jerome, 1961).

Demographic data: data collected from a questionnaire which gives information about the individual's vital statistics (Anderman, 1983).

Epidemiological survey: a survey of a study group to determine the prevalence of illness in that study group (Anderman, 1985).

Health: a condition of the body. A state of well being associated with freedom from illness of any kind (Guralnik, 1982).

Healthy: possessing or enjoying good health or a sound and vigorous mentality (Guralnik, 1982).

Hypothesis testing: a hypothesis is a supposition about a true state of nature. A hypothesis test is one that we would like to investigate with the objective of deciding whether we believe it to be true or false (Peterson, 1973).

Illness: an unhealthy condition of the body perceived by individuals within the study group (Guralnik, 1982).

Illness prevalence: the amount of disease associated with the study group (Anderman, 1985).

Inanimate reservoirs: areas in which bacterial and/or fungal organisms can grow outside of a living host (Bishop et al., 1985).

Indoor contagion: the spreading of disease by the movement of pathogenic organisms in an indoor environment (Gunderman, 1980).

Industrial Hygienist: the professional who determines and gives recommendations on the level of airborne and physical contaminants in the work place (Abercrombie, 1981).

Microbial aerosols: minute particles of water in which living organisms are entrained (Riley, 1972).

NIOSH: The National Institute of Occupational Safety and Health, the research agency for occupational safety and health (Abercrombie, 1981).

P value: the probability value used for hypothesis testing; if p value = 0.05, it is at the 95% confidence level (Peterson, 1973).

Pathogenic organisms: organisms that can produce illness in human beings (Guralnik, 1982).

Recall bias: the bias created by respondents to a questionnaire where they fail to place the right information on a question due to a failure to remember the real answer (T. Wetzler, President, Biochem Industrial Services, pers. comm.).

Respiratory illness: any viral bacterial disease, or allergy which attacks the throat, bronchial passage and/or lungs (Abercrombie, 1981).

Selection bias: the bias created by respondents to a questionnaire when the researcher draws the wrong conclusion to a problem due to only a certain type of respondent returning the questionnaire (Wetzler, 1986).

Unhealthy: not in a state of good or normal health; in an unsound, weak, or morbid condition (Guralnik, 1982).

Ventilation rate: the rate at which fresh air moves into the sample location (ACGIH, 1980).

Wellness: positive well-being, the kind of robustness that indicates respect for the body and appreciation of its worth (Cunningham, 1982).

Chapter II

REVIEW OF THE LITERATURE

Indoor air quality in the nonmanufacturing setting has received relatively little notice from researchers and regulatory officials. Workers, however, are more numerous in this type of industrial setting than in the more traditional production work centers (Spengler & Sexton, 1983).

People in this work environment risk exposure to many factors which may be related to illness. The inhalation of biological aerosols is a primary mechanism of contagion for most acute respiratory infections (Raloff, 1984). Air cooling equipment, humidifiers, nebulizers, flush toilets, and carpeting can incubate and distribute pathogenic organisms indoors. Legionnaires disease and humidifier fever are two examples of air conditioner-borne illness (Spengler & Sexton, 1983).

The incidence of respiratory illness is currently one person per 100 persons a year with 4.5 days average lost time per illness (Spengler & Sexton, 1983). Considering the loss of productivity due to the absence of the employee as well as the medical cost and the trauma suffered by the family of the victim, the impact of indoor contagion is significant (Spengler & Sexton, 1983). Little information is available on the relationship between ventilation rates and the density of airborne organisms. This study attempted to establish that relationship in an office setting as well as look at how ventilation affects airborne densities of bacteria and their relationship to rates. Future research will need to address the density of background bacterial organisms allowable to minimize worker illness in the office environment.

Relationship to Energy Conservation and Respiratory Illness

To gain an understanding of why we are just now studying a possible relationship between respiratory illness and ventilation rates, it is important to study current weatherization practices for energy conservation and current ventilation practices in the United States.

During the early 1970s the petroleum price sky-rocketed. Operators of facilities had to find ways of reducing their energy costs. Windows were permanently sealed, high performance insulation to minimize the entry of outside air was put into place, and complex systems utilizing new energy recovery components and air-flow mechanisms were incorporated to keep the building livable. William F. Heineman, an architect, compared the new super-sealed buildings to a space ship. He stated that once we enter, we are completely dependent upon the building's support systems for survival. The amount and quality of the air we breath is totally dependent on what occurs within the system (Bishop et al., 1985).

Home weatherization and energy controls in office buildings have had a substantial impact on inside environments with particular respect to decreases in ventilation rates. An ASHRE publication states that in a typical ventilated building without energy controls, the energy required to heat and cool outdoor air amounts to 20 to 50 percent of the energy used (ASHRE, 1981). Potential conflicts exist between air quality and energy economics, and are apparent in existing building codes (ACGIH, 1980). States now are beginning to inform the public of the potential health hazards associated with building tightening (Woods, 1979). It is possible that disease organisms have a much greater potential for buildup in an environment with low air movement or recirculated air.

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRE) standard, entitled "Energy Conservation in New Building Design," specifies the minimum values of ventilation to be used for design purposes (1975). This standard is the most prevalent in current local and state building codes. To allow for as much efficiency as possible, the standard allows for incorporation of some method of recirculated air.

A "marriage" of energy conservation and indoor air quality is currently being explored. A joint American Hospital Association and Honeywell four-phase study that began in 1983 was designed to evaluate ventilation methods. Its aim was to improve both indoor air quality and reduce energy consumption. The ASHRE standard (1981) entitled "Ventilation for Acceptable Indoor Air Quality," was designed to help clarify the optimum balance between energy conservation and the health and safety of the work force. Though the task is not an easy one, up-grading of ventilation equipment, awareness of potential problems, and improved air quality sampling techniques are reducing potential indoor air quality problems (Duffy, 1985).

Possible Relationship of Ventilation Rate to Disease

The American Conference of Governmental Industrial Hygenists has recommended that recirculated air not be used anytime a potential contaminant can be released in sufficient quantity to cause adverse health impact. They base this recommendation on the following:

- Air cleaners may not be effective enough to remove an adequate amount of the contaminant.
- Poor maintenance of air cleaners can result in the return of a contaminant to an occupied space.
- Improper operation or failure of an air cleaner can result in elevated concentrations of a hazardous contaminant (Woods, 1979).

Chemical contaminants are relatively easy to measure and hence can be controlled; however, the relationship of pathogenic organisms to worker illness is not understood. With continuing increases in energy costs, office buildings will be designed to conserve heat and refrigeration. How much ventilation is needed to maintain pathogenic organism densities at a minimal level, or if these organisms build up in the office environment, needs to be answered. This study's objectives do not address the above questions directly;

however, this study will attempt to quantify the risk to workers from these contaminants.

The ASHRE standard (1981), entitled "Ventilation for Acceptable Indoor Air Quality," is the first step by ASHRE to address indoor air problems in any work environment. The standard states that indoor air should not contain contaminants that exceed concentrations known to impair or cause discomfort to occupants. The standard recommends that outdoor air requirements for an office space containing no smokers be set at a minimum of five cubic feet per minute per person. This level is the minimum rate necessary to dilute the CO_2 produced by each individual's metabolism. The standard does little to actually recommend rates to prevent indoor air quality problems. Further problems exist when applying ASHRE standards to open office space design. In this style of building the make-up and exhaust vents for ventilation are in the ceiling. Little exchange of air within each cubical may exist at the desk level. Proper measurements of air movement have not been extensively made at the office worker's breathing level. With the existence of these dead zones, proper dilution of airborne bacterial organisms might not occur.

It was also possible that too much ventilation and/or refrigeration of office areas may be a potential risk to worker's health. The ventilation and air conditioning systems of some buildings have been shown to be the source of microbial aerosols, either from contaminated air entering the system or directly from microbial growth within the system (Spendlove & Fannin, 1983). External sources of bacterial contaminants can penetrate the structure through the air intakes, and inside organisms are spread through the recirculating features of most ventilation designs. Correlations between illness and air recirculation systems have been established in partially closed air systems on submarines and surface ships. These instances indicate that disease organisms can spread from one individual to infect an entire crew (Houk, 1980). Microbial growth in ventilation systems has been established to exist any time water is present or the humidity in the system exceeds 97 percent. Legionella species are the best example of this (Gunderman, 1980). Again the question of how much ventilation (in this case, how much is too much) needs to be addressed.

It was not the objective of this study to establish the recommended ventilation rates for office areas to minimize exposure of potential disease organisms to workers. However, by the establishment of a positive or negative correlation between the background concentrations of total aerobic bacteria and specific ventilation rates, a measurement technique may begin to be developed.

Effect of Airborne Pathogenic Organisms in the Work Environment

Once pathogenic organisms are introduced into a work environment, how they are transmitted and where they can build up reservoirs for future disease transmissions can be explored. This has been done in hospital settings.

The mode of transmittal can be from a variety of sources. Most opportunistic bacteria, however, are derived from the microbial flora of the individuals who are present in the work areas themselves (Preston, 1980).

In the early 1900s it was commonly believed that airborne transmission of disease was of very little importance. Transmission of disease organisms was believed to be rare or even impossible over distance. The evidence which was available indicated that infection by means of the air was of little importance (Chapin, 1910). It is now believed that respiratory infections are transmitted from person to person, and that the source of the disease organism is the respiratory tract of the infected person. The infected person's airborne organisms must either die or be vented to the outdoors for the air to become noninfectious. Droplet nuclei, the vehicles that carry the infectious organisms are produced by coughing, sneezing, singing or even talking (Riley, 1982).

Inanimate reservoirs such as the floor covering may also influence the concentration of airborne contagion. Microbial concentrations on carpeted floors are found to be up to 100 million organisms per square meter (Spendlove & Fannin, 1983). Other potential sources can be floor drains and waste disposal systems. Legionella bacteria have been found, for example, in water samples taken from a rooftop air conditioning unit serving the banquet room at the Detroit Airport Hilton Inn.

Airborne bacterial particles can be divided into three groups. These groups are separated by size and include dust-borne bacteria, droplet-borne bacteria and bacteria representing the droplet from which all or most of the moisture has evaporated (Walter, 1966). Each size of particle can be transmitted or stored in a fashion different from the others.

It has been observed by Spendlove (1983) that the atmosphere of a populated building constitutes an ecological unit throughout which aerosols from various sources move on air currents. Once the organisms are released into the work environment regardless of the source, they are dissipated by the air currents. Whether the organism has the potential to cause illness or not depends on the dose (concentration) and length of exposure by the person at risk.

Level of Risk from Airborne Pathogenic Organisms

Most of these organisms have the potential to reach a level of hazard to susceptible people sharing the same air supply. Visible organisms in droplets can and do remain airborne and potentially infectious (Riley, 1974).

Hypersensitivity pneumonitis is one example of an illness which has been found in office workers since 1970. Acute symptoms are manifest four to eight hours after inhalation of dust containing the microbial agent. Sources of the microbial contamination in office buildings include elements of the heating, ventilation, and air conditioning system (Morey, 1984).

At what level of risk are office employees exposed during their working hours? How many people are truly affected by these hazards? Few assessments are available on the number of office workers nationwide who may be affected with respect to these health risks. In order to evaluate the hazard, the number of individuals, the severity of exposures, and the consequences of these exposures must be examined. There is, however, very little information available to address these questions (Arndt & Chapman, 1982). Accurate assessment of risk is difficult without data linking illness, ventilation rates, and a method for evaluating the level of organisms present in the work environment.

Current Study on the Relationship of Ventilation and Bacteria Density

Robert Morris in 1986, however, demonstrated in a laboratory environment that airflow rates directly affected bacteria levels. He found levels of bacterial organisms after a "typical" shutdown period (48 hours) of up to 16,300 colony-forming units per meter cubed (CFU/m^3) as compared to outside concentrations of 115

CFU/m^3. Seventy-eight air exchanges per hour were required to drop the indoor airborne bacteria concentration to 340 CFU/m^3.

Chapter III

METHODS AND PROCEDURES

Study Design

This study was constructed to collect two sets of data. The first set of data resulted from the measurement of airborne bacteria concentrations in each office area. These concentrations were collected and compared to the following independent variables: a. temperature, b. humidity, c. number of employees, d. time of day sampled, e. density of employees in the sampling area, f. velocity of air movement, and g. the air exchange rate. These independent variables were obtained from the air monitoring summary sheet and represented factors which were observed and noted during each sampling period.

The second set of data resulted from calculating the percentage of healthy individuals in each of the following categories: a. company worked for, b. sickness frequency, c. illness time of day, d. place of ill health, e. allergy and allergy type, f. floor covering, g. smoking, and h. opinion of the air handling system. The independent variables were taken from a preinvestigation health questionnaire (Appendix 2) administered to employees in each surveyed study area.

Subjects

Fifty-four samples at three companies, Hewlett Packard, Intellidex, and Summit Corporation, were taken to determine the sample size of bacteria density. Six sampling sites were chosen from each of the three companies. The companies were chosen because of their proximity to Oregon State University. All three were electronic equipment or software manufacturers.

Hewlett Packard employs approximately 2000 employees. Its buildings use a variable ventilation system which adjusts the amount of fresh air coming into the building. This was performed automatically by sensors which regulate the inside temperature by adding outside air. Intellidex had an employee population of 500 to 700. The building was equipped with a series of individual heat pumps located throughout the plant. Fresh air is brought in at a steady rate of 10 percent of the total. Summit Corporation employs 200 people. Like Hewlett Packard, it used a variable ventilation system which continuously adjusts air flow from the outside to regulate building temperature.

The six locations at each company represented selected areas, which met three criteria. The first criterion specified an ability to segregate the location from other employee areas. The second specified that the area was in a non-manufacturing setting (office, etc.), and the third, that the areas constitute a representative sampling of the total office capacity of each company.

The entire study was repeated three times in each area, 30 days apart. For the purpose of definition in this study, the combined sample (taken from six plates of different particle sizes) was defined as a single sample. Each plate was separately evaluated, however, to determine the settling rate of viable organisms.

Treatment

This study was accomplished by a discrete sequence of events which included the following activities:

1. The three companies were selected.

2. Samples were collected to determine the most appropriate sampling period, which (a) gave adequate results (a representative sample, around 60 to 70 colonies), (b) gave an even distribution of colonies for a medium density of colonies on the plate, and (c)

did not allow the organisms to dry out on the plates. It was determined that 45 minutes represented the appropriate sampling time.

3. The preinvestigation Health questionnaire was administered to the three Oregon electronics companies.

4. Six office areas were sampled in each selected location for bacteria densities.

5. Each office area was characterized regarding ventilation flow.

6. A comparison was made of ventilation rates, bacteria densities and illness prevalence.

7. The process was repeated two more times in each setting, 30 days apart.

Statistical Analysis

Consultation with the Statistical Consultant Services at the Oregon State University Computer Center resulted in the selection of appropriate statistical tests for the data in this study. For the bacterial density comparisons, a correlation coefficient analysis was conducted. Bacteria density was compared to the independent variables listed in the study design. A hypothesis testing method was designed, in which the null hypothesis listed no correlation and the alternative hypothesis listed a positive correlation. Whether the correlation coefficients were significant was set at a 95 percent confidence level (p value $\leq$ 0.05).

For the illness prevalence data, percentages of healthy versus unhealthy responses were compared to the list of independent variables listed in the study design (Peterson, 1973).

Instruments: Equipment/Calculation Methods

Preinvestigation Health Questionnaire

The epidemiology section of the Benton County Health Department, in consultation with the State of Oregon Health Division, and the Oregon State University (OSU) Department of Health, prepared the preinvestigation health questionnaire that was used in this study. The instrument was originally developed to address concerns over the indoor air quality of a Benton County building. This questionnaire was obtained and suggested for use in this study to assess the degree and level of apparent respiratory illness. This level of respiratory illness was determined from workers' perceptions of their wellness and was derived from how they answered the questionnaire. Additional information associated with the construction of this questionnaire can be obtained from Dr. William Anderman, formerly of the Department of Health at OSU (Anderman, pers. comm.).

Model 1640 Air Velocity Meter

This meter was a hand-held anemometer used for making air velocity measurements from 0 to 60 feet per minute (TSI Corporation). It was designed for ease of operation and transportability. The readout was in units of velocity. To measure velocity the sensor was placed in line with the air movement and the equipment was allowed to be exposed to the air flow for one minute. It was possible to calibrate the meter sensor by checking and aligning the scale at zero air flow. The error factor in reading the scale was approximately plus or minus 0.5 feet per minute.

Flow Sensor 1 ACFM Microbial Air Samplers/Bacteria Density Determinations

This instrument was a multi-orifice cascade impactor, which was designed to measure the concentration and particle-size distribution of airborne bacterial aerosols (Flowsensor, McLean, VA). The microbial particles can then be collected on bacteriological agar and incubated in situ for counting and identification. This sampling device was used as a substitute for the respiratory tract as a collector of viable airborne particles and, as such, reproduces the lung penetration of these particles. The impactor consists of six stages, with each stage containing multiple, precision-drilled orifices. When air was drawn through the sampler, multiple jets of air at each stage direct any airborne particles towards the surface of the agar collection surface. The size of the jet orifices were constant for each stage but smaller, with each subsequent stage achieving segregation of organisms by size. The number of microbial aerobic particles per unit of volume of air sampled was computed by counting the number of bacterial colonies on each sample plate after incubation. This count assumed the microbiological theory that each colony represents a single particle.

This six-stage sampler had a flow rate of 30 L/min. The volume of agar in the petri dishes was adjusted for maximum collection efficiency.

A sandwich agar was used, based on the recommendation of Dr. William Anderman. It consisted of a first stage of sabouraud dextrose, four slides of nutrient agar and the bottom six slides as trypticase soy agar. The agars were prepared as recommended mixture provided by the manufacturer (Carolina Biological Supply, Burlington, NC). The flow sensor was precleaned and postcleaned between samples with isopropyl alcohol wipes.

After the samples were collected they were incubated at $35^{\circ}C$ for 48 hours. The samples were then counted for total colonies. The numbers from all six plates per sample were combined and that number was divided by the total volume of air sampled in cubic meters. This final number was the bacteria density for the sampling site (Flow Sensor, 1980).

Alnor Balometer/Ventilation Rate Calculations

This instrument (Alnor Instrument Company, Niles, IL) was designed to assist the user in rapid and accurate measurements of air distribution systems. The Balometer directly measured the average air flow rates and thus eliminates the need for multipoint "traverses," the resulting calculations, and use of K factors. In this study, the air was measured by directing air flow past a square manifold which senses 16 points. This manifold was connected to an Alnor Velometer, which was capable of reading air flows up to 2000 cubic feet per meter. Air exchanges were calculated for each sampling site during the sampling period.

The volume of air coming into the sampling area was provided by measuring the air flow of the supply air opening using the Alnor Balometer. The ducts were added together to arrive at the total cubic feet per minute (CFM) of air movement. This number was divided into the total area (cubic feet) of the room. The resultant number was divided by the percent of outside air. The outside air percentage was calculated by a ratio method developed by Bruce Hecht, a facilities engineer manager in charge of heating and ventilation systems for Hewlett Packard. This number was then divided into 60 (minutes per hour) to result in the air change over per hour rate (Alnor, 1975).

Chapter IV

RESULTS AND DISCUSSIONS

Bacteria Density and Ventilation Rates

The bacteria density had a range of 8 to 90 colony-forming units (CFU) per meter cubed (m^3) of air sampled. The mean and standard deviation for all sample points were 30 CFU/m^3 and 16.8 CFU/m^3 respectively. The ventilation range was 0 to 11.8 air changeovers per hour. The mean and standard deviation for all sample points were 2.6 and 3.0 changeovers per hour, respectively (see Table 1).

Table 1. Bacteria density and ventilation rate determinations

	Bacteria Densities (CFU/m^3)	Ventilation Rates (Air Changes/hour)
Range		
Low	8	0
High	90	11.8
Mean	16.8	2.6
Standard Deviation	30	3.0

Correlation of Bacteria Density to Environmental Conditions

The sample correlation coefficient estimates for bacteria density were determined for the seven environmental conditions of the work community surveyed at Hewlett Packard, Summit, and Intellidex Corporations. Each condition listed varied at each sampling site within the company and between companies. A confidence level of 95 percent was used with sample correlation coefficient estimates as the test statistics. The environmental conditions are listed below with an explanation of each.

- Temperature: the mean air temperature at the sampling site during the period of the sampling.
- Humidity: the mean moisture content of the air during the period of sampling for each sampling site.
- Number of employees: the number of workers located within the sampling area.
- Time of day: when the sampling occurred during the work shift.
- Density of employees: the number of workers

located within the sampling area divided by the square footage of the area.

- Velocity of air movement: the average speed of air movement next to the flow sensor sampler during the sampling period.
- A.P. exchange rate: how often the total air supplied to each sampling area was exchanged completely with free air from outside the building where the sampling was conducted.

All environmental conditions were chosen because they varied throughout the study and may have had a correlation to the bacteria density obtained for that area at that sampling time.

When all data were compiled (Table 2) no statistical significant correlations ($\underline{p} \leq 0.05$) were found.

Table 2. Sample Correlation Coefficient Estimates for Bacteria Density versus Environmental Conditions: All Companies Combined

	Correlation Coefficients	p-value
Temperature	0.04	0.80
Humidity	0.10	0.45
Number of employees	0.19	0.17
Time of day	-0.12	0.39
Density of employees	-0.07	0.62
Velocity of air movement	-0.22	0.11
Air exchange rate	-0.11	0.42

p value $\leq$ 0.05 indicates a significant correlation

When the data for Hewlett Packard (Table 3) were examined separately, again no statistically significant correlations were found.

Table 3. Sample Correlation Coefficient Estimates for Bacteria Density versus Environmental Conditions listed: Hewlett Packard

	Correlation Coefficients	p-value
Temperature	0.06	0.80
Humidity	-0.36	0.14
Number of employees	0.02	0.93
Time of day	-0.01	0.98
Density of employees	-0.20	0.42
Velocity of air movement	-0.18	0.47
Air exchange rate	-0.31	0.21

p value $\leq$ 0.05 indicates a significant correlation

A negative correlation for temperature and time of day of sample existed for bacteria density at Summit Corporation. This indicates that temperature and time of day varied inversely to bacterial density. For lower temperatures and samples which were taken earlier in the day at Summit, higher bacterial densities existed (Table 4).

Table 4. Sample Correlation Coefficient Estimates for Bacteria Density versus Environmental Conditions: Summit

	Correlation Coefficients	*p*-value
Temperature	-0.58	0.01*
Humidity	0.44	0.07
Number of employees	0.27	0.28
Time of day	-0.60	0.01*
Density of employees	-0.20	0.43
Velocity of air movement	-0.08	0.74
Air exchange rate	-0.13	0.61

*p value $\leq$ 0.05 indicates a significant correlation

A negative correlation was obtained at Intellidex between velocity of air movement and bacterial density. In areas at Intellidex which had lower air movement, higher bacterial densities existed (Table 5).

Table 5. Sample Correlation Coefficient Estimates for Bacteria Density versus Environmental Conditions: Intellidex

	Correlation Coefficients	p-value
Temperature	0.38	0.12
Humidity	0.38	0.12
Number of employees	0.26	0.31
Time of day	-0.01	0.99
Density of employees	-0.06	0.80
Velocity of air movement	-0.52	0.03*
Air exchange rate	-0.22	0.38

*p value $\leq$ 0.05 indications a significant correlation

Analysis of Pre-Investigation Health Questionnaire

The percentage of healthy and nonhealthy workers was listed for nine categories in Table 6. The health of the worker (see Definition of Terms, Chapter I) was assumed to compare well with each respondent's perception of good health as shown on the health questionnaire. The categories and percentages were obtained from the completed health questionnaires. For each company, questionnaires were administered only to workers in the six areas that were sampled for bacteria density.

The following is the list of questions about illness that the researcher attempted to answer by questionnaires.

1. Did the company the employees worked for affect whether the respondent was ill?

2. Did the frequency of illness over the past 30 days affect whether or not respondents were ill?

3. At what time of day did they feel ill?

4. At what place (home or work) did they feel ill?

5. Did the respondent have any allergies?

6. If there were allergies, were the types listed causing illness?

7. Did type of floor covering affect feeling of illness?

8. Did smokers in this study differ from nonsmokers in feeling ill?

9. Did the respondent's opinion of the air system relate to whether they felt ill?

Below is a description of the results obtained by the survey:

1. In each company, approximately 50 percent (+5%) of the employees responded that they were ill sometime in the last 30 days.

2. Outside of the first question regarding illness the rest of the responses to the preinvestigation health questionnaire were not usable. This instrument allowed for responses which conflicted with the intent of the

questions. Answers did not follow any logical course and were inconsistent.

Table 6. Percent of healthy workers listed by company from the preinvestigation health questionnaire.

Questionnaire Responses	% of healthy workers
Company working for	
HP	55
Intellidex	48
Summit	55

Discussion

The analysis of the results from this study suggest the following conclusions.

1. Forty-five minutes was the necessary sampling period for industrial office environments to obtain adequate bacteria colony formation on the cascade impaction collection media (easily readable at 60 to 70 colonies per plate). This sampling period was longer than that recommended by the Flow Sensor manufacturer (30 minutes) and the five- to ten-minute periods normally used in hospital sampling.

2. The results from this study suggest that the

normal bacteria density in office areas is 30 CFU/m^3.

Three areas, however, need to be re-evaluated in order to draw a final conclusion. The first was that background levels of bacteria were not taken outside of each company at the nine major sampling periods. The difference between the office area's bacterial density and these outside bacterial counts would have been useful to establish whether a building's ventilation system might have been magnifying the airborne bacteria population. Also, the ventilation air exchange rate could not be varied over a large range of values. Even with the relatively low bacteria densities measured in this study, a wider range of air exchange rates might have had an effect on airborne bacteria load. The third area was the type of agar medium used. Trypticase agar was considered in the NOISH sampling strategy to be the most appropriate medium to use for general bacteria counts. Different bacteria densities might have been achieved with use of this agar alone.

3. When testing the relationship between the background concentrations of total airborne bacteria and the different ventilation rates in specific office settings, as well as testing the relationship of bacteria densities to other factors at each corporation sampled,

the following conclusions can be drawn:

- The air exchange rate seems to have had no significant effect on airborne bacteria densities in the range normally experienced in industrial office settings. No statistically significant correlation in this study existed between airborne bacteria density and ventilation rates.
- The negative correlations of temperature and time of day ($p = 0.01$) to bacteria density at Summit Corporation needs to be examined further. These indicate that temperature and time of day of sample varied inversely to bacterial density for the data obtained at Summit Corporation. Since Summit was the only company with a variable ventilation system, which only operated during the day, further study is warranted in this area.
- The negative correlation of velocity of air movement ($p = 0.03$) and bacteria density at Intellidex Corporation was significant. Intellidex had a heat pump ventilation design that was different from that of the other two companies surveyed.

4. In measuring the incidence of respiratory illness in specific industrial office settings, most of the data obtained from the employee illness prevalence questionnaire was nonconclusive. Selection and recall bias may have had a significant impact on the results.

The reader is cautioned on the usability for drawing conclusions of the questionnaire responses (listed in Appendix 3), however, two items of data were interesting and need to be explored further. A majority of the respondents who saw themselves as nonhealthy had a much lower opinion of the office air handling system. The majority of these respondents rated it as poor. The reverse was true for the healthy people. This, coupled with the informal comments that were received, suggests that individuals who considered themselves to be sick wanted to focus the cause of their illness on the building ventilation system. Secondly, 65 percent of the people who had allergies considered themselves to be in good health. It can be hypothesized that some of the illness symptoms reported by the nonhealthy people were actually allergy symptoms.

These two factors suggest that respondent's attitude has as much to do with their perceived health as actual illness. The data which was obtained by this study can not draw any firm conclusions in this regard, however, employee concerns of their health and their tendency to focus their problems on their workplace is an area which management needs to address.

Chapter V

SUMMARY

Questions of indoor air quality and the problems caused by airborne microorganisms have received relatively little notice from researchers and professionals in the field. Industrial buildings built since 1970 have incorporated many ways, including recirculation, to reduce energy consumption. Because of this, problems have occurred from recirculated airborne pathogenic organisms. Few assessments are yet available of the levels of risk to which office employees are exposed from bio-aerosols in the workplace.

The two principal objectives proposed by this study were (a) to measure the incidence of respiratory illness in each of the sample areas in the study, and to date (b) to determine the relationship of bacteria density and ventilation rates in specific office settings. These objectives were set to evaluate factors in office areas as a preliminary investigation for assessing the level of risk from microorganisms in the office environment.

Fifty-four samples were collected from three companies in the Corvallis area. The companies were Hewlett Packard (HP), Summit, and Intellidex Corporations. Six sampling sites in each company were sampled three times each, 30 days apart. Each company had a different population size, ranging from HP's population of 2500 employees to Summit's population of 200. The two types of ventilation systems used by the companies in this study were heat pumps and variable ventilation demand systems.

This study was broken into seven distinct events. They are outlined as follows:

1. Selection of the three companies.
2. Determining the appropriate sampling length.
3. Administration of the preinvestigation health questionnaire.
4. Actual sampling for bacteria densities.
5. Determination of the air exchange rates.
6. Relationship of variables to each other.
7. Repeating the process two more times.

The study design consisted of two sets of data which correlate bacteria density to a seven environmental conditions and the percentage of healthy individuals to their responses to key phrases in the questionnaire. Correlation coefficient analysis was used to correlate bacteria density to the independent environmental conditions listed in the study design (95% confidence).

Conclusions

Three sets of significant findings were obtained from this study. The first involved the determination of bacteria densities and ventilation exchange in industrial office areas. The bacteria density concentrations had a range of 8 to 90 colony-forming units (CFU) per meter cubed (m^3) of air sampled. The ventilation range was 0 to 11.8 air exchanges per hour. Length of sampling time necessary to obtain a sample was 45 minutes. This amount of time will yield adequate bacteria colony density in an office environment.

The second finding was that no significant relationship existed between air exchange rates and bacteria densities in the industrial office areas sampled. No significant correlation existed with all data compiled together or each company listed separately (Tables 2-5) for total aerobic bacteria versus different ventilation rates. Three significant correlations ($p \leq 0.05$) did exist, however, with three other independent variables. Negative correlations of temperature ($p =$

0.01) and time of day (p = 0.01) existed when compared to bacteria density at Summit Corporation (Table 4). A negative correlation of velocity of air movement (p = 0.03) and bacteria density occurred at Intellidex.

The third finding was related to the incidence of illness (employees who percieved themselves to be ill over the past 30 days) at each company in the study. The incidence of illness at Hewlett Packard, Intellidex, and Summit Corporation was 54.9, 48.1 and 54.5 percent, respectively (Table 6).

Implications of Findings

Several implications can be drawn from this study. To measure microorganisms in a well environment the sampling period must be four and one-half times longer than the previous recommended time period. However, sampling for this length of time will be difficult because of potential organism death due to desiccation.

The average bacteria density of 16.8 CFU/m^3 was a level which can be used for comparison in future measurements of unhealthy industrial environments. This rate can serve as a no effect background level of comparison.

Since the range of ventilation rates in this study was small, the nonstatistically significant relationship of bacteria density to ventilation rates may be in error. Doubling of ventilation rates might change these results.

The air monitoring summary sheet developed in this study will be of use to anyone measuring microorganism densities in an industrial work environment.

A ventilation system which shuts down overnight as at one company in this study, may affect the bacteria densities of that work environment. Measurements for microorganisms in this kind of situation should take place in the afternoon after the organism density has stabilized.

Use of a health questionnaire has given nonconclusive results in this study. Without an illness for workers to report, selection and recall bias may have significantly affected the accuracy of the questionnaire results.

Fifty percent of all workers surveyed felt they were not well. It may be speculated that the workers perception of their health had as much to do with this percentage as actual illness.

Healthy people tended in this study to recognize that they had allergies. Education of employees regarding the potential effects of environmental allergies may lead to measures to reduce the percentage of the illness.

Many employees who reported illness had a low opinion regarding air-handling systems. Knowing this has potential value to management. Blaming the company for illness is more common if employees do not have an understanding of or if they dislike their ventilation system.

Recommendations for Future Research

If replication of this study was to occur, it is suggested that the researcher use the draft procedures from NIOSH published in the latter part of May 1986. These procedures used a different protocol for elements of bacterial sampling than was used in this study. The major differences are as follows: 1) blank samples were taken before taking the measurement sample. This procedure adjusts for possible background contamination of the sampling plates. 2) Outside baselines were taken to determine the normal rate of organisms going into the building. All results should be compared to these background rates. 3) Incubation periods should be 3 to 12 days, depending on the organisms. 3) A two-stage

Anderson Sampler should be used rather than a six-stage sampler. However, multiple-stage samplers can be used without error. 4) Trypticase soy agar should be used rather than the media-sandwich approach of sabourand dextrose, nutrient, and trypticase soy. 5) Sampling should only be conducted after medical or clinical reports indicate the existence of workplace-related illness and allergies that are likely due to bioaerosols (OSHA, 1986).

Also, since OSHA/NIOSH protocol addresses indoor air problems which have already occurred it is suggested that one area of future work focus on a chronological study of each company surveyed to obtain real time illness data. By using actual absentee rates from medical claims filed by workers and performing periodic bacteria sampling over the same time period, a statistical relationship between illness and bacteria rates could be determined.

Lastly, it is suggested that the following factors be taken into consideration if replication of this study occurs: 1) Eliminate recall and selection bias in the illness questionnaires. Better construction of questions minimize recall bias. Also, return rates varied from 55 to 92 percent. This variation needs to be minimized. 2) Duplication of sampling and use of additional sites needs to be explored. The sample size of 54 samples with only three companies may not reflect the true population. 3) A thorough review and followup sampling needs to be conducted to confirm the relationship of bacteria density to time of day, temperature, and velocity of air at Summit and Intellidex Corporations. 4) Other areas of the state and nation should be surveyed. 5) Replication of this study with higher ventilation rates needs to be accomplished. Ventilation rate ranges approaching three times this study's range would result in stronger conclusions. 6) The preinvestigation health questionnaire needs to be redesigned to minimize inconsistencies in the results. If a study of this type is conducted in the future a reliable instrument needs to be developed. 7) Employee attitude and its relationship to worker illness needs to be explored. Without a better understanding of this relationship misinterpretation of illness percentages can occur.

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APPENDICES

Air Monitoring Summary Sheet

Date:

1. Demographic Data

Company:___________ Building ____________ Department_________

Vertical Ceiling Height ______________

Location Code: ____________ Column/Post Number: ____________

Sampling pt:___________ Sampling Equipment used: ___________

Temp: ________________________ Humidity: _____________________

Suspected Contaminant: ______________________________________

Time of day sampling takes place: __________________________

Number of employees in area: ________________________________

____

Density of employees (people/sq. ft.):

A. Area Sampled ____

B. Individual Office Space __________________________________

2. Cleaning Data

Type of floor covering: _______ Last time cleaned: ______

Frequency: _________________

Type of cleaning (specify dry or wet): _____________________

Name of cleaner(s): ____

____

3. Ventilation Data

Air exchange rate for building: ____________________________

Number of vents: ______

CFM of air movement: ____

Velocity of air movement(AVE): ______________________________

Temperature:

A. Outside ________ B. Inside ________ C. Mixed duct______

Area of sampling point (cubic feet) ___________

Diagram of air flow: Diagram building location of sample:

4. Bacterial Density Data

Sample Number	Location	Initial Time	Final Time	Total Time	Flow Rate	Contaminant Amount	Contaminant Concentration (Colonies/m^3)

Results:____

Observations:____

PREINVESTIGATION HEALTH QUESTIONNAIRE

This questionnaire is being given to all occupants in this office area to gather preliminary data for an epidemiological study concerning of illness rates associated with different office environments. Your cooperation is needed in accurately completing this questionnaire.

Age:__________ Sex:__________ Date:______________________

# of people in household (home) _________
area/location of home ________________________________

1. Over the past one month have you felt less well than you may feel when you are in good health?
   Yes_________ No_________

2. If you answered yes to #1, please list the # of times you have experienced symptoms. If possible, please include dates of onset and recovery of symptoms.

   Fever________________ Cough__________________
   Nasal Congestion_____ Dizziness _____________
   Chest Congestion_____ Sore Eyes _____________
   Nausea_______________ Sore Throat ___________

3. If you experienced symptoms other than those listed above or wish to comment further on those you did check:____
   ____

4. Have you experienced these symptoms continuously or intermittently? _____________________________________

5. Are you still experiencing less than well feelings or discomfort? Yes_______ No________

6. If you are having feelings of discomfort, when and where do you feel poorly?

   Mornings____________ Weekends___________
   Afternoons__________ Home_______________
   Evenings____________ Office_____________
   Weekdays____________ Outside____________

7. Do you have any allergies? Yes____ No___ Type_________

8. Do you have air conditioning or heating duct in your work area? Yes______ No______

9. What kind of floor covering is present in your work area? Linoleum ____ Carpeting____
   Other (please specify) ________________________

10. Do you smoke? Yes_______ No_______

11. How long do you experience symptoms (described in two or three above) from onset until you feel well?
    ____

12. How many days have you been absent during the past 30 days due to a respiratory ailment? ___________________

13. Have any other members of your household missed work or school due to a respiratory illness?
    # of persons ___________ Days missed _______________

14. In your opinion, the operation of the heating-air-conditioning system in your area is:
    Good________ Fair________ Poor________ Other_______

Percent of healthy workers listed by responses from the preinvestigation health questionnaire.

Questionnarie Responses	% of healthy workers
Company working for	
HP	55
Intellidex	48
Summit	55
Sickness frequency	
Intermittently	0
Continuously	10
Blank	93
Time of poor health	
Morning	0
Afternoon	0
Evening	25
Twice or more	5
Place of poor health	
Home	0
Work	0
Both	4
Blank	75
Allergy	
Yes	60
No	40
Allergy type	
Hay fever	57
Aromataic hydrocarbons	0
Food	100
Medicine	60
Smoke	100
Insects	50
Dust	80
None	49

Percent of healthy workers listed by responses from the preinvestigation health questionnaire. (Continued)

Questionnarie Responses	% of healthy workers
Floor Covering	
Linoleum	59
Carpeting	52
Concrete	50
Raised floor	25
Smoking	
No	45
Yes	55
Opinion of Air System	
Good	66
Fair	54
Poor	42